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ABSTRACT

Strategic Choice of Financing Systems in Regulated and Interconnected Industries*

The growing importance of inter-network exchanges in infrastructure-based utilities influences regulatory choices and access-pricing for downstream services using the networks. We analyse this problem in a setting where the infrastructure managers of two bordering countries are in charge of pricing the access to their networks for downstream transport firms that provide international services. Network costs can be financed either through a subsidy or solely through user charges. Access charges are affected by the incomplete internalization of consumers' surplus and infrastructure costs.

Because of these distortions, it turns out that in a non-cooperative setting the second-best outcome consists in the simultaneous adoption of the no-subsidy system. Either this outcome is not an equilibrium, however, or the two countries could end up by choosing either the subsidy or the no-subsidy system, depending on the magnitude of the fixed costs of the networks and the characteristics of the final demand for services; moreover, in the latter case, the second-best outcome is not a stable equilibrium. Other properties of these equilibria are studied, as well as the impact of supranational policies aimed at alleviating the excessive pricing of access on international services.

The coordination problems deriving from the existence of different equilibria can, sometimes, be partially solved by separating the choice of a regulatory mode from the access-pricing stage, thereby allowing the infrastructure managers to commit to use a specific financing system before setting the access price.

JEL Classification: L51
Keywords: infrastructure financing, interconnected networks and Ramsey pricing

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1 Introduction

During the last two decades, network industries have undergone major changes in regulatory framework, market structure and demand features. In fact, regulatory oversight has been almost entirely removed from those segments which displayed no significant returns to scale, while allowing competition and facilitating entry has become a major priority. However, infrastructure networks, characterized by non-negligible returns to scale and large fixed costs, are essential facilities and, as such, remain the subject of significant regulatory intervention.

Starting more recently, globalization is leading to an ever-growing number of international transactions. This is particularly true for telecommunications, and should also become the case for the transport industries in a near future. For the latter, this trend is reinforced by the strong political will to develop international freight transportation in order to reinforce the cohesion of the European Union. However, the conditions regulating network access differ significantly across countries. For example, consider the case of road traffic. Motorway tolls vary both in level and in nature: Highways are free in Germany, while in Switzerland or Austria a one-year sticker ('vignette') is required; in Italy and France, fees are usage-based. The different access pricing schemes also entail varying levels of infrastructure costs coverage by users. Consider for instance the case of railway networks: The French charging system has enabled RFF to cover about 25% of its total cost, while the percentage is 40% for SCHIG in Austria; on the other hand, the German access pricing system has been set with the aim of recovering all costs, excluding those related to new or enhanced infrastructure[1]. In general, the role played by network access pricing can be markedly dissimilar depending on the objective of the infrastructure manager or, more generally, on the choice of the mode of regulation. In view of these differences, particular attention should be devoted to infrastructure access pricing for inter-network services[2].

The aim of this paper is to study the interaction between infrastructure managers in charge of pricing the access to their networks, which are exploited by downstream firms to provide final services. Our stylized model is set in the framework of a transport industry (for example, railroads or trucking) and considers two national networks which are used by downstream international services. Infrastructure managers maximize national welfare while financing their network costs.

The question we ask is the following: Does the interaction between the infrastructure managers' access pricing decisions affect their choice of a regulatory mode?

We draw a basic distinction between regulatory modes according to the type of cost recovery principle adopted. In fact, the fraction of network costs which is not covered by access revenues could be funded through taxes levied on the economy as a whole: We name this kind of approach subsidy financing system. Alternatively, access charges imposed on downstream users could be meant to recover total infrastructure costs: We call this approach no-subsidy financing system. The difference is that under the subsidy financing system the cost of the infrastructure deficit is evaluated at the shadow cost of public funds, whereas under a no-subsidy financing system it is evaluated at the shadow cost of the strict budget constraint.

If the two countries were perfectly cooperating, optimal access prices would obey standard Ramsey-Boiteux formulas. The optimal choice of a financing system could be char-

[1]See NERA (1998).

[2]In the railway case, a particular concern in this respect is expressed by EC Directive 14/2001, which upholds that coordination across countries is required in order to avoid the negative impact of the lacking harmonization of charging systems on service efficiency and market share.

acterized as follows: When network costs are small, the shadow cost of infrastructure financing under the no-subsidy system is smaller than the shadow cost of public funds and access revenues alone must cover infrastructure costs; by contrast, when infrastructure costs are high, the infrastructure manager would use a subsidy since financing the network costs only through access revenues would imply excessive distortions.

Taking the cooperative case as a benchmark, we analyze the choice of a financing system by two infrastructure managers acting independently. In particular, we first study the equilibria of a one-stage complete information game where non-cooperating infrastructure managers choose simultaneously a financing system and the access charges for their networks. In this environment, pricing decisions are tightly bound to the choice of a regulatory mode. In fact, a country's adoption of the no-subsidy system will imply that its optimal charge is always positively related to the opponent's fee, while under the subsidy system the strategic relation between access charges depends on the characteristics of the final demand.

This intuitively paves the way for multiple equilibria: Unless charges are (strong) strategic complements under both financing systems, the final outcome of the game will differ according to the expectations about the opponent's moves. This creates a coordination problem for the infrastructure managers, which is even more dire since the possible equilibria are not Pareto equivalent. In particular, we show that the second-best solution implies the adoption of the no-subsidy system in both countries. This choice leads to lower access charges, since each infrastructure manager fears his opponent's reaction. The incentive to reduce prices counteracts the upward distortions due to non-cooperation. In fact, self-interested infrastructure managers only internalize a fraction of the total social surplus (*constituency effect*) and half of the actual infrastructure cost (*double marginalization effect*). Even though the choice of the no-subsidy system in both countries is socially beneficial, it cannot fully compensate for these distortions, and the total price paid by downstream firms will always be higher than in the cooperative case. Moreover, when this outcome emerges as an equilibrium, it is not stable.

However, one can wonder whether the impact of non-cooperation can at least be reduced by allowing different choice mechanisms. In particular, we investigate whether giving the infrastructure managers the possibility to commit to the choice of a financing system before setting the access prices could possibly favor their coordination on the second-best outcome. In other words, we separate the (first- stage) adoption of a regulatory mode from the (second-stage) determination of access prices.

The choice of a regulatory mode depends on the sign and relative magnitude of the direct and indirect effects. In fact, the adoption of a financing system in a given country affects its welfare both through a direct influence on the network charge and by indirectly modifying access revenue and consumers' surplus because of the change induced in the fee set by the opponent. For example, when access fees are strategic substitutes, the indirect effect provides an incentive to free-ride on its opponent, sticking to the no-subsidy system even with high fixed costs in order to trigger a charge reduction in the neighboring country.

The magnitude of the indirect effect depends on the strength of the strategic interaction. Moreover, the stronger this effect, the higher the commitment power of the first-stage choice of a financing system. Therefore, we expect that the possibility to use choose strategically a regulatory mode will deploy its effects mainly in the presence of a significant interaction between access charges.

For example, in the case of strong strategic complementarity the sequential game has a completely different outcome than the simultaneous one: There exists a unique equilibrium, where both infrastructure managers choose the no-subsidy system. Indeed, we show that the possibility to commit to the financing system before deciding the access price provides the infrastructure managers with an incentive to choose the no-subsidy system in order to alleviate the distortion on international services.

In the strong strategic substitutability case, the equilibrium of the sequential game involves again both infrastructure managers choosing the no-subsidy system. However, the infrastructure managers' incentives are now different.

Our analysis suggests the potential importance of the role of a supra-national authority in coordinating the implementation of a usage-based access pricing scheme across countries. However, care should be exerted in translating our results into policy guidelines. In fact, the welfare-improving effect of the no-subsidy system is strengthened as fixed costs increase, since the infrastructure managers react by jointly reducing access charges in order to boost demand; this allows both satisfying the budget constraint and raising consumers' surplus. This feature is potentially dangerous: The mandatory adoption of the no-subsidy system could lead to distortions in the infrastructure managers' investment and cost reducing behavior.

Our paper borrows from distinct economic literatures. First, we use the work on regulation under a budget constraint, pioneered by Boiteux (1956) and Ramsey (1927) in a different context. We also refer to the literature on access pricing and interconnection, which has especially developed as regards the telecommunications sector; see Laffont and Tirole (2000) for instance. Chang (1996) studies the problem of pricing access in a vertically separated industry but does not consider the issue of interconnection, which is central to our analysis. Armstrong (2001) analyzes two-way interconnection between telecommunications networks providing international calling services to captive consumers. Although similar in some respects, our work is more focussed on the choice of the mode of regulation.

Due to its emphasis on the coordination issues between infrastructure managers, our model also borrows from the insights obtained by the strategic trade literature, initiated by Brander and Spencer (1985). The impact of non-cooperation between policy-makers setting access prices can be viewed as a tax competition game (see e.g. Wilson (1999)); in our setting, the fiscal revenue may be derived from two types of taxation and serves to finance a public infrastructure. The main feature that distinguishes our paper from these literatures consists in the first place in the externalities between governments created by the interdependency between budget constraints and, second, in our focus on the choice of the financing system when governments compete.

The outline of the paper is as follows. In section 2 we describe the model and present the Ramsey-Boiteux benchmark. In section 3 we introduce the simultaneous non-cooperative game, in which infrastructure managers chooses simultaneously their financing system and access price. After having characterized the network managers' best-responses, we derive the equilibria of this game and focus on some of their properties. Then, building on this analysis, we introduce the sequential game in Section 4: In each country, regulatory modes are now decided prior access prices. Section 5 offers some extensions and discussions of the initial setting. All proofs are contained in the Appendix.

2 The model

We consider two countries denoted by $i = 1, 2$. In country i an infrastructure manager IM_i sets an access charge, while downstream firms use the network to provide transport services to final consumers. Information is complete, both for the infrastructure manager and the downstream firms in a given country and across countries.

The final demand. Let q_* be the international demand for transport services[3] and $S_*(q_*)$ the associated net total consumers' surplus, that is, the net consumers' surplus of *both* countries when quantity $q_*(p_*)$ of international services is consumed at price p_*. We assume that $q'_* \leq 0$ and obtain $\frac{dS_*}{dp_*} = -q_*$. Let $\eta_* = \frac{-q'_* p_*}{q_*}$ be the price elasticity of the demand.

