The Welfare Gains of Cooperative Public Infrastructure Policies: A Trade and Supply-Side View*

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Abstract

We investigate the optimal levels of public investment in infrastructure in a two-country open-economy model with production externality and distortionary taxation. In the model, transport costs fall with local and foreign stocks of public infrastructure, but more strongly with the foreign stock. We provide empirical evidence supporting this assumption, and show that it generates sizable welfare gains from international cooperation, from 0.15% in the baseline case to more than 5% of permanent consumption under alternative calibrations. We also discuss the endogenous responses of cooperative and non-cooperative levels of public investment in infrastructure to productivity shocks.

Keywords: Public infrastructure, endogenous transport costs, international cooperation, open economy.

JEL Classification: E32, E62, F41, H54.

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1 Introduction

Since the 2008 Great Recession, public infrastructure has been at the core of political discussions, leading to various attempts to spur more investment. In the European Union, a stimulus package was adopted right at the beginning of the crisis in 2008, with a 32 billions euros budget allocated to investment in infrastructure.[1] These measures subsequently stalled because of the Maastricht Treaty deficit and debt limits in several countries.[2] As a consequence, public investment has further decreased in many European Union countries. Indeed, according to the Council of Europe Development Bank (2017), public investment levels were, on average, 10.8% lower in 2015 than the 2009 peaks. Today, the needs for infrastructure investment are still high in various areas, especially due to their positive effects on potential growth. For instance, the recent 50 billions euros investment plan proposed by the Macron administration in France includes several propositions to raise the quantity and/or quality of infrastructure. According to the European Investment Bank (EIB), public investment would have to increase by 50% compared to 2014 levels to meet policy goals in terms of trade growth and further integration of the EU internal markets. Publicly or privately financed infrastructure are thus at the center of many questions pertaining to potential growth and market integration, in a context of binding funding constraints, especially for publicly financed investment in infrastructure.

In this paper, we investigate the macroeconomic effects of investment in public infrastructure on GDP and trade, and highlight the welfare gains from cooperation in choosing the optimal level of public investment in infrastructure. We build a two-country real model with tradable goods, and investment in public infrastructure, which is financed through distortionary taxes on labor income. Our assumptions are that the stock of public infrastructure (*i*) generates a positive externality on local production, (*ii*) lowers transport costs in both countries, and more substantially in the partner economy, as shown empirically by Limao & Venables (2001) and confirmed by our own estimations, and (*iii*) raises distortionary taxes. Given these assumptions and the fact that we abstract from nominal rigidities, monetary policy and public debt, our paper definitely focuses on two types of macroeconomic effects: the supply and trade effects of investment in public infrastructure.

We show that the positive effects of investment in infrastructure — through positive production and trade externalities — funded by distortionary taxes dominate their underlying negative effects — larger labor wedges and consumption crowding out — for a plausible

[1] See European commission 2009.

[2] In 2012, the Fiscal Compact has been signed by state members stipulating that a structural deficit limit of 0.5% of GDP should be adopted in national legislation.

calibration. More precisely, there are direct and indirect effects that are purely local and others are channeled through foreign trade. While the production externality and distortionary effects of taxation are purely local, the transport cost externality effect is international, opening some space for potential welfare gains from cooperation. In particular, if the welfare gains from an increase in public infrastructure investment — through the fall of transport costs — mostly benefit to the foreign households, and less to the local households, while the costs are borne by local households, non-cooperative (Nash) solutions will feature sub-optimally low levels of infrastructure investment — and taxes — and cooperative (Ramsey) policies will generate both higher levels of public investment and taxes, as well as welfare gains. According to our calibration, the public infrastructure investment to GDP ratio resulting from a non-cooperative (Nash) equilibrium is 4.3%, which is higher than currently observed in the data 3.53% — which we consider as our baseline case — but lower than the 4.8% investment ratio implied by the cooperative solution. Our results suggest that the potential welfare gains from adopting a cooperative strategy when choosing the levels of public investment in infrastructure range from 0.15 % — in the baseline calibration — to more than 5% of consumption equivalent, for instance when the production externality is close to zero.

Our results are based on the assumption that transport costs depend more on the country's trading partner infrastructure than to its own infrastructure. In other words, the elasticity of transport costs with respect to local public infrastructure has to be lower than the elasticity with respect to foreign public infrastructure. This result was shown to hold empirically by Limao & Venables (2001). From the theoretical point of view, Naito (2016) gives a functional form for transport costs and adopts the same assumption about the respective elasticities. We follow the steps of Limao & Venables (2001) and estimate these elasticities using the functional form given by Naito (2016). The transport costs measure is built as the difference between CIF and FOB prices of merchandises, taken from the OECD International Transport and Insurance Cost of Merchandise Trade. Our dataset is composed of 12 representative products, 8 destination countries and 10 origin countries over a period of 22 years (1995-2016). Our empirical results back the assumption that transport costs are most affected by the foreign stock of infrastructure than by the local stock. Our estimations suggest that the elasticity of transport costs with respect to the foreign stock of public capital varies from 0.445 to 0.471 while the the elasticity of transport costs with respect to the local stock ranges from 0.057 to 0.093, depending on the specifications.

The welfare gains from cooperation uncovered in the baseline case are robust to different values of key parameters in the model such as the size of the production externality, the degree of openness of the economy and the Frisch elasticity of labor supply. However, the magnitude of welfare gains changes with regard to the level of these parameters. First, the higher the production externality, the higher the levels of public investment in infrastructure — and taxes, which results in lower levels of transport costs. For low levels of the production externality, we show that the Nash equilibrium features lower levels of public investment in infrastructure and taxes than the Ramsey equilibrium. The gap between the local costs induced by distortionary taxation and local benefits from investing in public infrastructure capital is larger, which widens the gap between Nash and cooperative solutions, and the welfare gains from cooperation are *much* larger in this case. Second, the Ramsey equilibrium is insensitive to the degree of the trade openness because the planner considers the whole economy as a closed economy, while public investment in infrastructure and tax rates decrease when the degree of openness increases. Higher degrees of openness thus widen the gap between local costs from higher taxation and the benefits from additional trade flow, since a rise in public infrastructure investment increases foreign consumption more than domestic consumption. The welfare gains from cooperation are thus non-monotonically increasing in the level of trade openness. Finally, optimal levels of investment in public infrastructure are roughly insensitive to the Frisch elasticity of labor supply in the Ramsey equilibrium while they decrease when labor supply becomes more elastic in the Nash equilibrium. In the latter case, the local costs induced by the rise in investment and taxation increase more than the associated benefits, that stem from a decrease in transport costs. As a result, the gap between Ramsey and Nash investment ratios and tax rates are wider when labor supply becomes more elastic, implying larger welfare gains from cooperation.

