CESifo WORKING PAPERS

7290
2018

October 2018

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CESifo

Impressum:

CESifo Working Papers
ISSN 2364-1428 (electronic version)
Publisher and distributor: Munich Society for the Promotion of Economic Research - CESifo GmbH
The international platform of Ludwigs-Maximilians University's Center for Economic Studies and the ifo Institute
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Editors: Clemens Fuest, Oliver Falck, Jasmin Gröschl
www.cesifo-group.org/wp

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CESifo *Working Paper No. 7290*
Category 1: Public Finance

Public Expenditure Spillovers: An Explanation for Heterogeneous Tax Reaction Functions

Abstract

This article provides a possible explanation for the heterogeneity of tax reaction functions under tax competition. In particular, we assume the existence of three jurisdictions, i, j and z, as well as of spillovers. Given this simple framework, we show that if jurisdictions compete to attract mobile capital, spillovers can lead to asymmetric responses. In fact, jurisdiction i may react positively to a change in the tax rate of jurisdiction j and negatively to the change occurred in jurisdiction z. These findings are helpful to understand the mixed results of the empirical literature. Moreover, they have policy implications in that they explain the lack of tax convergence among jurisdictions. In particular, if at least some tax reaction functions have a negative slope, there are no symmetric equilibria, and the well-known tax-cut-cum-base-base-broadening policy would fail to hold.

JEL-Codes: H250, H200, H400.

Keywords: tax competition, spillovers, asymmetric reaction functions.

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1st October 2018

1 Introduction

It is well known that mobility of production factors can affect government fiscal strategies. These phenomena distort trade, investment patterns, erode national tax bases and shift part of the tax burden onto less mobile tax bases. For this reason, economists have extensively analysed tax strategies since the pioneering articles by Zodrow and Mieszkowski (1986) and Wilson (1986).[1] It is also well known and widely acknowledged that public goods and services may produce positive or negative spillovers (their existence being well documented by Revelli 2005; Ojede et al. 2018; López et al. 2017; Solé-Ollé 2006; Banzhaf and Chupp, 2011; Oates, 2002; Ogawa and Wildasin, 2009; Oates, 2008). Surprisingly, there is very little research which deals with the interactions between these two phenomena. We argue that spillovers may affect the fiscal strategies of jurisdictions. Hence, their inclusion in the tax competition analysis can enrich our understanding of fiscal strategies.

The theoretical literature on tax competition shows that if tax rates are strategic tools, strategic complementarity or strategic substitutability may arise. Despite these efforts, there is agreement neither on the sign of the reaction functions nor on their magnitude (see, e.g.,Leibrecht and Hochgatterer, 2012). The mainstream literature assumes that tax competition is a Nash game where tax rates are set simultaneously.[2] and show that tax rates are strategic complement at an international level (see Devereux et al., 2008; Redoano, 2014; Egger and Raff, 2015). However, they become strategic substitutes at sub-national or sub-federal level (e.g., Chirinko and Wilson, 2017; Parchet, 2014). Accordingly, Brueckner and Saavedra (2001) show that strategic substitution may occur when governments maximize a linear utility function, if the marginal value of private goods exceeds that of public goods.[3] Mintz and Tulkens

[1]Given the heterogeneity among jurisdictions, since the beginning of 1990s the literature has also focused on asymmetric tax competition. See, e.g.,Wilson (1991); Bucovetsky (1991); Kanbur and Keen (1993).

[2]Alternatively, tax rates may be set sequentially following a Stackelberg game. However, only a few articles support this hypothesis (among them, see e.g. Altshuler and Goodspeed 2015; Hory 2017).

[3]Most research has recognised the role of FDI flows in the tax competition process, though only few authors take this relationship explicitly into account. Two papers modelling tax rates and tax bases are Egger and Raff (2015) and Ghinamo et al. (2010). Egger and Raff (2015) studied strategic interactions both for tax rates and in tax bases. Using a sample of both European and non-European countries (over the 1982-2005 period), they found that countries respond to the other countries' statutory tax rate cuts by reducing their own tax

(1986) pointed out that tax rates may be strategic substitutes if private consumption and public goods are complements. A similar result can be obtained if jurisdictions use public spending (instead of taxes) as their relevant strategic tool (see e.g., Wildasin, 1988).[4] More recently, Vrijburg and de Mooij (2016) have shown that the slope of reaction functions depends on the jurisdiction's objective function. If countries maximize tax revenues, the slope of reaction functions is always positive; on the other hand, if jurisdictions maximize welfare, a negative slope (reflecting the fact that tax rates are strategic substitutes) can be obtained with realistic parameter values.

A recent paper Miniaci et al. (2018) has shown that strategic complementarity (with a positive slope of reaction functions) may coexist with strategic substitutability. Their empirical analysis shows an interesting feature in the slope of the reaction functions: given countries i, j, and z, country i may react positively to a change in the tax rate of country j and negatively to the change occurred in country z. In other words, their empirical analysis support two different evidences: 1. asymmetric response between two countries, i.e., country i may react positively (negatively) to an increase in the tax rate of country j while country j may react by decreasing (increasing) its tax rate if country i increases its tax rate; 2. country i reacts positively to a change in the tax rate of country j and negatively to the change occurred in country i.

This evidence is at odds with the existing empirical literature, which estimates reaction functions assuming (without testing) that the reaction function of each jurisdiction to changes in the tax rate by other competitors are either strategic complements or strategic substitutes.

In this paper we develop a model which provides a rationale for these heterogeneous effects, by modelling public spending spillovers (in line with Bjorvatn and Schjelderup, 2002); we argue that spillovers can lead to asymmetric effects in tax competition. This result is novel since, so far, the theoretical literature on tax competition and

rates (although they are expected to raise depreciation allowances). Ghinamo et al. (2010) considered the simultaneous determination of the corporate tax rate and the FDI inflows and found that this model supports the hypothesis of strategic complementarity.