We assume that country i only internalizes a part $\theta_i \in (0,1)$ of the international surplus. In other words, q_* is the total level of round-trip demand for transport (for example, from Paris to Brussels and back to Paris), and θ_i is the fraction of consumers of country i that originates this demand. Then $\theta_1 + \theta_2 = 1$ and the surplus from international services accruing to country i amounts to $\theta_i S_*(q_*)$.[4,5]

The infrastructure managers and the modes of regulation. Each infrastructure manager maximizes the welfare of his country, which is composed of three terms: The net consumers' surplus, the infrastructure profit and the fraction of the downstream firms' profits that benefits this country (through, say, shares in these firms held by citizens).

To simplify the exposition, we assume that international services travel in each country half of the total number of kilometers. Denoting by $t_i \geq 0$ the subsidy given to the infrastructure by IM_i, the profit of the infrastructure in country i is:

$$\pi_i^{infra} \equiv t_i + (a_{*i} - c_u)q_* - k_i,$$

where a_{*i} is the access charge for a unit of international transport, while c_u is the (constant) marginal cost of the infrastructure in both countries and k_i is the fixed cost of the network.

The infrastructure manager is allowed to finance the infrastructure through taxes levied on the rest of the economy. Taxation is imperfect and has distortionary effects on the whole economy. In our partial equilibrium approach, we denote by λ_{pf} the shadow cost of public funds which captures this effect[6], and we assume that λ_{pf} is the same in both countries.[7]

We will assume that downstream firms behave competitively. While reasonable for motorway traffic, this assumption is only an approximation for the situation envisaged by the EU for the railway sector in the future.

Let c_d be the constant marginal cost for downstream firms. Since we consider round-trip travel demand, the resulting price for international transport services will be given by $p_* = a_{*1} + a_{*2} + c_d$.

With downstream competitive behavior, transport firms raise no profit and the infras-

[3] Demand is defined in terms of tons-km, the standard unit in freight transport industries.

[4] Other interpretations could easily be thought of. For example, let θ_{ij}^i be the fraction of consumers having a demand for transport from i to j that belongs to country i and q_{ij}^i the related demand. For $i, j = 1, 2$ and $i \neq j$, we have that $\theta_{ij}^i + \theta_{ij}^j = 1$, while $q_{ij} = q_{ij}^i + q_{ij}^j$ is the total demand for international transport from country i to country j. Thus, we are able to define the (net) surplus $S_{ij}(q_{ij})$ related to the demand for international transport. Under the assumption of an isotropic travel pattern ($q_{ij} = q_{ji}$) and with equal prices, we have $S_{ij}(q_{ij}) = S_{ji}(q_{ji})$ and the surplus of consumers in country i related to international transport can be written as $\theta_{ij}^i S_{ij}(q_{ij}) + \theta_{ji}^i S_{ji}(q_{ji}) = \theta_i S_*(q_*)$, where $\theta_i = \theta_{ij}^i + \theta_{ji}^i$ and $q_{ij} = q_{ji} = q_*$.

[5] Our results carry over to cases in which a fraction of the net surplus accrues to a third country, the so-called 'absentee ownership' assumption in the tax competition literature.

[6] Laffont and Tirole (1993) endogenize this shadow cost of public funds in a general equilibrium framework.

[7] Equal costs of public funds across countries indicate that fiscal systems have been harmonized, which might be an appropriate assumption in an integrated area such as the EU. This assumption simplifies the comparison between the cooperation and non-cooperation scenarios. Indeed, if this assumption were not satisfied, cooperative infrastructure managers would only tax the country with the smallest cost of public funds.

tructure budget constraint coincides with the industry budget constraint. The program of the infrastructure manager in country i will be:

$$(\mathcal{P}_{IM_i}) \quad \begin{cases} \max\limits_{\{t_i \geq 0, a_{*i}\}} \left\{ \theta_i S_*(q_*) - (1+\lambda_{pf}) t_i + \pi_i^{infra} \right\} \\ \text{s.t. } (BB_i) : \pi_i^{infra} \geq 0. \end{cases}$$

In the following, we will consider two possible financing systems:

- *No-subsidy*: The infrastructure manager does not subsidize the infrastructure (i.e., $t_i = 0$) and imposes strict budget balance: Access pricing alone must cover network costs. The Lagrange multiplier associated to the strict budget constraint in country i is denoted by $\tilde{\lambda}_i \geq 0$.

- *Subsidy*: In this case, the subsidy is strictly positive and helps covering infrastructure costs. Provided that the budget constraint is binding, the shadow cost of infrastructure financing is equal to the shadow cost of public funds λ_{pf}.[8]

Social optimum. As a preliminary to the forthcoming analysis, we consider the benchmark case where the infrastructure managers perfectly cooperate. The unique infrastructure manager maximizes total social welfare under the constraint that the whole infrastructure breaks even:

$$\begin{cases} \max\limits_{\{t \geq 0, a_*\}} \{ S_*(q_*) - (1+\lambda_{pf}) t + t + (a_* - 2c_u) q_* - k \} \\ \text{s.t. } (BB) : t + (a_* - 2c_u) q_* - k \geq 0 \end{cases}$$

where a_* is the unique access charge imposed on the international service and $k \equiv k_1 + k_2$. In this standard Ramsey-Boiteux problem, the budget constraint will always be binding at equilibrium due to the existence of network fixed costs. We focus now on the choice of financing system and access price.

Consider first the no-subsidy system and denote by $\tilde{\lambda}$ the value of the Lagrange multiplier associated to the strict budget constraint. The optimal access price a_*^{ns} is then given by[9]:

$$\frac{p_*(a_*^{ns}) - c_*}{p_*(a_*^{ns})} = \frac{\tilde{\lambda}}{1+\tilde{\lambda}} \frac{1}{\eta_*(a_*^{ns})}, \tag{1}$$

where $c_* = c_d + 2c_u$ is the social marginal cost of the international service. Intuitively, the value of the shadow cost of infrastructure financing $\tilde{\lambda}$ reflects the difference between the access price that would be set in the absence of the budget constraint (i.e., $2c_u$ in the perfect cooperation case) and the charge such that the infrastructure exactly breaks even. The larger this difference, the larger the distortion needed to ensure budget balance and the larger the shadow cost of infrastructure financing. Therefore, using Equation (1) and the binding strict budget balance condition, the following properties immediately obtain:

- The larger the infrastructure fixed costs, the larger the access price: $\frac{da_*^{ns}}{dk} > 0$.

[8] Indeed, simple manipulations show that when the subsidy is strictly positive, provided that the budget constraint is binding, the Lagrange multiplier associated to the budget balance condition is equal to the shadow cost of public funds: This traduces the fact that the infrastructure manager uses a level of public funds such that the marginal cost of this subsidy (due to distortionary taxation) is equal to its marginal benefit (relaxing the constraint).

[9] Note that $\tilde{\lambda}$ and a_*^{ns} are simultaneously characterized by the first-order condition and the binding budget constraint. In our framework, with only one final service, the access price under the no-subsidy system is actually completely determined by the binding budget constraint.

- The larger the infrastructure fixed costs, the higher the shadow cost of infrastructure financing under the no-subsidy system: $\frac{d\tilde{\lambda}}{dk} > 0$.[10]

Therefore, as long as the the infrastructure fixed cost is not too large, $\tilde{\lambda}(k) \leq \lambda_{pf}$ and the infrastructure manager will prefer not to subsidize the infrastructure since the shadow cost of public funds is larger than the shadow cost of financing the infrastructure through access revenues.[11] In this case, the intuition goes as follows: Providing the infrastructures with public subsidies is not socially beneficial when the indirect costs associated to these public funds (due to distortionary taxation) are larger than the social costs of the distortions imposed on the final services to cover the infrastructure costs with access revenues only.

Therefore, when the infrastructure costs are high, the distortion imposed on the access price under the no-subsidy system becomes too large and the infrastructure manager will use a subsidy to cover part of the network deficit; in that case, we obtain $\tilde{\lambda}(k) \geq \lambda_{pf}$ and the optimal access price a_*^s is given by:

$$\frac{p_*(a_*^s) - c_*}{p_*(a_*^s)} = \frac{\lambda_{pf}}{1 + \lambda_{pf}} \frac{1}{\eta_*(a_*^s)}.$$

The access charge must still be distorted away from the total marginal cost of infrastructure. However, the magnitude of this distortion now depends only on demand elasticity: The larger the elasticity, the lower the access price and the larger the subsidy provided to the network.

The choice of a financing system under perfect cooperation between infrastructure managers is summarized in Figure 1. The bold curve represents the (total) access price a_* set by the unique infrastructure manager as a function of network fixed costs:

$$a_* = \begin{cases} a_*^{ns}(k) & \text{if } \tilde{\lambda}(k) \leq \lambda_{pf} \quad (\Leftrightarrow k \leq \tilde{k}), \\ a_*^s & \text{if } \tilde{\lambda}(k) \geq \lambda_{pf} \quad (\Leftrightarrow k \geq \tilde{k}), \end{cases}$$

where $\tilde{k}$ is the level of infrastructure fixed costs such that the subsidy given to the infrastructure under the subsidy system is null: $\tilde{\lambda}(\tilde{k}) = \lambda_{pf}$.

The second-order condition associated to the infrastructure manager's maximization problem can be rewritten as follows:

$$\delta_* \equiv \frac{q_* q_*'' - q_*'^2}{q_*'^2} < \Delta_*,$$

with $\Delta_* = \frac{1+\tilde{\lambda}}{\tilde{\lambda}}$ in the no-subsidy case and $\Delta_* = \frac{1+\lambda_{pf}}{\lambda_{pf}}$ in the subsidy case. This condition is assumed to be satisfied in equilibrium. From now on, we will assume that δ_* is constant.[12]

[10] Indeed, an increase in the infrastructure fixed costs does not affect the socially optimal access price absent any financing constraint and decreases the infrastructure profit.

[11] In this case, the infrastructure manager would actually have an incentive to tax the infrastructure since raising funds from the industry is less socially costly than taxation.