This paper also investigates the optimal public investment levels after a productivity shock. We show that (asymmetric) productivity improvements in the home economy increase the Nash and cooperative levels of public investment in *both* home and foreign countries, but the rise is much smaller in the foreign country than in home country. Ramsey and Nash equilibria generate similar fluctuations of the economy after productivity shocks, although around different steady states: consumption is crowded out in both countries relative to the case where investment remains constant (the baseline case), which results in smoother fluctuations in consumption levels. This is actually welfare improving since risk-averse households dislike fluctuations in private consumption levels. As a consequence of the rise in the home public infrastructure, output increases more in the home economy and drops less in the foreign economy, because of the positive effects of the productive externality. An additional positive effect relates to the fall in transport costs in both countries, which is larger in the foreign economy than in the home country. The fall in terms of trade usually induced by positive productivity shocks is dampened, which along with stabilized consumption fluctuations (*i*) stabilizes the fluctuations of trade flows and (*ii*) attenuates the drop in foreign output.

The relevant literature has grown since Aschauer (1989)'s pioneering and provocative findings. He showed that the return on public investment was much higher than had been previously thought, and argued that the productivity slowdown experienced by the U.S. in the 1970s could be explained by a shortage of investment in public infrastructure. Aschauer (1989)'s work then prompted a large number of theoretical and empirical papers on public investment in infrastructure. This issue has been addressed in closed-economy growth models by Barro (1990), Glomm & Ravikumar (1994), Glomm & Ravikumar (1999), Turnovsky (1996), among others; in overlapping generation models by Heijdra & Meijdam (2002) and Bom & Ligthart (2014*a*), and also within a New-Keynesian model by Coenen, Straub & Trabandt (2013).[3] In addition, some studies deal with the issue of fiscal coordination and economic growth, such as Devereux & Mansoorian (1992) and Figuieres, Prieur & Tidball (2013). In particular, Devereux & Mansoorian (1992) extend Barro's (1990) framework to a two-country model of endogenous growth, and show that fiscal policy coordination may either raise or lower growth rates. However, to the best of our knowledge, little attention has been paid to transport/trade costs as a transmission mechanism of investment in public infrastructure, despite its presumed quantitative importance as shown by Casas (1983), Bougheas, Demetriades & Morgenroth (1999) and Limao & Venables (2001). For instance, New Economic Geography models give more importance to transport costs Fujita, Krugman & Venables (2001), but papers considering transport costs as depending on the stock of public infrastructure remain relatively scarce: Martin & Rogers (1995), Bougheas et al. (1999), Mun & Nakagawa (2008), Naito (2016) and Felbermayr & Tarasov (2019). All these papers consider static models and thus neglect the potentially interesting dynamic effects of investment in public infrastructure. Our paper fills the gap by analyzing the dynamic macroeconomic effects of investment in public infrastructure in a two-country model where transport/trade costs depend on the stock of public infrastructure of both countries.

The paper is organized as follows. Section 2 presents the model. Section 3 analyzes the steady-state implications of investment in public infrastructure under three configurations: when investment ratios are determined exogenously, based on a Nash equilibrium and based on a Ramsey (cooperative) equilibrium. The static gains from cooperation are then discussed. Section 4 reports the business cycles analysis. Section 5 concludes.

[3] See Gramlich (1994) or Bom & Ligthart (2014*b*) for an extensive literature review on public investment in infrastructure.

2 Model

The model consists of two countries, Home and Foreign. Each country produces tradable goods and consumption is a Cobb-Douglas bundle of these two goods. Trade requires the additional payment of (iceberg) transport costs that depend not only on a country's public infrastructure but also, on the stock of public infrastructure of its trading partner. Each period, the government in each country levies taxes on the labor income of households to fund its infrastructure investment. In each country, a representative firm produces a domestic good in a competitive market and benefits from the domestic public infrastructure, which enhances its productivity. In each country, an infinitely-lived representative household supplies labor, and derives utility from consumption. International financial markets are complete, *i.e.* households have access to state-contingent securities and share risks perfectly across countries. We allow for potential fluctuations driven by stochastic productivity shocks, investigated more particularly in Section 4. Home and Foreign consumption bundles are given by

$$c_t = \frac{c_{ht}^{1-\alpha} c_{ft}^{\alpha}}{(1-\alpha)^{1-\alpha}\alpha^{\alpha}} \text{ and } c_t^* = \frac{c_{ft}^{*(1-\alpha)} c_{ht}^{*\alpha}}{(1-\alpha)^{1-\alpha}\alpha^{\alpha}}, \tag{1}$$

where $\alpha \in [0, 1/2]$ measures the weight of imported goods in home consumption basket, h subscripts denote the consumption of goods produced in the Home country and f subscripts the consumption of goods produced in the Foreign country. The trade elasticity is implicitly set to one. Households minimize total expenditure on consumption

$$p_{ht}c_{ht} + (1+\tau_t)\, s_t p_{ft}^* c_{ft} \quad \text{and} \quad p_{ft}^* c_{ft}^* + (1+\tau_t^*)\, s_t^{-1} p_{ht} c_{ht}^*, \tag{2}$$

subject to the above-defined consumption bundles. It is apparent from Equation (2) that the law of one price holds. Variable s_t denotes the nominal exchange rate, and τ_t and τ_t^* are (iceberg) transport costs paid by Home and Foreign households, respectively, to import goods. Using (1) and (2) to solve the expenditure optimization problem yields the following demand functions

$$c_{ht} = (1-\alpha)(1+\tau_t)^{\alpha} q_t^{\alpha} c_t, \text{ and } c_{ft} = \alpha (1+\tau_t)^{\alpha-1} q_t^{\alpha-1} c_t, \tag{3}$$

$$c_{ft}^* = (1-\alpha)(1+\tau_t^*)^{\alpha} q_t^{-\alpha} c_t^*, \text{ and } c_{ht}^* = \alpha (1+\tau_t^*)^{\alpha-1} q_t^{1-\alpha} c_t^*, \tag{4}$$

where the terms of trade are defined as $q_t = s_t p^*_{ft}/p_{ht}$, implying

$$p_t c_t = p_{ht} c_{ht} + (1+\tau_t) s_t p^*_{ft} c_{ft}, \tag{5}$$

$$p^*_t c^*_t = p^*_{ft} c^*_{ft} + (1+\tau^*_t) s_t^{-1} p_{ht} c^*_{ht}, \tag{6}$$

where

$$p_t = p_{ht}^{1-\alpha} \left((1+\tau_t) s_t p^*_{ft} \right)^{\alpha} \text{ and } p^*_t = p_{ft}^{*1-\alpha} \left((1+\tau^*_t) s_t^{-1} p_{ht} \right)^{\alpha}. \tag{7}$$