[12] For instance, $\delta_* = 0$ (respectively -1, $1/\eta_*$) when the international demand is exponential (respectively linear, iso-elastic with parameter η_*). We also emphasize that for most of our results we only need that the sign of δ_* be constant.

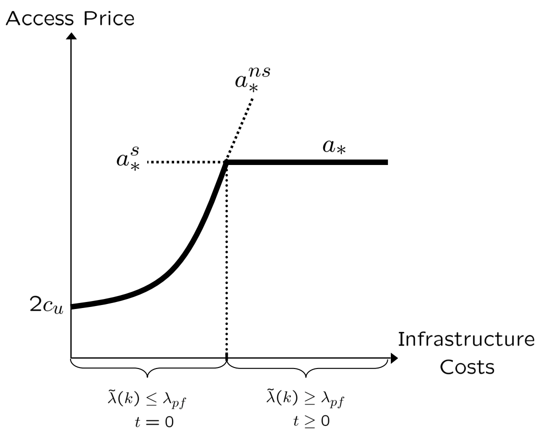

Figure 1: Optimal financing system and access price under perfect cooperation.

3 The interaction between the infrastructure managers' regulatory choices

From now on, we return to the assumption of non-cooperative infrastructure managers. In this section we will consider a one-stage game where the infrastructure managers choose *simultaneously* and non-cooperatively a financing system and an access charge for their networks. Each country chooses a financing system and access price considering as given the access charge and mode of regulation adopted by its neighbor.

The analysis of this scenario will highlight the characteristics of the interaction between the infrastructure managers' decisions. Building on this, in Section 4 we will deal with a two-stage game depicting the strategic choice of a financing system.

We now start by determining the shape of the best-response (in access price); then we study the equilibria of the simultaneous game.

3.1 Best-response functions

At this stage, we consider that the budget-balance constraint is binding in both countries. Later on, we will be more explicit about the conditions under which this assumption holds and the impact on our results when it is not satisfied.

Pricing policy and the mode of regulation. An infrastructure manager's reaction function will depend on the mode of regulation he adopts. In fact, solving $(\mathcal{P}_{IM_i})$ leads to the following optimality conditions for access charges:

- If $t_i = 0$ then:

$$\frac{a_{*i}^{ns} - c_u}{p_*} = \frac{1 + \tilde{\lambda}_i - \theta_i}{1 + \tilde{\lambda}_i} \frac{1}{\eta_*}. \tag{2}$$

- If $t_i > 0$ then:

$$\frac{a_{*i}^{s} - c_u}{p_*} = \frac{1 + \lambda_{pf} - \theta_i}{1 + \lambda_{pf}} \frac{1}{\eta_*}. \tag{3}$$

Assume first that IM_i adopts the subsidy system and let $SW_i(a^s_{*i}, a_{*j})$ be country i's welfare for a given access price a_{*j} in country j. Using Equation (3), we have:

$$\frac{da^s_{*i}}{da_{*j}} = -\frac{\frac{\partial^2 SW_i(a^s_{*i}, a_{*j})}{\partial a_{*i}\partial a_{*j}}}{\frac{\partial^2 SW_i(a^s_{*i}, a_{*j})}{\partial a^2_{*i}}} \tag{4}$$

$$= \frac{(1+\lambda_{pf}-\theta_i)\delta_*}{(1+\lambda_{pf})-(1+\lambda_{pf}-\theta_i)\delta_*}. \tag{5}$$

The second-order condition in country i[13] implies that the denominator of the right-hand side of Equation (5) is positive. Therefore, the type of strategic interaction under the subsidy system depends on the sign of δ_*.

Lemma 1. *Assume that country i adopts the subsidy system. Then, access prices are strategic complements (respectively substitutes) iff $\delta_* \geq 0$ (respectively $\delta_* \leq 0$).*

If IM_i adopts the subsidy system, his reaction to a change in the access price set in country j will depend on the characteristics of the final demand.[14]

Assume now that IM_i adopts the no-subsidy system and denote by $SW_i(a^{ns}_{*i}, a_{*j})$ the corresponding welfare in country i. In this case, a change in country j's access price modifies the shadow cost of the budget constraint in country i because it affects its access revenue. Keeping this effect into account, simple manipulations lead to (we adapt the definition of the strategic interaction given by Equation (4)):

$$\frac{da^{ns}_{*i}}{da_{*j}} = \frac{(1+\tilde{\lambda}_i-\theta_i)\delta_*}{(1+\tilde{\lambda}_i)-(1+\tilde{\lambda}_i-\theta_i)\delta_*} + \frac{\frac{\theta_i}{1+\tilde{\lambda}_i}\frac{q_*}{-q'_*}}{(1+\tilde{\lambda}_i)-(1+\tilde{\lambda}_i-\theta_i)\delta_*}\frac{d\tilde{\lambda}_i}{da_{*j}}. \tag{6}$$

Differentiating the optimality condition given by Equation (2) and rearranging terms yields:

$$\frac{da^{ns}_{*i}}{da_{*j}} = \frac{\theta_i}{(1+\tilde{\lambda}_i)^2}\frac{q_*}{-q'_*}\frac{d\tilde{\lambda}_i}{da_{*j}} + \frac{1+\tilde{\lambda}_i-\theta_i}{1+\tilde{\lambda}_i}\left[1+\frac{da^{ns}_{*i}}{da_{*j}}\right]\delta_*. \tag{7}$$

Then, Equation (7) allows us to rewrite Equation (6) as follows[15]:

$$\frac{da^{ns}_{*i}}{da_{*j}} = \frac{1+\tilde{\lambda}_i-\theta_i}{\theta_i},$$

which is always strictly positive.

Lemma 2. *Assume that country i adopts the no-subsidy system. Then, access prices are strategic complements.*

When country i chooses the no-subsidy system, it will react to a change in a_{*j} by modifying its own price in the same direction, whatever the characteristics of final demand. The use of the no-subsidy system forces access prices to be strategic complements.

[13] This condition amounts to $\delta_* < \frac{1+\lambda_{pf}}{1+\lambda_{pf}-\theta_i}$.

[14] This condition is typically found in contexts where competing firms offer complementary products; see Hendricks, Piccione and Tan (1997) for instance.

[15] Under the no-subsidy system, since there is only one final service, the access price is completely determined by the binding budget constraint. The strategic interaction could therefore be obtained directly by differentiating this condition. That would show that the strategic interaction under the no-subsidy system does not depend directly on θ_i. While reminding that the Lagrangean is endogenous, we keep our formulation in terms of the former, mainly for consistency reason but also because this approach will enable us to characterize in a simple way the best-response functions.

In order to fully characterize the best-responses in access prices, it remains to determine the choice of financing system in each country.

In this simultaneous setting, since each infrastructure manager considers the access price set in the neighboring country as fixed, the choice of a mode of regulation simply depends on the comparison between the shadow cost of public funds λ_{pf} and the shadow cost of infrastructure financing under the no-subsidy system $\tilde{\lambda}_i(a_{*j})$: Given a_{*j}, if $\tilde{\lambda}_i(a_{*j}) \leq \lambda_{pf}$ (respectively $\tilde{\lambda}_i(a_{*j}) \geq \lambda_{pf}$), then the infrastructure manager in country i will choose the no-subsidy system (respectively the subsidy system).

In Appendix A.1, we prove that:

$$\text{Sign}\left[\frac{d\tilde{\lambda}_i}{da_{*j}}\right] = \text{Sign}\left[1 - \delta_*\right].$$

As an illustration, consider the case $\delta_* < 1$. In that situation, the shadow cost of infrastructure financing under the no-subsidy system in country i is an increasing function of the access price set in country j; we define $\tilde{a}_{*j}$ the access price in country j such that the shadow cost of infrastructure financing under the no subsidy system in country i is equal to the shadow cost of public funds: $\tilde{\lambda}_i(\tilde{a}_{*j}) = \lambda_{pf}$.[16] Therefore, the best-response in access price in country i is defined as follows:

$$a_{*i}(a_{*j})|_{\delta_*<1} = \begin{cases} a_{*i}^{ns}(a_{*j}) & \text{if } a_{*j} \leq \tilde{a}_{*j} \quad (\Leftrightarrow \tilde{\lambda}_i(a_{*j}) \leq \lambda_{pf}), \\ a_{*i}^{s}(a_{*j}) & \text{if } a_{*j} \geq \tilde{a}_{*j} \quad (\Leftrightarrow \tilde{\lambda}_i(a_{*j}) \geq \lambda_{pf}). \end{cases}$$

At this point, the analogy with the perfect cooperation case should become clear: In the simultaneous game, IM_i takes as given the access price set in country j and a_{*j} acts like an 'additional cost' from the viewpoint of country i.

For future reference, we introduce the following notation: When country i adopts the no-subsidy system and country j chooses the subsidy one, the Lagrange multiplier associated to the budget constraint in country i is denoted by $\tilde{\lambda}_i^{ns,s}$; access prices[17] are denoted by $a_{*i}^{ns,s}$ and $a_{*j}^{ns,s}$; the final price is denoted by $p_*^{ns,s}$. Finally, welfare in country j is $SW_j^{ns,s} = \theta_j S_*(q_*(a_{*i}^{ns,s}, a_{*j}^{ns,s})) + (1 + \lambda_{pf})[(a_{*j}^{ns,s} - c_u)q_*(a_{*i}^{ns,s}, a_{*j}^{ns,s}) - k_j]$ and welfare in country i is $SW_i^{ns,s} = \theta_i S_*(q_*(a_{*i}^{ns,s}, a_{*j}^{ns,s}))$. A similar notation carries over to the other cases.

Focusing on relevant scenarios. We will now explicitly state some assumptions underlying our analysis and concerning the infrastructure fixed costs. In fact, in order to focus on the most interesting cases, we restrict the possible values of k_i and k_j.

First, we assume that fixed costs are not too large (respectively not too low); otherwise, an infrastructure manager would prefer to subsidize (respectively not to subsidize) his network even when facing a very low (respectively high) access charge in the neighboring country. In other words, $\tilde{\lambda}_i$, which depends both on k_i and a_{*j}, would be larger (respectively smaller) than λ_{pf} for *any* value of a_{*j} in the relevant range.