We first focus on the Home representative household, who derives utility from aggregate consumption, c_t, and disutility from working hours, n_t. The representative household solves:

$$\max E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left(\frac{c_t^{1-\sigma}}{1-\sigma} - \omega \frac{n_t^{1+\psi}}{1+\psi} \right) \right\}, \tag{8}$$

subject to its budget constraint

$$p_t c_t + E_t \left\{ \Lambda_{t,t+1} d_{t+1} \right\} = d_t + (1-\kappa_t) w_t n_t. \tag{9}$$

In Equation (9), d_t is a portfolio of internationally traded state-contingent assets, $\Lambda_{t,t+1}$ a stochastic discount factor attached to the one-period-ahead payments of the portfolio, and E_t is the conditional expectation operator. In addition, κ_t is the labor income tax, and w_t the nominal wage. In Equation (8), $\beta < 1$ stands for the subjective discount factor, σ is the coefficient of relative risk-aversion, and $\psi > 0$ is the inverse Frisch elasticity of labor. The first-order conditions imply

$$\beta \left(\frac{c_t}{c_{t+1}} \right)^{\sigma} \pi_{t+1}^{-1} = \Lambda_{t,t+1}, \tag{10}$$

$$\omega n_t^{\psi} c_t^{\sigma} = (1-\kappa_t) w_t^r (1+\tau_t)^{-\alpha} q_t^{-\alpha}, \tag{11}$$

where $w_t^r = w_t/p_{ht}$ is the real wage expressed in units of the domestic good. Equation (10) is the Euler equation on the state-contingent assets, where $\pi_{t+1} = p_{t+1}/p_t$.[4] Expectations are absent from Equation (10) since the return is state-contingent. Equation (11) is the labor supply equation, which is affected by the relative price of the domestic good because the real wage w_t^r is paid in units of the Home good while consumption is expressed in units of the composite good. A similar problem is faced by the Foreign household, which gives

[4] The paper considers flexible prices so that the Euler equation determines the real interest rate residually, without any feedback effects on other key variables.

the following Foreign labor supply equation

$$\omega n_t^{*\psi} c_t^{*\sigma} = (1-\kappa_t^*)\, w_t^{r*} (1+\tau_t^*)^{-\alpha} q_t^{\alpha}, \tag{12}$$

and the following risk-sharing equation between households of both countries:

$$c_t^{\sigma} = \Phi \frac{s_t p_t^*}{p_t} c_t^{*\sigma} = \Phi \left(\frac{1+\tau_t^*}{1+\tau_t}\right)^{\alpha} q_t^{1-2\alpha} c_t^{*\sigma}. \tag{13}$$

A representative firm produces the domestic good using the simple production function

$$y_t = a_t n_t (k_t)^{\gamma}, \tag{14}$$

where a_t is an exogenous measure of productivity and $0 \leq \gamma \leq 1$ measures the elasticity of output with respect to public infrastructure. This production function features a productive externality from the stock of public infrastructure k_t accumulated over period $t-1$, an assumption that receives a large support in the literature.[5] The profit maximization of the representative firm in Home country results in $w_t^r = w_t/p_{ht} = a_t (k_t)^{\gamma}$. The government pays for the level of investment in public infrastructure using the labor income tax rate so that

$$\kappa_t y_t = i_t, \tag{15}$$

which implies that the tax rate, κ_t, is also the ratio of public investment to GDP, i_t/y_t. The law of motion for public infrastructure is given by

$$k_{t+1} = (1-\delta) k_t + i_t, \tag{16}$$

where δ denotes the depreciation rate of the stock of public infrastructure. Combining (15) and (16), and using (14) yield the following public capital accumulation equations

$$k_{t+1} = (1-\delta) k_t + \kappa_t a_t n_t (k_t)^{\gamma}, \tag{17}$$

$$k_{t+1}^* = (1-\delta) k_t^* + \kappa_t^* a_t^* n_t^* (k_t^*)^{\gamma}. \tag{18}$$

Finally, the presence of iceberg transport costs to trade goods means that for $1+\tau_t$ (>1) units of good exported only 1 arrives because τ_t units melt away in transit: τ_t denotes the import transport cost rate for the Home country (or the export transport cost rate for the Foreign country). We follow the literature that makes transport costs endogenous by

[5] See Baxter & King (1993), Glomm & Ravikumar (1994) or more recently Bom & Ligthart (2014*a*), among others.

assuming that increasing the stock of public infrastructure reduces transport costs. In addition, transport costs are a function of the stocks of public infrastructure of both countries (Home and Foreign).[6] Accordingly, we assume the following specification for the transport cost functions:[7]

$$\tau_t = \eta \left(\overline{k}/k_t\right)^{\mu} \left(\overline{k}/k_t^*\right)^{\chi}, \tag{19}$$
$$\tau_t^* = \eta \left(\overline{k}/k_t^*\right)^{\mu} \left(\overline{k}/k_t\right)^{\chi}, \tag{20}$$

where $\overline{k}$ is a parameter that captures other factors affecting the transport costs, such as geography or trade agreements, and η is a normalizing factor, which sets the minimum possible level of transport cost. Parameters μ and χ respectively denote the elasticities of one country's import transport cost with respect to its own stock of public infrastructure and to the foreign stock of public infrastructure. In Section 3.1, we propose an estimation of these elasticities, and show that transport costs not only depend negatively on a country's own stock of public infrastructure capital, but also, and even more negatively on its trading partner's stock of public infrastructure, implying $\mu < \chi$.

The above equations describe a decentralized equilibrium in which, conditional on $\mathcal{K}_t = \{\kappa_t, \kappa_t^*\}$, agents optimize with respect to their budget constraints for given prices, and for which prices adjust to clear labor and goods markets according to

$$a_t n_t \left(k_t\right)^{\gamma} \left(1-\kappa_t\right) = \left(1-\alpha\right)\left(1+\tau_t\right)^{\alpha} q_t^{\alpha} c_t + \alpha \left(1+\tau_t^*\right)^{\alpha-1} q_t^{1-\alpha} c_t^*, \tag{21}$$
$$a_t^* n_t^* \left(k_t^*\right)^{\gamma} \left(1-\kappa_t^*\right) = \left(1-\alpha\right)\left(1+\tau_t^*\right)^{\alpha} q_t^{-\alpha} c_t^* + \alpha \left(1+\tau_t\right)^{\alpha-1} q_t^{\alpha-1} c_t. \tag{22}$$

The market clearing conditions (21) and (22), the labor supply equations (11) and (12), and the public infrastructure accumulation equations (17) and (18), summarize the macroeconomic effects of changes in κ_t and κ_t^*. The positive effects of an increase in tax rates, κ_t (or κ_t^*) are channeled through the supply of goods and through trade.

First, higher tax rates raise the level of public investment, which has a positive effect on future aggregate production through the production externality (see Equation (14)). Beyond the direct effect on output that allows to raise households future consumption or decrease their labor supply (see Equations (21) and (22)), there is an indirect effect. With higher future output (see the second term on the right-hand side of (17) and (18)), the future levels of public investment increase as well, which then further spurs the accumulation of

[6] See Limao & Venables (2001) or Naito (2016), among others.

[7] We propose an empirical analysis of this specification, and find that it is supported by the data.

public infrastructure. This indirect effect suggests that public investment in infrastructure has immediate but also future positive (productive) and persistent effects.

Second, the rise in future stocks of public infrastructure lowers the future levels of transport costs, allowing for larger trade flows, and thus higher levels of consumption. However, higher local levels of public infrastructure lower foreign transport costs more than local transport costs since $\chi >> \mu$. As such, a larger share of the consumption gains related to an increase in the local stock of public infrastructure falls on foreign households, which creates a public good game configuration: local governments have an incentive to let the foreign government invest in public infrastructure, which can lead to sub-optimally low levels of public investment if countries do not cooperate.

Third, increasing κ_t and κ_t^* also introduces some costs. The left-hand sides of Equations (21) and (22) clearly show that an increase in tax rates produces a crowding-out effect on consumption levels, with negative welfare consequences. In addition, the labor supply conditions (11) and (12), show that an increase in tax rates widens labor wedges, pushing households to reduce their supply of hours worked, with negative effects on output and then consumption.

We consider three alternative ways of setting κ_t and κ_t^*. One is the baseline solution where tax rates are constant and set exogenously to their observed average values in the data, using public investment to GDP ratios. This equilibrium is mostly used to set the calibration of key parameters. The second one is the cooperative solution, in which a central planner chooses tax rates so as to maximize aggregate welfare:

$$\max_{\kappa_t,\kappa_t^*} E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left(\frac{c_t^{1-\sigma}}{1-\sigma} - \omega \frac{n_t^{1+\psi}}{1+\psi} + \frac{c_t^{*1-\sigma}}{1-\sigma} - \omega \frac{n_t^{*1+\psi}}{1+\psi} \right) \right\} \tag{23}$$

conditional on the equations describing a decentralized equilibrium, (11), (12), (17), (18), (19), (20), (21), (22), and

$$c_t^{\sigma} \quad = \quad \Phi \left(\frac{1+\tau_t^*}{1+\tau_t} \right)^{\alpha} q_t^{1-2\alpha} c_t^{*\sigma}. \tag{24}$$

In other words, we solve the dual form of the Ramsey problem at the aggregate level. Finally, the third one is the non-cooperative or Nash solution: in each country, a planner maximizes a national welfare function for a given value of the tax rate in the other country and conditional on the equations describing a decentralized equilibrium. In particular, the planner of the Home country solves

$$\max_{\kappa_t,\kappa_t^*=\kappa^*} E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left(\frac{c_t^{1-\sigma}}{1-\sigma} - \omega \frac{n_t^{1+\psi}}{1+\psi} \right) \right\}, \tag{25}$$

while the planner of the Foreign country solves

$$\max_{\kappa_t^*,\kappa_t=\kappa} E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left(\frac{c_t^{*1-\sigma}}{1-\sigma} - \omega \frac{n_t^{*1+\psi}}{1+\psi} \right) \right\}, \tag{26}$$

both subject to the same set of equations (11), (12), (17), (18), (19), (20), (21), (22), and (24). The joint set of first-order conditions implied by solving Equations (25) and (26) forms the Nash equilibrium of our economy.

Overall, optimal policies will equate the marginal costs and benefits from setting the tax rates/levels of investment in public infrastructure. While the first (production externality) and third (distortionary taxation) effects are purely local, the second one (transport cost externality) is international, which opens a possibility of welfare gains from cooperation. In particular, if the welfare gains from an increase in levels of public investment in infrastructure (and tax rates) through the fall of transport costs mostly benefit to foreign households, and benefit less to local households, while the costs are borne by local households, non-cooperative (Nash) solutions will likely feature a sub-optimally low levels of investment and taxation, and cooperative (Ramsey) policies will generate welfare gains.

3 Steady-state analysis

Let us first focus on the steady-state implications of the three equilibria defined in the previous section. We first present our approach to calibrate the various parameters of the model before reporting and commenting the steady-state results along with a sensitivity analysis.

3.1 Transport costs and public capital: empirics

First, given that the elasticities of transport costs to the stocks of public infrastructure are key parameters in our framework, we estimate them using transport costs data. The theoretical model follows from Naito (2016) and points to the following functional form:

$$\tau_{it} = \eta \left(\overline{k}/k_{it}\right)^{\mu} \left(\overline{k}/k_{jt}\right)^{\chi} \tag{27}$$

where k_{it} is the stock of public capital in country i at time t. Taking the log, we get

$$\log(\tau_{it}) = \underbrace{\eta + (\mu + \chi)\log\left(\bar{k}\right)}_{cst} - \mu \log(k_{it}) - \chi \log(k_{jt}) \tag{28}$$

As Limao & Venables (2001), we estimate this equation using panel data. The interest variable is a measure of transport costs, built as the difference between CIF and FOB prices of merchandises, expressed in percentage terms, taken from the OECD International Transport and Insurance Cost of Merchandise Trade. The database is product-based and we consider a sample of 12 representative products indexed in k: aluminum bars, cars, cell batteries, coffee, crude oil, fuel woods, iron bars, military weapons, rice, rubber, soya beans and sugar. Further, we consider 8 destination countries indexed in j: France, Germany, Italy, Japan, New Zealand, Turkey, United Kingdom, United States, and 10 origin countries indexed in i: the 8 destination countries plus Mexico and Canada. Finally, transport costs for each product and each country pair are observed for 22 years (1995-2016). Our dataset is thus one of transport costs panel data, $\log(\tau_{ijkt})$, with products, k, destination, j, origin, i, and time, t, effects. The explanatory variables considered are the following. First, each country pair is associated with its bilateral distance ($dist_{ij}$), taken from the Geodist CEPII database. Second, we introduce a dummy for each country pair (isl_{ij}) that takes value 1 if either the destination or the origin country is an island (Japan, New Zealand and the United Kingdom), and 0 otherwise. Third, we introduce the possibility that transport costs are affected by a trend and consider a variable $time_t$. We also introduce the average log-level of GDP per capita over the 22 years in the origin (local) country $\log Y_i$ and in the destination (foreign) country $\log Y_j$, to control for size. Finally, we consider measures of $\log k_{it}$ in the origin country and $\log k_{jt}$ in the destination country using the public levels of capital stocks divided by private capital stocks, to consider capacity-corrected stocks of public capital. These variables, as well as GDPs, are expressed in billions of constant 2011 international dollars, range from 1995 to 2016, and are taken from the IMF FAD database.[8] The estimation results are reported in Table 1.