Second, let us come back on our assumption that the budget constraint is binding. Since only a fraction of the net surplus and the infrastructure costs associated to the international services is internalized by IM_i, it might be possible that the budget constraint is not binding in that country. Whether that constraint is binding in one country or not

[16] We implicitly assume that $\tilde{a}_{*j} \geq 0$ always exists; otherwise, this would imply that IM_i would never use the no-subsidy financing system and the analysis would be immediate.

[17] They solve the system formed by (by permuting indices in) (3) for country j and (2) for country i.

depends in a complex way on the different parameters of the model and on the anticipated level of access price set in the other country. Instead of considering all the possible cases (e.g., the budget constraint in country i is binding for some values of a_{*j} and slack otherwise), we shall assume, in a first time, that the infrastructure fixed cost in each country is sufficiently large to ensure that this constraint is indeed binding for any value of the access price set in the other country in the relevant range. This assumption will be relaxed in Section 5.1.

We can now determine the equilibria of our game. While we mainly focus on symmetric situations to illustrate our results with simple graphical representations, various asymmetries could be easily considered.

3.2 Equilibria of the simultaneous game

Having determined the best-responses of the infrastructure managers, the equilibria of the simultaneous game can be easily obtained. Thus, we obtain different configurations depending on the value of δ_*.

Case 1: $\boldsymbol{0 \leq \delta_* < \frac{1+\lambda_{pf}}{1+2\lambda_{pf}}}$. The best-response functions can be drawn as shown in Figure 2.[18] In the case of weak strategic complementarity under the subsidy system,

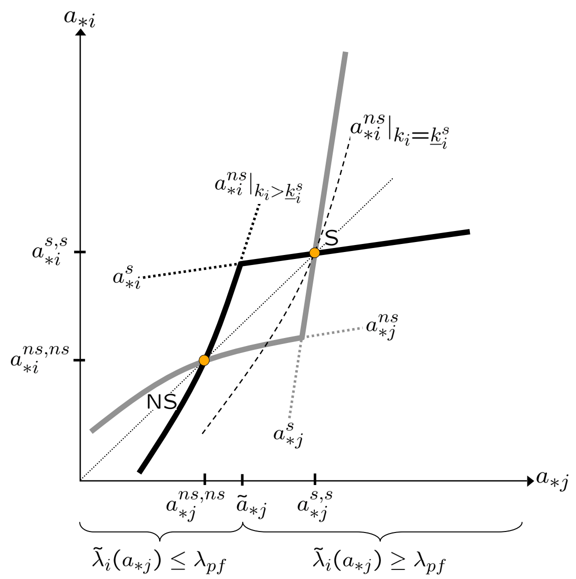

Figure 2: Equilibria in the symmetric case when $0 \leq \delta_* < \frac{1+\lambda_{pf}}{1+2\lambda_{pf}}$.

there exist multiple equilibria. The underlying intuition can be explained as follows. In order to choose a financing system, IM_i must anticipate the level of the access charge set in country j. If this charge were low, IM_i would face a (relatively) large residual demand and could thus afford adopting the no-subsidy system. In a symmetric setting, there exists an equilibrium in which both infrastructure managers do not subsidize their networks. This equilibrium is labelled by NS in Figure 2.

By contrast, if IM_i anticipates that IM_j will set a high access price, then the distortion needed to finance the infrastructure under strict budget balance becomes large, and IM_i

[18] In Appendix A.1, we provide additional results on the shape of the best-response functions.

will adopt the subsidy system. This equilibrium is labelled by S in Figure 2. Notice that the S-equilibrium is stable since:

$$\left|\frac{da^s_{*i}}{da_{*j}}\right| \leq \left|\frac{da^s_{*j}}{da_{*i}}\right|^{-1} \Leftrightarrow \delta_* \leq \frac{1+\lambda_{pf}}{1+2\lambda_{pf}}.$$

Finally, let us highlight the role of the restrictions we made on the infrastructure fixed costs. In Figure 2, the dashed curve corresponds to the access price set in country i under the no-subsidy system when k_i is such that, given $a^{s,s}_{*j}$ (the largest equilibrium access price set in country j), IM_i is exactly indifferent between the two modes of regulation. Remind that, for a fixed a_{*j}, the higher k_i, the larger a^{ns}_{*i}. Therefore, when for values of k_i sufficiently smaller than $\underline{k}^s_i$ no equilibrium exists. Similarly, when k_i is very large, then only the S-equilibrium emerges. Since the impact of these assumptions on the best-response curves is straightforward, we shall not repeat it in the sequel.

Case 2: $1 > \delta_* \geq \frac{1+\lambda_{pf}}{1+2\lambda_{pf}}$. In this case of intermediate strategic complementarity under the subsidy system, at equilibrium both infrastructure managers will subsidize their infrastructure, as represented in Figure 3. Graphically, when δ_* increases, an infrastructure manager tends to adopt the subsidy system more 'rapidly', i.e. for smaller values of the access price set in the other country. When δ_* is sufficiently large, this prevents the emergence of the NS-outcome. The S-equilibrium is unique and unstable.

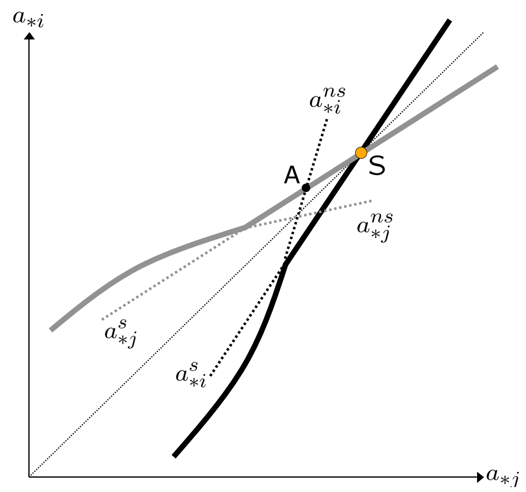

Figure 3: Equilibrium in the symmetric case when $1 > \delta_* \geq \frac{1+\lambda_{pf}}{1+2\lambda_{pf}}$.

Case 3: $\delta_* \geq 1$. With strong strategic complementarity under the subsidy system, we show in Appendix A.1 that a^{ns}_{*i} is a concave function of a_{*j}. Moreover, $\tilde{\lambda}_i$ is now decreasing with a_{*j}.[19] Thus, country i will adopt the subsidy system for low values of a_{*j}, while when the latter grows it will switch to the no-subsidy system. The unique equilibrium of the game consists in the simultaneous adoption of the subsidy system by both infrastructure

[19]Indeed, a change in a_{*j} modifies both the unconstrained access price in country i and the access charge such that the infrastructure of that country exactly breaks even: When $\delta_* \geq 1$, an increase in a_{*j} tends to reduce the distance between these two access prices.

managers and is represented in Figure 4.[20] The S-equilibrium is unique and unstable.

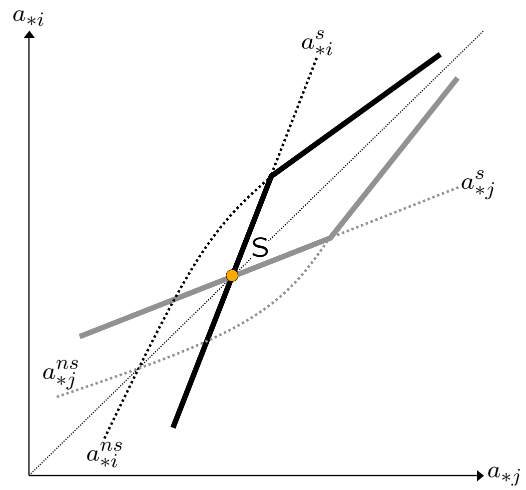

Figure 4: Equilibrium in the symmetric case when $\delta_* \geq 1$.

Case 4: $\boldsymbol{\delta_* < 0}$. With strategic substitutability under the subsidy system, we obtain again multiple equilibria, as shown in Figure 5. The underlying intuition is similar to the one we discussed in the weak strategic complementarity case. The S-equilibrium is stable.

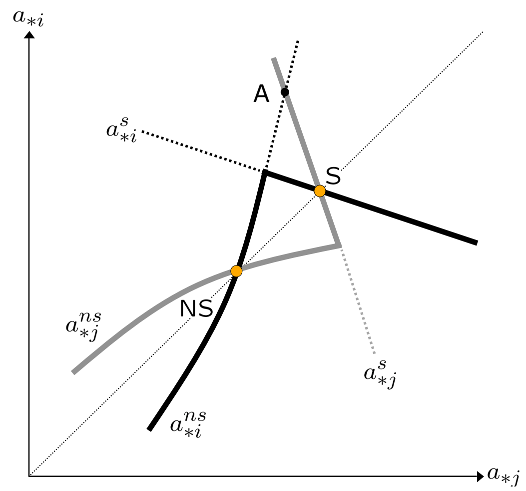

Figure 5: Equilibria in the symmetric case when $\delta_* < 0$.

Summary. In the simultaneous game, we obtain two broad cases:

[20]Notice that $\left|\frac{da^{ns}_{*i}}{da_{*j}}\right| > \left|\frac{da^{ns}_{*j}}{da_{*i}}\right|^{-1}$; this implies that there exists no equilibrium in which both infrastructure managers choose the no-subsidy system.

- First, when $\delta_* \geq \frac{1+\lambda_{pf}}{1+2\lambda_{pf}}$ a unique equilibrium emerges. However, this equilibrium is unstable, highlighting the need for coordination between non-cooperative infrastructure managers.

- Second, when $\delta_* < \frac{1+\lambda_{pf}}{1+2\lambda_{pf}}$, two equilibria exist. We shall come back later on some interesting properties of these equilibria and their welfare properties.

Let us focus on the case in which at least one stable equilibrium exists. With the help of the graphical representations, we can determine the equilibria of the simultaneous game under alternative assumptions about the infrastructure costs:

- If infrastructure costs are sufficiently large in both countries, then only the S-equilibrium emerges, whatever the value of δ_*. When infrastructure costs are very high, each country always prefers to subsidize its own network whatever the access price implemented in the other country. By contrast, if infrastructure costs are sufficiently low in at least one country, then no equilibrium exists.