Table 1 reports point estimates and t-stats under six different specifications. The first one restricts the set of explanatory variables to the bilateral distance, the island dummy and the effect of time. It considers product k fixed effects, as in several other specifications. The second specification adds the average levels of GDP per capita in the destination and origin countries, and keeps including product fixed-effects. The third one adds the measure of public capital in the country of origin, again with product fixed effects. Finally, specification

[8] Appendix A reports a list and description of the variables, and provides links to the databases.

Table 1: Estimation results

Dependent variable: $\log(\tau_{ijkt})$						
Specification #	1	2	3	4	5	6
$cst.$	–	–	–	-5.096 (-43.90)	–	-5.755 (-29.81)
$dist_{ij}$	0.251 (47.68)	0.248 (46.81)	0.253 (46.52)	0.235 (40.80)	0.250 (46.66)	0.247 (46.30)
isl_{ij}	0.085 (6.53)	0.109 (8.12)	0.117 (8.64)	0.227 (14.71)	0.235 (16.42)	0.237 (16.53)
$time_t$	-0.011 (-10.89)	-0.011 (-10.99)	-0.011 (-11.44)	-0.014 (-13.40)	-0.014 (-14.93)	-0.014 (-14.94)
$\log \overline{Y}_i$	–	0.131 (7.39)	0.123 (7.32)	0.150 (7.95)	0.112 (6.41)	0.104 (5.99)
$\log \overline{Y}_j$	–	-0.247 (-14.16)	-0.246 (-14.08)	-0.301 (-16.19)	-0.284 (-16.47)	-0.291 (-16.87)
$-\log\left(1/k_{it}^g\right)$	–	–	0.089 (14.15)	0.057 (2.51)	0.093 (4.44)	0.088 (4.20)
$-\log\left(1/k_{jt}^g\right)$	–	–	–	0.445 (20.04)	0.471 (22.88)	0.470 (22.79)
Product k FE	Yes	Yes	Yes	No	Yes	No
Product k RE	No	No	No	No	No	Yes
σ	0.5772	0.5673	0.5667	0.6425	0.5479	0.5494
R^2	0.1580	0.1725	0.1734	0.1689	0.2008	0.1994
$Obs.$	15224	15224	15224	15224	15224	15224
$Haus.$	–	–	–	–	–	41.03

4 to 6 include all the explanatory variables and are estimated respectively using a pooled, product fixed effect and product random effect estimators.

Our results provide several insights. First, as expected, bilateral distance affects transport costs positively, the coefficient is remarkably stable across specifications and statistically significant. Second, the island dummy is always significant and, as in Limao & Venables (2001), affects transport costs positively. Third, our sample of transport costs feature a downward trend over time, and its magnitude is very stable across specifications. Fourth, average GDP per capita levels have differentiated effects: shipping from a large country (in terms of GDP per capita) implies paying relatively smaller transport costs while shipping to a large country (in terms of GDP per capita) implies paying relatively more. While the first sign is similar to that reported by Limao & Venables (2001), the other is not. However, these variables are only introduced as controls, and our main interest lies in the estimation of the elasticities of transport costs to the stocks of public capital.

Specifications 4 to 6 provide the main results of interest: both destination and origin stocks of public capital affect transport costs negatively, as in Limao & Venables (2001). Further, as in their paper, we find that the stronger effect comes from the stock of public capital of the country of origin — the foreign stock when goods are imported — while the effect of the local stock of public capital has more limited impact. The former varies from 0.445 to 0.471 while the latter varies from 0.057 to 0.093, depending on specifications. Notice that, while Limao & Venables (2001) report point estimates that tend to favor constant returns to scale in, home and foreign, public infrastructure, our point estimates rather point to decreasing returns to scale. This might be explained by the fact that the index they use for public infrastructure is a bundle of actual public transport infrastructure while we consider the whole stock of public capital, corrected for capacity using the private stock of capital. As such, our measure includes capital assets that are not purely related to transport infrastructure, *e.g.* public schools, buildings, hospitals, which may account for lower elasticities. However, key to the point made in our paper — in line with Limao & Venables (2001) — is that the foreign stock has more impact on domestic transport costs than the domestic stock. This result motivates the externality from which the gains from policy cooperation arise. Finally, since the fixed effect estimator (specification 5) features a smaller variance of residuals than the pooled estimator (specification 4), and since the Hausmann statistic points to a rejection of product random effects (specification 6) compared to product fixed effects (specification 5), our favored specification is the one featuring all explanatory variables and product fixed effects (specification 5). We thus keep the following values for elasticities of interest: $\mu = 0.093$ and $\chi = 0.471$.

3.2 Parameter values

The other parameters of the model are calibrated in the following way. Our baseline calibration is symmetric across both countries. Bom & Ligthart (2014*a*) analyze the dynamic macroeconomic effects of public investment in infrastructure under a balanced budget fiscal rule in a small open economy. They use a calibration based on OECD countries so we borrow some of their parameter values: the real interest rate is 4% annually, implying $\beta = 0.99$ in our quarterly set-up. The stock of public infrastructure depreciates at 6% annually, or 1.5% quarterly. Further, we set $\gamma = 0.08$ as a benchmark value. In line with macro estimates, we set the Frisch elasticity of labor supply to $1/\psi = 0.5$, the risk-aversion parameter to $\sigma = 1.5$, the labor disutility parameter to $\omega = 1$, the openness parameter to $\alpha = 0.15$ — inducing a 30% trade flows to GDP ratio in the steady state, close to U.S. numbers. Given the potential importance of some parameters for our results, a sensitivity analysis is conducted with respect to the production externality, γ, the trade openness parameter, α, and the Frisch elasticity on labor supply, $1/\psi$.

Finally, our calibration strategy for transport cost parameters is the following. The elasticities μ and χ are set to their estimated values in Section 3.1. Further, we equate the tax rate in the baseline case (exogenous κ and thus κ^*) to the average value of the public investment to GDP ratio observed in the data for a subset of OECD countries between 1995 and 2016, $i/y = \kappa = \kappa^* = 3.53\%$.[9] This exogenous level of κ determines a steady-state level of public capital in both countries. We set the absolute minimum level of transport costs at $\eta = 0.02$ and adjust $\overline{k} = 23.17$ to obtain a level of transport costs that matches the average transport costs observed in the sample used in Section 3.1, *i.e.* $\tau = \tau^* = 0.07$.[10] The above numbers are imposed in the baseline steady-state with exogenous κ and κ^*. When optimal Ramsey and Nash policies are considered, κ and κ^* are determined endogenously while keeping η and $\overline{k}$ fixed at their calibrated value. Parameter values are summarized in Table 2 below.