- Finally, consider the situation where k_j is larger than $\underline{k}_j^s$ but k_i is slightly smaller than $\underline{k}_i^s$. In that configuration of infrastructure costs, multiple equilibria emerge; the interesting point is that an asymmetric equilibrium, in which the 'high infrastructure cost country j' subsidize its network and the 'low infrastructure cost country i' does not subsidize its infrastructure, exists.

3.3 Properties of the No-Subsidy equilibrium

Before turning to the analysis of the strategic choice of a financing system, we illustrate some significant features of the no-subsidy equilibrium.

Strategic role of network (fixed) costs. Starting from the NS-equilibrium, let us analyze the consequences of an increase in country i's fixed cost. For a given a_{*j}, the increase in k_i tightens the strict budget constraint to be satisfied by IM_i: Graphically, the a_{*i}^{ns}-curve moves to the north-west. This implies that access prices in both countries will be *smaller* at equilibrium: As fixed costs grow, access charges will be reduced at the NS-equilibrium.

Lemma 3. *In the* NS*-equilibrium the access price in country i is decreasing with the infrastructure fixed costs of both countries:* $\frac{d}{dk_i} a_{*i}^{ns,ns} < 0$ *and* $\frac{d}{dk_j} a_{*i}^{ns,ns} < 0$.

Proof. See Appendix A.2. □

When no subsidies are used to cover the infrastructure costs, the larger the infrastructure fixed cost in country i is, the larger is the access price set in that country, for a given access price set in country j, to satisfy the strict budget-balance requirement. Therefore, the larger the infrastructure fixed cost is, the stronger is IM_i's commitment to impose a high access price. At equilibrium, these anticipations realize, leading both infrastructure managers to set lower access price. This result highlights the role of network fixed costs as a commitment device for an infrastructure manager that deters the rival from implementing too high an access price.

Welfare analysis. Not surprisingly, non-cooperation between the infrastructure managers distorts access charges with respect to the cooperative benchmark. Nonetheless, we want to determine which equilibrium configuration minimizes the social cost due to these distortions.

Let us first consider the S-equilibrium. The access charge in country i is characterized by Equation (3) and is distorted upwards because of two effects. First, IM_i does not fully internalize the effect of his decisions on total net consumers' surplus ($\theta_i < 1$). The access charge in country i will thus be excessive: This is the *constituency effect*. Moreover, even if each infrastructure manager perfectly internalized all surplus (i.e., $\theta_i = \theta_j = 1$), the equilibrium price would be distorted, since the infrastructure (variable) cost of the international service perceived in each country is half of the actual infrastructure cost. This is the *double marginalization effect*. These distortions affect access charges whatever the choices of financing systems by the non-cooperative countries.

However, the total access price $a_{*i} + a_{*j}$ is the lowest when both countries adopt the no-subsidy system. This is immediate from the previous graphical representations and is shown in Appendix A.3. Intuitively, the no-subsidy system entails strategic complementarity and thus creates the conditions for access charges to remain low at equilibrium. This softens the upward distortions due to the constituency and double marginalization effects.

From Lemma 3, at the no-subsidy equilibrium there is a scope for the use of investment as a strategic device (when part of the investment cost is covered through access revenues). This also implies that infrastructure managers might not have the correct incentives for cost-minimization. Since these two dimensions are absent from our analysis, one should be careful in translating our results directly into policy guidelines. In fact, the mandatory adoption of the no-subsidy system could lead to distortions in the infrastructure managers' investment and cost-reducing behavior.

The comparison with the cooperative case depends on the characteristic of the international demand. We prove in Appendix A.3 that when both S- and NS-equilibria exist, that is when $\delta_* < \frac{1+\lambda_{pf}}{1+2\lambda_{pf}}$, access prices are always excessively distorted since the final price in the NS-equilibrium is larger than the cooperative monopoly price, i.e. the final price that would result if both networks were managed by a single entity which would only care about the infrastructure profit. In our simplified environment, this result could suggest that delegating the management of both networks to a unique privately-owned entity, which would only care about the profit derived from the pricing of access, would be a valid policy recommendation, provided that certain conditions on the international demand are met. While highlighting the distortions deriving from non-cooperation, we also emphasize that other variables (such as investment incentives or X-inefficiencies), though absent from our setting, nonetheless play a significant role in determining the social desirability of infrastructure privatization.[21] We summarize these results in the following proposition.

Proposition 1. *Under non-cooperation between infrastructure managers:*

- *The total access price paid by the downstream sector is minimized when both infrastructure managers adopt the no-subsidy system.*
- *When $\delta_* < \frac{1+\lambda_{pf}}{1+2\lambda_{pf}}$, the total no-subsidy access price is larger than the socially optimal access price, whatever the financing system adopted under perfect cooperation.*

Proof. See Appendix A.3. □

[21] Moreover, this is no longer the case when $\delta_* \geq \frac{1+\lambda_{pf}}{1+2\lambda_{pf}}$.

Finally, even though the NS-equilibrium is Pareto-superior, it also appears to be unstable:

$$\left|\frac{da_{*i}^{ns}}{da_{*j}}\right| > \left|\frac{da_{*j}^{ns}}{da_{*i}}\right|^{-1},$$

In the simultaneous game, infrastructure managers unambiguously would like to commit not to subsidize their infrastructures; however, since the NS-equilibrium is unstable, small deviations from the corresponding equilibrium access prices would provide the infrastructure managers with an incentive to subsidize their infrastructures, a Pareto-dominated outcome. Obviously, this property of the NS-equilibrium is related to Lemma 3.

The impact of supra-national subsidy policies. Suppose that a supra-national authority, say the European Commission, decides to implement a policy which aims at developing international exchanges. In order to promote the international traffic, this policy should try to minimize the distortions on access pricing due to non cooperation between national infrastructure managers. Thus, the authority should provide measures apt to make each country internalize the externalities it creates. Since access prices are excessively high, at a first glance this goal could be achieved by means of (per unit) infrastructure subsidies in both countries. However, the impact of such a policy strongly depends both on the type of equilibrium that emerges in the simultaneous game and on the characteristics of the final international demand. To see this, one can refer to our representation of the different scenarios in the above figures, considering that a per-unit subsidy of the national infrastructures translates into lower infrastructure marginal costs.

Consider first the no-subsidy equilibrium. If national infrastructures are subsidized, then for a given access price in country j, the strict budget balance constraint is relaxed in country i: a_{*i}^{ns} tends to move downwards, leading, at equilibrium, to higher access prices! Indeed we can follow the logic of Lemma 3 to show that lower infrastructure costs soften the infrastructure managers' incentives to price reduction and lead to higher access prices in a no-subsidy equilibrium.

By contrast, consider now the subsidy equilibrium. It is immediate to check that a subsidy in both countries leads to lower access prices in the cases of weak strategic complementarity and strategic substitutability, but to higher access prices in the cases of intermediate and strong strategic complementarity under the subsidy system.

Therefore, policies aimed at developing international services through subsidies assigned to national networks might turn out to have a negative impact on welfare depending on the financing system chosen by the two countries and the characteristics of final demand. This highlights that such policies should in fact be contingent on the modes of regulation that are implemented by national infrastructure managers.

4 The commitment value of the regulatory modes

The timing we have considered so far, in which each infrastructure manager chooses simultaneously both the financing system and the access price in his country, has enabled us to get a better understanding of some of the specificities of the interaction between these national regulatory decisions. However, this timing might not adequately reflect the real decision-making process since the decision to use public funds or not to finance the infrastructure in a given country typically emanates from the political principal of the infrastructure manager; moreover, such a decision on the regulatory mode commits in the long term the decisions undertaken by the infrastructure manager (like the level of access prices). It is therefore of interest to focus on the situation in which subsidies are decided prior the access prices. In this section, we shall focus on the strategic use of the financing system absent any issue of conflicting objectives between an infrastructure manager and his political principal. The game we consider is the following:[22]

- The infrastructure managers independently choose a financing system.
- The infrastructure managers non-cooperatively set an access charge in their countries.

This game will be referred to as the 'sequential game'. The question we ask can therefore be stated as follows: Will the infrastructure managers succeed in coordinating on the socially preferable outcome?

We study the infrastructure managers' best-responses proceeding by backward induction. For given financing systems, the access price subgame can be immediately inferred from the study of the simultaneous game and will not be repeated. Then, it remains to examine the infrastructure managers' incentives to finance their networks through subsidies. This decision now implies two, sometimes countervailing effects.

First, country i's choice of a financing system has a direct influence on its access charge a_{*i}. Second, this choice also induces a change in the access charge set by IM_j, and this (indirectly) affects country i's consumers' surplus and access revenue. The sign and magnitude of the latter effect are determined by the type of strategic interaction, which in turn depends (inter alia) on the regulatory mode.

When choosing a financing system, country i considers as given the *financing system* adopted in country j, but knows that the access charge in that country will depend on his own decision. Differently from the simultaneous game, the choice of a financing system cannot directly derive from the comparison between the endogenous Lagrange multiplier and the exogenous shadow cost of public funds, since the former will eventually result from country j's access price. In other words, given the financing mode chosen by his opponent, country i could prefer to adopt the no-subsidy rather than the subsidy system even though $\tilde{\lambda}_i > \lambda_{pf}$, for example because it anticipates that in the former case the access charge in country j will be lower and this reduction will increase its own net consumers' surplus.

4.1 Choice of a financing system in country *i* when country *j* adopts the no-subsidy system

From the viewpoint of country i, if IM_j chooses the no-subsidy system, he is in fact committing to react to a change in a_{*i} by modifying his own price in the same direction, whatever the characteristics of the final demand. In our previous analysis, moreover, we observed that the simultaneous adoption of strict budget balance by both countries implies that both access prices will decrease. Therefore, choosing the no-subsidy system becomes appealing for IM_i since this will raise net surplus and infrastructure revenue.

Proposition 2. *When country j adopts the no-subsidy financing system, country i adopts the no-subsidy system.*

Proof. See Appendix A.4. □

[22] We could think of the following more general game: The political principal of IM_i chooses first the maximal level of subsidy T_i that could be used to finance the infrastructure deficit; then, the infrastructure manager decides the access price and the level of subsidy $t_i \leq T_i$. Our simplified game focusses on the polar cases $T_i = 0$ and $T_i = +\infty$.