Table 2: Baseline parameter values

Discount factor	$\beta = 0.99$
Risk aversion parameter	$\sigma = 1.5$
Labor disutility parameter	$\omega = 1$
Labor supply elasticity	$1/\psi = 0.5$
Trade openness	$\alpha = 0.15$
Public infrastructure depreciation	$\delta = 0.015$
Public infrastructure production externality	$\gamma = 0.08$
Absolute minimum of transport costs	$\eta = 0.02$
Max. level of public infrastructure	$\overline{k} = 23.17$ — implies $\tau = 0.07$ for $\kappa = 0.0353$
Elast. of transport costs to local public infrastructure	$\mu = 0.093$
Elast. of transport costs to foreign public infrastructure	$\chi = 0.471$

3.3 Results

Before assessing the effects of different parameter values, let us first discuss the results for the baseline calibration. As already mentioned, in the baseline case, $i/y = \kappa = \kappa^* = 3.53\%$ implies $\tau = \tau^* = 0.07$. Under the Nash equilibrium, optimal tax rates and levels of public investment are 4.3%, roughly 1pp above their baseline value, implying a moderate fall in transport costs from 7% to 6.2%, less than 1pp. The Ramsey equilibrium implies substantially larger optimal tax rates, around 4.8%, and therefore much lower transport costs (5.8% against 7% in the baseline case). These results illustrate the forces at play. Optimal tax rates are larger than observed tax rates, calling for an increase in public investment in infrastructure. Remembering that the productive externality is $\gamma = 0.08$, the policy prescription is however not to equate the tax rate with the social return of this externality, because taxation is distortionary and brings some social costs on its own.

[9] The subset of OECD countries includes the destination countries (minus Turkey) used in Section 3.1.

[10] The resulting maximum level of public infrastructure $\overline{k}$ is roughly 6 times larger than the annual level of GDP. It is large enough to prevent policy-makers to reach it given the distortionary effects of labor income taxation.

Finally, the Ramsey investment ratios and tax rates are larger because this equilibrium internalizes the transport cost externality while the Nash equilibrium does not. As such, for the baseline calibration, the Ramsey steady-state generates a 0.15% consumption equivalent welfare gain compared to the Nash steady-state. Compared to the baseline equilibrium where investment ratios match their observed values from the data, the welfare gains are much larger, around 1.4% of consumption equivalent. Roughly 10% of this number, 0.15%, comes from the welfare gain from cooperation while the rest stems from the efficiency gains associated with setting the tax rates and levels of public investment optimally.

Figure 1 and 2 below show the steady-state tax rates κ and κ^*, and the resulting levels of transport costs τ and τ^* for the three equilibria. They also display the steady-state consumption equivalent welfare gains from cooperation (Ramsey compared to Nash), and the consumption equivalent welfare gains from optimal policies (Nash and Ramsey respectively compared to the baseline case of exogenous and constant κ and κ^*). The Figures report the results for various values of the productive externality (from $\gamma = 0.01$ to $\gamma = 0.1$), for various values of the openness parameter (from $\alpha = 0$ to $\alpha = 0.5$), for various values of the Frisch elasticity (from $1/\psi = 0.2$ to $1/\psi = 4$) and for various levels of relative TFP (from $a^*/a = 0.8$ to $a^*/a = 1$), to gauge the impact of these parameters on the policy trade-offs faced by policymakers.

Figure 1: Steady-state results, varying the productive externality γ and trade openness α