A simple illustration of this proposition can be obtained looking at Figure 5. When country i commits in the first stage to a strict budget balance system, its second-stage best-response curve is given by a_{*i}^{ns}. If country j adopts the no-subsidy system instead of the subsidy one, access prices will change from A to NS and will be lower in both countries.

A consequence of Proposition 2 is that no-subsidy in both countries is always an equilibrium of the sequential game. Whether this is the unique equilibrium of that game depends on country i's incentive to choose not to subsidize its infrastructure when country j subsidizes its own network.

4.2 Choice of a financing system in country i when country j adopts the subsidy system

As we have shown, when country j adopts the subsidy system, the slope of its reaction function is determined by the characteristics of final demand. As a consequence, our results depend on the sign and magnitude of δ_*.

When δ_* is positive and sufficiently large, access charges are strong strategic complements and, as in the previous case, country i will adopt the no-subsidy system.

Proposition 3. *Assume that δ_* is positive and large (i.e., $\delta_* > \overline{\delta}_{*i}^{+}$). Then, when country j adopts the subsidy system, country i adopts the no-subsidy system.*

Proof. See Appendix A.5. □

The intuition can be obtained from Figure 3.[23] Starting from S, if IM_i deviates to the no-subsidy system (point A) access prices decrease in both countries and welfare increases. This is no longer the case when access prices are weak strategic complements.

Proposition 4. *Assume that δ_* is positive and small (i.e., $\delta_* \in [0, \underline{\delta}_{*i}^{+})$). Then, when country j adopts the subsidy system, country i adopts the subsidy system.*

Proof. See Appendix A.6. □

When strategic complementarity is weak, country j's reaction is not strong enough to favor the adoption of the no-subsidy system. Graphically, consider Figure 2. Starting from S, if IM_i deviates to the no-subsidy system access prices will increase in both countries. The direct and indirect effects both lead to the adoption of the subsidy system.

In the case of strategic substitutes, the direct and the strategic effects are conflicting: When IM_i deviates from the subsidy to the no-subsidy system, a_{*i} increases but this triggers a decrease in a_{*j}. For a given level of the infrastructure deficit in country i, the stronger the strategic effect (i.e., the smaller δ_*), the larger the incentive to choose the no-subsidy system. However, as the infrastructure deficit grows, the magnitude of the direct effect increases, leading to the adoption of the subsidy system.

Proposition 5. *Assume that δ_* is strictly negative.*

- *If δ_* is sufficiently small (i.e., $\delta_* < \underline{\delta}_{*i}^{-}$), then when country j adopts the subsidy system country i always chooses the no-subsidy system.*
- *If δ_* is sufficiently large (i.e., $\delta_* > \underline{\delta}_{*i}^{-}$), then when country j adopts the subsidy system, there exists $\tilde{k}_i^s$ such that:*

[23] The intuition is similar if we consider Figure 4.

- *For low infrastructure costs (i.e., $k_i < \tilde{k}_i^s$), country i adopts the no-subsidy system;*
- *For high infrastructure costs (i.e., $k_i \geq \tilde{k}_i^s$), country i adopts the subsidy system.*

Proof. See Appendix A.6. □

Again, an intuition can be obtained from Figure 5. When IM_j chooses the subsidy system and IM_i moves from the subsidy to the no-subsidy system, then access prices move from S to A. In this case, IM_i adopts a priori (i.e., for a given access price set in country j) a sub-optimal mode of regulation, increasing the shadow cost of infrastructure financing and his access price; however, IM_j is led to reduce his own access charge. The incentive of IM_i to choose the no-subsidy system is built on two conflicting forces whose relative magnitude depends on the level of infrastructure cost in country i (which, roughly speaking, represents how much IM_i loses by increasing his access price) and on the strength of the strategic interaction between access prices (which determines the gain for IM_i from free-riding on the decrease in a_{*j}).

Taken together, Propositions 3, 4 and 5 give a characterization of the choice of a financing system in one country, given that the other country has adopted the subsidy system[24].

4.3 Equilibria of the sequential game

Since we have determined the best-reply functions at the first stage of the sequential game, it simply remains to determine the equilibria of the overall game. We obtain the following propositions[25].

Proposition 6. *Assume that δ_* is either positive and sufficiently large (i.e., $\delta_* > \max\{\overline{\delta}_{*i}^+, \overline{\delta}_{*j}^+\}$) or negative and sufficiently small (i.e., $\delta_* < \min\{\underline{\delta}_{*i}^-, \underline{\delta}_{*j}^-\}$). Then, both infrastructure managers adopt the no-subsidy system.*

Proof. See Appendix A.7. □

In order to compare the results of the sequential game with those of the simultaneous one, let us focus on symmetric settings. In this case, $\overline{\delta}_{*i}^+ \equiv \overline{\delta}_{*j}^+ = \frac{1+\lambda_{pf}}{1+2\lambda_{pf}}$. Then, we can directly refer to Figures 3 and 4 for a comparison, and note that the sequential game has a completely different outcome from the simultaneous one. With strong complementarity, the opportunity to commit to a regulatory mode leads the infrastructure managers to select a Pareto-superior outcome with respect to the simultaneous case: Both countries will choose the no-subsidy system.

Under (strong) strategic substitutability, due to the strength of the indirect effect, the two countries succeed in coordinating on the NS equilibrium: Each infrastructure manager has a strong incentive to adopt the no-subsidy system in order to free-ride on the access price set in the other country. However, this free-riding incentive, which is potentially harmful for total social welfare, leads to both infrastructure managers adopting the no-subsidy system at equilibrium . In this case, the second-best outcome emerges as an equilibrium exactly because the two infrastructure managers have distorted individual incentives.

The remaining cases are gathered in the next proposition.

[24] For $\delta_* \in (\underline{\delta}_{*i}^+, \overline{\delta}_{*i}^+)$ (provided that this interval is non-empty), the choice of a financing system in country i cannot be characterized in a simple way.

[25] We focus on pure strategy equilibria.

Proposition 7.

- *Assume that* δ_* *is positive and small (i.e.,* $0 < \delta_* < \min\ \underline{\delta}^+_{*i}, \underline{\delta}^+_{*j}$*). Then, two equilibria can arise: Either both infrastructure managers choose the subsidy system, or they both choose the no-subsidy system.*

- *Assume that* δ_* *is negative and large (i.e.,* $0 > \delta_* > \max\ \underline{\delta}^-_{*i}, \underline{\delta}^-_{*j}$*). Then, the equilibrium choice depends on the level of the infrastructure deficit in the two countries:*

  1. *If the infrastructure deficit is small in both countries (i.e.* $k_i < \tilde{k}^s_i$ *for* $i = 1, 2$*), then both infrastructure managers choose the no-subsidy system.*
  2. *If the infrastructure deficit is small in country* i *and large in country* j *(i.e.* $k_i < \tilde{k}^s_i$ *and* $k_j > \tilde{k}^s_j$*), then both infrastructure managers adopt the no-subsidy system.*
  3. *If the infrastructure deficit is large in both countries (i.e.* $k_i > \tilde{k}^s_i$ *for* $i = 1, 2$*), then two equilibria can emerge: Either both infrastructure managers choose the no-subsidy system, or they both choose the subsidy system.*

Proof. See Appendix A.7. □

Under weak strategic complementarity, two equilibria emerge where both countries choose the same system. With reference to Figure 2, we note that the outcome of the sequential game is unchanged with respect to the simultaneous one: The opportunity to commit to a financing system offers no significant advantages, since the reaction expected from the neighboring country is not strong enough to lead the two infrastructure managers to a single equilibrium.

Under weak strategic substitutability, the equilibrium outcomes depend on the relative magnitude of the direct and indirect effects. A low infrastructure deficit reduces the impact of the direct effect and favors the adoption of the no-subsidy system. Thus, when the deficit in (at least) one country is low, the NS-equilibrium emerges. However, when the infrastructure deficit is large in both countries the balance between the direct and indirect effects becomes uncertain and we obtain multiple equilibria where both countries adopt the same regulatory mode.

Renegotiation-proofness and the commitment value of the regulatory mode. In the sequential game, the infrastructure managers might have an incentive to deviate, ex post, from their choice of financing system.

In order to see this, consider that infrastructure managers have both decided to commit to a strict budget-balance condition.

When $\delta_* < \frac{1+\lambda_{pf}}{1+2\lambda_{pf}}$, we observe that in the NS-equilibrium, the shadow cost of infrastructure financing is lower than the shadow cost of public funds. Therefore, given the access price set in country j, country i has no incentive to deviate from its choice of financing system.

Things turn out to be different when $\delta_* \geq \frac{1+\lambda_{pf}}{1+2\lambda_{pf}}$. Indeed, in that case, an infrastructure manager has ex post an incentive to deviate from the no-subsidy system to the subsidy one since, given the access price set in the other country, this would lead to a lower shadow cost of infrastructure financing.

Therefore, the NS-equilibrium might not be renegotiation-proof in the sense that ex post each infrastructure manager might have an incentive to deviate since he is not on his best-response in access price. This highlights the fact that the choice of regulatory modes must credibly commit the infrastructure managers. The institutional separation between the access pricing decisions and the choices of financing systems might be a way to restore the credibility of the regulatory modes; however, this raises also the possibility of inefficiencies created by conflicting objectives between these institutions.

5 Extensions

5.1 Profit-maximizing infrastructure manager

In the spirit of the classic Ramsey-Boiteux framework, the previous analysis assumed that the budget constraint, both under the subsidy and the no-subsidy systems, was binding at equilibrium. However, this might no longer be the case with non-cooperating infrastructure managers who only care about a fraction of the total net surplus associated to international transport. Indeed, if, say, θ_j is sufficiently small, then IM_j mostly cares about infrastructure profit. In this section, we discuss the robustness of our results to such a situation.