(a) Varying γ **(b)** Varying α

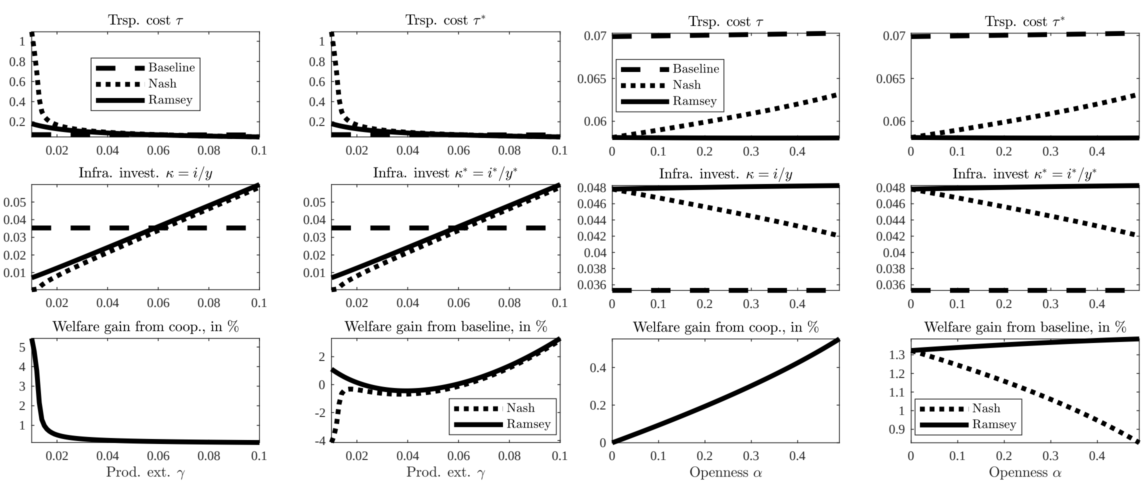


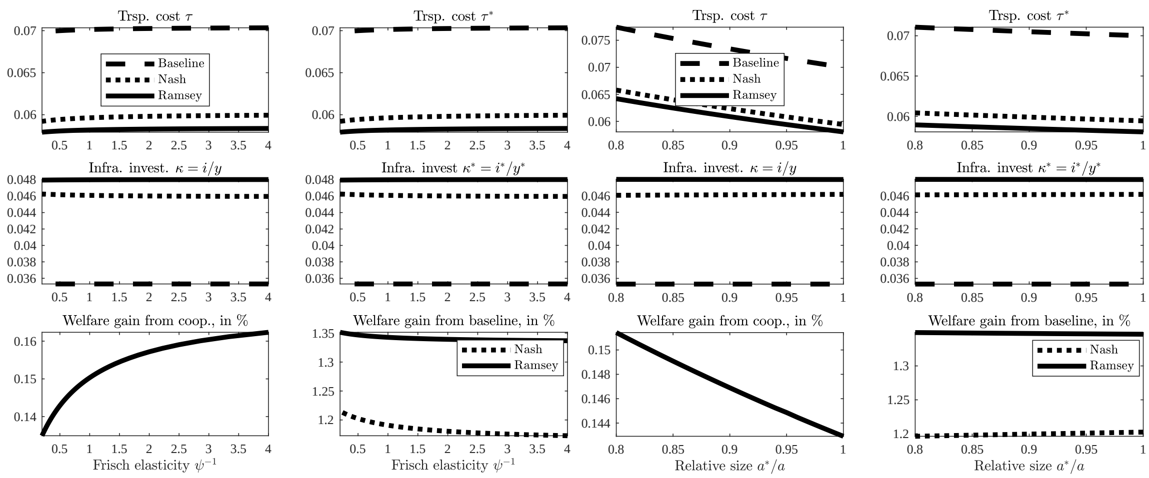
Figure 1 shows that the production externality is a key parameter, that shapes the various welfare gains in the model. First, larger levels of γ call for larger levels of taxation and public investment in infrastructure, which produces lower levels of transport costs. Hence, because tax rates and levels of public investment are fixed in the baseline case, the welfare gains from optimal policies (Ramsey or Nash) compared to the baseline increase. They can reach as much as 3% (Ramsey vs. baseline) when the productive externality is as large as $\gamma = 0.1$. When the externality is less important (when γ is smaller), tax rates and public investment levels decrease and transport costs increase, but much more in the Nash equilibrium than in the Ramsey equilibrium. The chief reason is that the local production externality is relatively less important compared to the external transport cost externality. While this does not make much difference for the Ramsey optimal tax rates, it does for the Nash optimal tax rates. Indeed, the lower γ, the wider the gap between the local costs (the tax distortion) and the local benefits from investing in public infrastructure, which further emphasizes the difference between Ramsey and Nash investment ratios. Hence, the welfare gains from cooperation increase when γ is lower, because the relative importance of the transport cost externality is magnified. The welfare gains from cooperation can represent up to 5% of consumption equivalent, a very large number according to the usual standards of the literature on international cooperation.

The relative size of the two positive externalities seems to be crucial in shaping the welfare gains from cooperation. As such, the right panel in Figure 1 reports the results for various levels of trade openness, which governs part of the importance of the trade externality. Indeed, when policies are determined optimally, the planner considers the world economy as a closed economy, no matter what the level of trade openness. Therefore the optimal tax rates and investment ratios remain unaffected by the degree of trade openness in the Ramsey steady state. On the contrary, trade openness critically amplifies the relative importance of the transport cost externality in the Nash steady state. When α is larger, a fall in transport costs generates a larger shift in trade flows and thus has more effects on the steady-state levels of consumption. When a country raises its tax rate and investment ratio unilaterally, it increases foreign consumption more than domestic consumption. As a consequence, the gap between the Nash and Ramsey steady states increases with trade openness, which lowers the incentive of local planners to invest in public infrastructure in the Nash equilibrium. The welfare gains from cooperation are thus non-monotonically increasing in α. They reach 0.6% of consumption equivalent when $\alpha = 0.5$, a number that is not off charts when considering the degrees of trade openness observed among OECD countries.

The left panel in Figure 2 shows the sensitivity of the steady-state tax rates and investment ratios as a function of the labor supply elasticity. The optimal levels of tax rates are not affected by the labor supply elasticity in the Ramsey steady state while they decrease when labor supply becomes more elastic (a fall in ψ) in the Nash steady state. The latter result is not surprising, as the distortions from high labor tax rate increase when labor supply

Figure 2: Steady-state results, varying the Frisch elasticity $1/\psi$ and relative TFP levels a^*/a

(a) Varying $1/\psi$ **(b)** Varying a^*/a



become more elastic.[11] In this case, the costs associated with additional distortionary taxation outweigh the benefits from a decrease in transport costs. Hence, the welfare gains from the Nash equilibrium with respect to the baseline situation drop, because local planners have less incentive to increase investment ratios. As a result, the gap between Ramsey and Nash equilibrium investment ratios widens with the Frisch elasticity of labor supply, implying larger welfare gains from cooperation.

The right panel in Figure 2 produces an additional set of interesting results, pertaining to the effect of size — more precisely relative TFP levels — on the steady-state tax rates and investment ratios. When one of the two-country becomes poorer, in terms of relative GDP per capita, both Ramsey and Nash steady states imply that tax rates and investment ratios should remain constant. However, identical tax rates and investment ratios translate into larger (respectively smaller) stocks of public infrastructure in the richer (resp. poorer) country, which results in smaller (resp. larger) transport costs in the poorer (resp. richer) country, since $\chi >> \mu$. In any case, the relative importance of asymmetry in steady-state TFP levels is quantitatively small in our model.

[11] On the contrary, in the limiting case of zero labor supply elasticity — labor becomes a fixed endowment — taxation become non-distortionary at all.

4 Optimal public investment over the business cycle

We now track the behavior of our economy under the three policy regimes after unexpected productivity shocks. In the baseline regime, the policy is passive in the sense that tax rates / investment ratios are constant, *i.e.* $\kappa_t = \kappa$ and $\kappa_t^* = \kappa^*$. The Nash and Ramsey regimes are characterized by time-varying levels κ_t and κ_t^*. We consider country-specific productivity shocks, where

$$\log(a_t/a) = \rho_a \log(a_{t-1}/a) + \sigma_a \epsilon_{at} \text{ and } \log(a_t^*/a^*) = \rho_a \log\left(a_{t-1}^*/a^*\right) + \sigma_a \epsilon_{a^*t}, \qquad (29)$$