Consider that IM_j's problem is:

$$\max_{\{t_j \geq 0, a_{*j}\}} \quad \{\theta_j S_*(q_*) - (1+\lambda_{pf})t_j + t_j + (a_{*j} - c_u)q_* - k_j\}.$$

That is, we consider that the infrastructure budget constraint in country j will be slack in the range of relevant access prices. Since taxation is distortionary, IM_j will not provide any subsidy to the infrastructure: $t_j = 0$. For a profit-maximizing infrastructure manager, there is no gain to use a costly subsidy, either in the simultaneous or the sequential game. Moreover, the optimal access charge in country j is now given by $\frac{a_{*j}-c_u}{p_*} = \frac{1-\theta_j}{\eta_*}$ and the strategic interaction from the viewpoint of country j is given by:

$$\frac{da_{*j}}{da_{*i}} = \frac{(1-\theta_j)\delta_*}{1-(1-\theta_j)\delta_*}. \tag{8}$$

The second order condition in country j[26] implies that the denominator of the right-hand side of Equation (8) is positive. Therefore, the type of strategic interaction now depends on the sign of δ_*. The situation is then analogous to the one we obtained in the case where both budget constraints are binding and country j has chosen the subsidy system and can be inferred from our previous analysis of the simultaneous and the sequential games.

Things would have been (much) more complicated had we considered the possibility that wether the budget constraint in a given country is binding or not depends on the level of access price set in the other country. In our working paper (Bassanini and Pouyet, 2002), we consider this possibility in a simple example. The important change is that such a possibility may lead to the existence of another equilibrium in which both infrastructure managers do not subsidize the infrastructures and keep the access prices at a sufficiently low level in order that the budget constraints are not binding. Whether this equilibrium exists at all depends on conditions on the infrastructure costs, on the characteristics of the international demand and on the countries' valuations for international services.

5.2 Domestic and international services

Let us briefly consider the case in which services are purely internal to each country. Then, the problem faced by an infrastructure manager does not depend on the access price set

[26]This condition amounts to $\delta_* < \frac{1}{1-\theta_j}$.

in the other country and the setting is analogous to the perfect cooperation situation. With purely domestic services, each infrastructure manager perfectly internalizes all the effects associated to the choice of the mode of regulation and access price. Therefore, social welfare does not suffer from non-coordination between countries.

To summarize, when downstream services are purely domestic and the infrastructure fixed costs are sufficiently large (respectively low), the subsidy (respectively no-subsidy) system is the socially optimal mode of regulation and each infrastructure manager has the correct incentive to choose that financing system. By contrast, when downstream services are purely international, it becomes socially preferable to prevent countries from subsidizing their infrastructure deficit since this softens the negative externalities on the access prices for international services.

We are then tempted to draw the following scenario. With the development of international services and the decrease of infrastructure deficits, countries should evolve towards a system where access pricing is usage-based. During this transition, different types of equilibria can emerge; therefore, such a move requires some coordination. If domestic services remain relatively important, it may be efficient to subsidize the networks; when the international demand is sufficiently stronger than the domestic one, it could become preferable to encourage the adoption of a usage-based pricing system. Simultaneously, a thorough study of the countries' incentives to choose one system or the other is needed, keeping into account also the previously mentioned issues concerning investment choices. In order to reach reliable policy conclusions, such a work should be complemented with an empirical analysis as the one performed by Ivaldi and Gagnepain (1999) for local transport services in France. We leave for future research a complete analysis of these intermediate cases.

6 Conclusions

In this paper, we have analyzed the choice of a financing system in two countries linked by inter-network transport services provided by downstream firms to final users. Access charges for these services are affected by distortions due to the incomplete internalization of the related surplus and infrastructure costs. Moreover, the interaction between the infrastructure managers' decisions at the downstream level leads to a strategic interdependence relation between the access prices set upstream.

While in a cooperative setting the socially optimal regulatory mode depends on network fixed costs, in the non-cooperative case the (second-best) solution consists in the simultaneous adoption of a usage-based pricing principle in both countries. However, either this situation is not an equilibrium or other equilibria may emerge, where both countries choose to subsidize their transport networks. This creates a coordination problem between the infrastructure managers, which is only partially solved by the possibility of committing to use a specific financing system before setting the access price.

Thus, our analysis highlights the importance of the role of a supra-national authority ensuring coordination between both the access pricing decisions and the choices of financing systems in different countries, in order to minimize distortions on downstream services.

Our results are only a preliminary step in the study of the optimal choice of network financing systems, and require further analysis before being translated into policy guidelines. In fact, we argue that the mandatory adoption of the no-subsidy system could lead to distortions in the infrastructure managers' investment and cost reducing behavior.

Moreover, in our simplified framework, we have not dealt explicitly with domestic services. In general, a scenario considering both national and international services could lead to different results in terms of the infrastructure managers' non-cooperative financing choices as well as the second-best outcome, depending on the relative magnitude of the national and international demand for services.

We have also remained silent on a number of questions.

For instance, our model implicitly assumes that networks are interconnected: Transport services can always go from one country to the other. However, it has been argued that the development of the international traffic also suffers from a poor quality of interconnection. This is the so-called interoperability problem, which appears to be critical for the development of intra-European networks.

Similarly, we have just alluded to the strategic role of investment in this non-cooperative setting. For instance, the decisions to create or to close lines should be incorporated in our framework, e.g. the fixed cost of maintaining the line is much lower for an only-freight line because of lower safety standards. This choice should not be neutral with respect to the interaction between infrastructure managers.

These extensions are left for future research.

A Appendix

A.1 Properties of the best-response functions

Lemma 4. *The following properties hold:*

- $$Sign\left[\frac{d^2a_{*i}^{ns}}{da_{*j}^2}\right] = Sign\left[\frac{d\tilde{\lambda}_i}{da_{*j}}\right] = Sign\left[1-\delta_*\right], \qquad (\mathcal{C}_1)$$
- $$\frac{da_{*i}^{s}}{da_{*j}} \leq \left.\frac{da_{*i}^{ns}}{da_{*j}}\right|_{\tilde{\lambda}_i=\lambda_{pf}} \Leftrightarrow \delta_* \leq 1. \qquad (\mathcal{C}_2)$$

Proof. $(\mathcal{C}_2)$ is immediate.

Totally differentiating Equation (2) with respect to a_{*i}^{ns} and a_{*j}, we obtain:

$$da_{*i}^{ns} = \frac{\theta_i}{(1+\tilde{\lambda}_i)^2}\frac{q_*}{-q_*'}d\tilde{\lambda}_i + \frac{1+\tilde{\lambda}_i-\theta_i}{1+\tilde{\lambda}_i}\delta_*\left(1+\frac{da_{*i}^{ns}}{da_{*j}}\right)da_{*j},$$

which can be rearranged as follows:

$$\frac{1+\tilde{\lambda}_i-\theta_i}{\theta_i}(1-\delta_*) = \frac{\theta_i}{(1+\tilde{\lambda}_i)^2}\frac{q_*}{-q_*'}\frac{d\tilde{\lambda}_i}{da_{*j}}$$

This concludes the proof of $(\mathcal{C}_3)$. □

A.2 Proof of Lemma 3

Let us focus on the setting of the access price in country i under the no-subsidy system. Differentiating the budget constraint in country j, we get:

$$\frac{da_{*j}^{ns,ns}}{dk_i} = \frac{1+\tilde{\lambda}_j^{ns,ns}-\theta_j}{\theta_j}\frac{da_{*i}^{ns,ns}}{dk_i}. \qquad (A.1)$$

Then, differentiating the budget-balance condition in country i, we obtain:

$$da_{*i}^{ns,ns}\left[q_* + (a_{*i}^{ns,ns} - c_u)q_*'\right] + da_{*j}^{ns,ns}(a_{*i}^{ns,ns} - c_u)q_*' = dk_i,$$

which can be rearranged as follows (using the optimality condition in country i):

$$\frac{da_{*i}^{ns,ns}}{dk_i} = \frac{1}{q_*}\frac{(1+\tilde{\lambda}_i^{ns,ns})\theta_j}{\theta_i\theta_j - (1+\tilde{\lambda}_j^{ns,ns} - \theta_j)(1+\tilde{\lambda}_i^{ns,ns} - \theta_i)} < 0 \quad \forall\tilde{\lambda}_i^{ns,ns}, \tilde{\lambda}_j^{ns,ns} > 0.$$

Then, using Equation $(A.1)$ we obtain that $\frac{da_{*i}^{ns,ns}}{dk_j} < 0\ \forall\tilde{\lambda}_i^{ns,ns}, \tilde{\lambda}_j^{ns,ns} > 0$.

A.3 Proof of Proposition 1

Consider first the function $\mathcal{A}(p_*) \equiv \frac{p_*-c_*}{p_*}\eta_*$. We have: $\mathcal{A}'(p_*) \propto 1 - \frac{p_*-c_*}{p_*}\eta_*\delta_*$. We distinguish two cases.

First case: $\boldsymbol{\delta_* < \frac{1+\lambda_{pf}}{1+2\lambda_{pf}}}$. Given Lemma 4 and the assumptions on the infrastructure fixed costs, we have $\tilde{\lambda}_i^{ns,ns} \leq \lambda_{pf}$, $i = 1, 2$. Simple manipulations show that this also implies $\mathcal{A}'(p_*) \geq 0$. Now, since $\frac{1+\tilde{\lambda}_i^{ns,ns}-\theta_i}{1+\tilde{\lambda}_i^{ns,ns}} + \frac{1+\tilde{\lambda}_j^{ns,ns}-\theta_j}{1+\tilde{\lambda}_j^{ns,ns}} \leq \frac{1+2\lambda_{pf}}{1+\lambda_{pf}}$, we obtain $p_*^{ns,ns} \leq p_*^{s,s}$.

Notice now that: $\frac{1+\tilde{\lambda}_i^{ns,ns}-\theta_i}{1+\tilde{\lambda}_i^{ns,ns}} + \frac{1+\tilde{\lambda}_j^{ns,ns}-\theta_j}{1+\tilde{\lambda}_j^{ns,ns}} > 1 > \frac{\lambda_{pf}}{1+\lambda_{pf}}$. This implies that the final price when both infrastructure managers choose the no-subsidy system is larger than the 'monopoly' access price and the highest access price that can emerge under perfect cooperation.

Second case: $\boldsymbol{\delta_* \geq \frac{1+\lambda_{pf}}{1+2\lambda_{pf}}}$. We have now $\tilde{\lambda}_i^{ns,ns} \geq \lambda_{pf}$. But now $\mathcal{A}'(p_*) \leq 0$. Therefore we obtain again that $p_*^{ns,ns} \leq p_*^{s,s}$. But $p_*^{ns,ns}$ is now smaller than the highest price under perfect cooperation.

A.4 Proof of Proposition 2

First, we define $\underline{k}_i^{ns}$ as the value of country i's infrastructure fixed cost such that when country i adopts the subsidy system and country j the no-subsidy one, the subsidy in the former country is equal to 0. $\underline{k}_i^{ns}$ depends on the endogenous shadow cost of the budget constraint in country j, $\tilde{\lambda}_j^{s,ns}$.

We define $\Delta SW_i^{ns} \equiv SW_i^{s,ns} - SW_i^{ns,ns}$ the welfare difference in country i between the subsidy- and the no-subsidy system when IM_j has chosen the no-subsidy system. We have $\Delta SW_i^{ns}|_{k_i=\underline{k}_i^{ns}} = 0$. We have $\frac{dSW_i^{s,ns}}{dk_i} = -(1+\lambda_{pf})$ and $\frac{dSW_i^{ns,ns}}{dk_i} = -\theta_i q_*(1+\frac{da_{*j}^{ns,ns}}{da_{*i}^{ns,ns}})\frac{da_{*i}^{ns,ns}}{dk_i}$. Since $1+\frac{da_{*j}^{ns,ns}}{da_{*i}^{ns,ns}} > 0$ and $\frac{da_{*i}^{ns,ns}}{dk_i} < 0$ (from Lemma 3), we immediately obtain that $\frac{d\Delta SW_i^{ns}}{dk_i}$ is *always* negative. This concludes the proof of Proposition 2.

A.5 Proof of Proposition 3

First, we define $\underline{k}_i^{s}$ as the value of country i's infrastructure fixed cost such that when country i adopts the subsidy system and country j the subsidy one, the subsidy in the former country is equal to 0.

Let us denote by $\Delta SW_i^s \equiv SW_i^{s,s} - SW_i^{ns,s}$ the gain for country i related to the deviation from the subsidy to the no-subsidy system, given that IM_j chooses the subsidy system. Then, $\Delta SW_i^s|_{k_i=\underline{k}_i^s} = 0$.

We have $\frac{dSW_i^{s,s}}{dk_i} = -(1+\lambda_{pf})$ and $\frac{dSW_i^{ns,s}}{dk_i} = -\theta_i q_*(a_{*i}^{ns,s}, a_{*j}^{ns,s})\left(1+\frac{da_{*j}^{ns,s}}{da_{*i}^{ns,s}}\right)\frac{da_{*i}^{ns,s}}{dk_i}$, where the strategic interaction between access prices is now given by Equation (5). The strict budget balance constraint in country i when country j adopts the subsidy-system is:

$$(a_{*i}^{ns,s} - c_u)q_*(a_{*i}^{ns,s}, a_{*j}^{ns,s}) = k_i. \qquad (BB_i^{ns,s})$$

Totally differentiating $(BB_i^{ns,s})$ yields:

$$\frac{da_{*i}^{ns,s}}{dk_i} = \frac{1}{q_*\left\{1+(a_{*i}^{ns,s}-c_u)\frac{q'_*}{q_*}\left(1+\frac{da_{*j}^{ns,s}}{da_{*i}^{ns,s}}\right)\right\}} = \frac{1}{q_*\left\{1-\frac{1+\tilde{\lambda}_i^{ns,s}-\theta_i}{1+\tilde{\lambda}_i^{ns,s}}\left(1+\frac{da_{*j}^{ns,s}}{da_{*i}^{ns,s}}\right)\right\}}.$$

Then, simple manipulations lead to:

$$\frac{d\Delta SW_i^s}{dk_i} = -(1+\lambda_{pf}) + \frac{\theta_i(1+\lambda_{pf})(1+\tilde{\lambda}_i^{ns,s})}{\theta_i(1+\lambda_{pf}) - (1+\tilde{\lambda}_i^{ns,s})(1+\lambda_{pf}-\theta_j)\delta_*}. \qquad (A.2)$$

Now, assume that $\theta_i(1+\lambda_{pf}) - (1+\tilde{\lambda}_i^{ns,s})(1+\lambda_{pf}-\theta_j)\delta_* < 0 \quad \forall\tilde{\lambda}_i^{ns,s} \geq 0$, which is equivalent to $\delta_* > \overline{\delta}_{*i}^+ \equiv \frac{\theta_i(1+\lambda_{pf})}{\theta_i+\lambda_{pf}} > 0$. In this case, both terms of the right-hand side of $(A.2)$ are negative for all parameter configurations. This gives us Proposition 3. It is immediate to check that $\delta_* > \overline{\delta}_{*i}^+ \Leftrightarrow \frac{da_{*i}^{ns,s}}{dk_i} \leq 0 \ \forall\tilde{\lambda}_i^{ns,s} > 0$. Note that in the symmetric case, $\overline{\delta}_{*i}^+ = \frac{1+\lambda_{pf}}{1+2\lambda_{pf}}$.

A.6 Proof of Propositions 4 and 5

From Equation $(A.2)$, we obtain:

$$\lim_{k_i\to\underline{k}_i^s}\frac{d\Delta SW_i^s}{dk_i^s} = \frac{(1+\lambda_{pf})(1+\lambda_{pf}-\theta_j)\delta_*}{\theta_i-(1+\lambda_{pf}-\theta_j)\delta_*}. \qquad (A.3)$$

For δ_* positive but not too large, the right-hand side of Equation $(A.3)$ is positive. Simple computations show that:

$$\frac{d^2\Delta SW_i^s}{dk_i^2} = \left\{\frac{(1+\lambda_{pf})\theta_i}{(1+\lambda_{pf})\theta_i - (1+\tilde{\lambda}_i^{ns,s})(1+\lambda_{pf}-\theta_j)\delta_*}\right\}^2\frac{d\tilde{\lambda}_i^{ns,s}}{dk_i}.$$

But, since $\frac{da_{*i}^{ns,s}}{dk_i} = \frac{da_{*i}^{ns,s}}{d\tilde{\lambda}_i^{ns,s}}\frac{d\tilde{\lambda}_i^{ns,s}}{dk_i}$, we can deduce that

$$\text{Sign}\left[\frac{d\tilde{\lambda}_i^{ns,s}}{dk_i}\right] = \text{Sign}\left[\frac{da_{*i}^{ns,s}}{d\tilde{\lambda}_i^{ns,s}}\right]\times\text{Sign}\left[\frac{da_{*i}^{ns,s}}{dk_i}\right] = \text{Sign}\left[1-\omega_*^s\delta_*\right]\times\text{Sign}\left[1-\omega_*^s\right], \quad (A.4)$$

where $\omega_*^s = \frac{1+\tilde{\lambda}_i^{ns,s}-\theta_i}{1+\tilde{\lambda}_i^{ns,s}}\frac{1+\lambda_{pf}}{(1+\lambda_{pf})-(1+\lambda_{pf}-\theta_j)\delta_*}$. Consequently, for δ_* positive and small, ΔSW_i^s is strictly convex in k_i. Defining $\underline{\delta}_{*i}^+ \equiv \frac{\theta_i(1+\lambda_{pf})}{(1+\tilde{\lambda}_i)(\lambda_{pf}+\theta_i)}$ as the highest positive value of δ_* such that $1-\omega_*^s$, $1-\omega_*^s\delta_*$ and $\theta_i-(1+\lambda_{pf}-\theta_j)\delta_*$ are simultaneously positive, we obtain

Proposition 4.

If $\delta_* < 0$, the first and second term in the right-hand side of $(A.4)$ are strictly positive. But we now obtain $\lim_{k_i \to \underline{k}_i^s} \frac{d\Delta SW_i^s}{dk_i} < 0$. Given that the welfare difference ΔSW_i^s is still strictly convex, two cases have to be distinguished depending on whether the sign of its derivative eventually becomes positive or not; this is equivalent to study the sign of:

$$\lim_{k_i \to +\infty} \frac{d\Delta SW_i^s}{dk_i^s} = (1+\lambda_{pf}) \frac{\theta_i + (1+\lambda_{pf} - \theta_j)\delta_*}{-\delta_*(1+\lambda_{pf} - \theta_j)}.$$

Defining $\underline{\delta}_*^- \equiv \frac{-\theta_i}{1+\lambda_{pf}-\theta_j}$, the proof of Proposition 5 is complete.

A.7 Proof of Propositions 6 and 7

When $\delta_* > \max\{\overline{\delta}_{*i}^+, \overline{\delta}_{*j}^+\}$ or $\delta_* < \min\{\underline{\delta}_{*i}^-, \underline{\delta}_{*j}^-\}$, each infrastructure manager has a dominant strategy and we do not need to compare $\underline{k}_i^s$ and $\underline{k}_i^{ns}$.

Similarly, when $0 < \delta_* < \min\{\underline{\delta}_{*i}^+, \underline{\delta}_{*j}^+\}$, the first-stage best-responses of the infrastructure managers do not depend on the levels of infrastructure deficit and we do not need to compare $\underline{k}_i^s$ and $\underline{k}_i^{ns}$.

When $\max\{\underline{\delta}_{*i}^-, \underline{\delta}_{*j}^-\} < \delta_* < 0$, using $(A.4)$, we have $\frac{d\tilde{\lambda}_j^{s,ns}}{dk_j} > 0$. Therefore, $\tilde{\lambda}_j^{s,ns} \geq \lambda_{pf}$ and $a_{*i}^{ns,s} \geq a_{*i}^{s,s}$ for all $k_j \geq \underline{k}_j^s$. This implies that $\underline{k}_i^{ns} \leq \underline{k}_i^s$. Since we focus only on cases where, under a subsidy system, the subsidy given to the infrastructure is positive, we restrict attention to cases where $k_i \geq \underline{k}_i^s$. Then, it suffices to use Propositions 1 and 5 to determine the equilibrium.

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