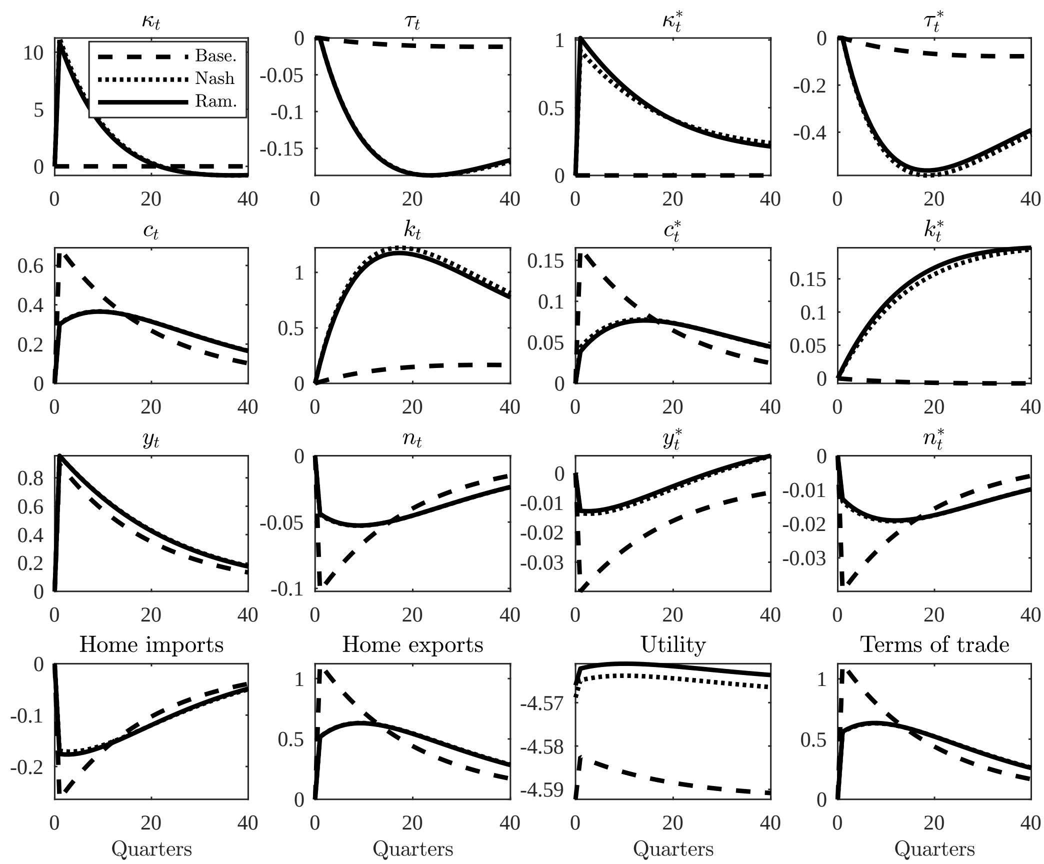
with normally distributed innovations. The persistence of productivity shocks is $\rho_a = 0.95$ and the standard deviation of innovations is $\sigma_a = 0.01$.

The model is solved by taking a second-order approximation around each of the three steady states using perturbation methods. Figure 3 reports the dynamics of the three regimes after a 1% positive Home productivity shock.

Starting with the effects of productivity shocks with constant tax rates (baseline case), Figure 3 shows that a productivity shock in the Home economy raises output and consumption in the Home economy, and implies decreasing hours worked. Our calibration implies that the substitution effect is dominated by the wealth effects on labor supply. The shock makes Home products relatively cheaper, terms of trade fall, which pushes both Home and Foreign consumers to substitute Foreign goods to Home goods: Home imports fall while Home exports (Foreign imports) rise. Because of the lesser demand for Foreign goods, Foreign output falls, inducing a one for one drop in hours worked by Foreign households. However, the expenditure switching effect implied by cheaper Home goods allows Foreign households to sustain a slightly higher level of consumption. Because tax rates and investment ratios are constant in the baseline case, investment in public infrastructure follows the dynamics of output in each country, increasing mildly in the Home economy and falling by a negligible amount in the Foreign economy. As a consequence, transport costs fall slightly in the Home economy and a bit more in the Foreign economy, because they depend more heavily on the (increasing) stock of public infrastructure of the Home economy.

Now focusing on Nash and Ramsey dynamics, they are overall very similar and imply almost identical paths of our economies. The optimal policy consists in increasing significantly the tax rate in the Home economy (by more than 10%, implying an approximate 0.5pp increase). The stock of public infrastructure rises substantially and persistently. The Foreign tax rate rises as well in the Foreign economy, but by 1.5% only. In comparison to the baseline

Figure 3: Impulse responses to a 1% productivity shock in the domestic economy.



Note: Percentage deviations, except for aggregate utility, reported in level.

case, Ramsey and Nash equilibria produce the following differences in terms of dynamics. First, the rise in public investment in infrastructure produces a crowding-out effect on consumption in both countries, attenuating the fluctuations in consumption levels. This is actually welfare improving since risk-averse households dislike fluctuations in private consumption levels. Second, as a result of the positive externality on production induced by the rise in public infrastructure in both countries, output does not fall as much as in the baseline case in the Foreign economy and increases more than in the baseline case in the Home economy. A third effect is the drop in transport costs in both countries, which is more significant in the Foreign country than in the Home country. Therefore the fall in terms of trade is dampened, which, jointly with attenuated consumption fluctuations (*i*) stabilizes the fluctuations of trade flows and (*ii*) reduces the drop in Foreign output. The Nash case generates a slightly smaller increase in the Foreign tax rate and investment ratio than the Ramsey case, leading to a slightly larger drop in the labor supply of Foreign households, and a slightly larger drop in Foreign output.

5 Conclusion

Investment in public infrastructure and infrastructure building in general is crucial to growth and economic development. In this paper, we show that the question of the optimal provision of public infrastructure in a two-country model with endogenous trade costs has a typical public good game structure. The Nash solution yields lower stocks of public infrastructure than the (Ramsey) cooperative solution, and the welfare gains from cooperation can be as large as 5% of consumption equivalent. The underlying reason is that public infrastructure produce large positive externalities on production and trade, and that the benefits from investing in public infrastructure in the form of lower trade and transport costs are captured by those agents that do not pay for the investment.

These results may not be very surprising given the documented positive externalities associated with investment in public infrastructure. However, the observed rates of public investment to GDP remain particularly low in most developed economies, ranging from 3% to 4% over the last 20 years. These numbers are low, especially compared to the observed shares of total public expenditure in GDP. In addition, they are broadly consistent with (although lower than) the numbers found for Nash equilibria in our model. If anything, our results thus call for more public investment in infrastructure, and for more coordination in the investment strategies of advanced economies, especially within areas where institutional arrangements exist to foster cooperation, *e.g.* the European Union or the Eurozone. The associated welfare gains are almost certainly large.

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A Data description

- τ_{ijkt}: transport cost, taken from the OECD International Transport and Insurance Cost of Merchandise Trade (`https://stats.oecd.org/Index.aspx?DataSetCode=CIF_FOB_ITIC`). 12 representative products (k): aluminum bars, cars, cell batteries, coffee, crude oil, fuel woods, iron bars, military weapons, rice, rubber, soya beans and sugar. 8 destination countries (j): France, Germany, Italy, Japan, New Zealand, Turkey, United Kingdom, United States, and 10 origin countries (i): the 8 destination countries plus Mexico and Canada. The time range (t) is 1995-2016.

- $dist_{ij}$: bilateral distance, taken from the Geodist CEPII database (`http://www.cepii.fr/cepii/fr/bdd_modele/presentation.asp?id=6`).

- isl_{ij}: dummy variable, equals one if one of the two countries (i or j) is an island, and zero otherwise.

- $\log \bar{Y}_i$: log-level of GDP per capita of country i, taken from the IMF FAD database (`https://www.imf.org/external/np/fad/publicinvestment/`). Average value between 1995 and 2016.

- $\log k_{it}$: log-level of the ratio of public to private capital stock of country i, taken from the IMF FAD database (`https://www.imf.org/external/np/fad/publicinvestment/`).