[4] On this topic, see Wilson and Wildasin (2004); Fuest et al. (2005) and Wilson (1999). Recently, Keen and Konrad (2013) have provided an interesting review of the tax competition literature.

spillovers, implicitly assumes symmetric reaction functions. Hence, positive spillover effects may only reduce or even eliminate tax competition (and its under-provision effects).

The most common form of spillovers studied in in the fiscal federalism literature deals with a positive effect that the expenditure of a jurisdiction has on its neighbours.[5] However, public expenditure can cause relevant negative spillovers. For instance, public infrastructure usually causes negative spillovers (Boarnet, 1998; Sloboda and Yao, 2008); negative externalities are also common in the environmental protection literature (Banzhaf and Chupp, 2011; Oates, 2002; Ogawa and Wildasin, 2009). Moreover, expenditure programmes, particularly those intrinsically related to citizen welfare, may produces positive/negative externalities to other regions. As shown by Brekke et al. (2016), if Regions differ in income, public health care expenditure of rich regions may negatively affect welfare of the poorer region through patients mobility.[6]

The rest of the paper is organized as follows. Section 2 presents the model, where three jurisdictions aim at maximizing their own welfare, under full capital mobility and public expenditure spillovers and the main findings of our analysi. Section 3 summarises results and discusses their policy implications.

2 The model

In this Section we introduce a model which focuses on tax competition under spillover effects. In particular we let three jurisdictions choose strategically their tax policies. Each of them is inhabited by a representative consumer. Two goods are produced:

1. a private good c_i, homogeneous across countries, whose price is equal to one and acts as numeraire in this simplified economy;
2. a public good g_i which may produce spillovers across countries at rate β. Spillovers are assumed to be jurisdiction-specific.

In line with Wildasin (1988), we assume that the production function uses capital as variable input. Other factors are assumed to be

[5]According to Solé-Ollé (2006), in Spain one Euro of local spending provides the same utility to a typical resident as three Euro of neighbours' spending.

[6]In Italy the payment of extra-regional hospital admission has generated additional amounts of financial flows in favour of central–northern regions, exacerbating the north–south gradient in Italy's National Health System (see Cergas-Bocconi, 2017).

fixed and jurisdiction-specific. The production function in jurisdictions $i = 1, 2, 3$ is for simplicity quadratic, i.e:

$$f(k_i) = (b_i(a_i - k_i)k_i) \tag{1}$$

where b_i and a_i are jurisdiction-specific productivity parameters and k_i is capital, with $f(k_i) \geq 0$, i.e., $k_i \leq \frac{b_i a_i}{2}$.

Private good c_i can be either consumed or used to produce the public good g_i. We can therefore measure the production of the public good in terms of private foregone consumption. The provision of public goods is financed by a source-based tax on capital. Given the tax rate t_i, the balanced budget constraint for jurisdiction i will then be equal to

$$g_i = t_i k_i,$$

for i=1, 2, 3. Given these assumptions, the after-tax profit will then be:

$$\Pi_i = (b_i(a_i - k_i)k_i) - (r + t_i)\, k_i \tag{2}$$

where r is the equilibrium interest rate (free capital mobility means that this variable is equal in all the three jurisdictions). Finally, the total quantity of capital for this three-jurisdiction economy is equal to $K = k_1 + k_2 + k_2$.

Consumer i earns the after-tax profit of the local firm and a return equal to r times net endowment invested abroad. Denoting θ_i the share of total capital owned by the local jurisdiction, consumer i's budget constraint will be equal to:

$$c_i = b_i(a_i - k_i)k_i - (r + t_i)\, k_i + \theta_i r K, \tag{3}$$

with $\sum_{i=1}^{3} \theta_i = 1$.

Consumers' utility depends on the quantity of private good they can consume and on the level of the public good produced. Moreover, we assume that there is some spillover effect due to foreign public spending. Following Bjorvatn and Schjelderup (2002), i.e., assuming that each consumer's utility function is linear in both c_i and g_i (with $i = 1, 2, 3$), we can write:

$$U_i = \alpha_i c_i + (1 - \alpha_i) \left(g_i + \sum_{i=1; i \neq j}^{n} \beta_{ij} g_j \right), \tag{4}$$

where α_i and (1-α_i) are the relative weight for private consumption and public good, respectively. β_{ij} measures the spillover effect of jurisdiction j's public spending on consumer i's utility. Since we use a broad definition of spillovers, the following inequality $\beta_{ij} \neq \beta_{ji}$ may hold.[7]

2.1 Capital allocation

Each firm maximises its after-tax profit, i.e:

$$Max_{k_i}\Pi_i = (b_i(a_i - k_i)k_i) - (r + t_i)\, k_i \tag{5}$$

Hence, the demand for capital in each jurisdiction is obtained by solving this following problem. Writing the FOC as:

$$\frac{\partial \Pi_i}{\partial k_i} : ((b_i(a_i - k_i)k_i) - (r + t_i)\, k_i)$$

and rearranging, we obtain the demand for capital in each jurisdiction i:

$$k_i = \frac{a_i}{2} - \frac{t_i + r}{2b_i}. \tag{6}$$

In the absence of arbitrage, there is one interest rate for all jurisdictions, which can be obtained by solving the four-equation system:

$$\begin{aligned} k_i &= \frac{a_i}{2} - \frac{t_i + r}{2b_i} \qquad with\ i = 1, 2, 3, \\ K &= k_1 + k_2 + k_2. \end{aligned} \tag{7}$$

Rearranging (7) thus gives:

$$\begin{aligned}
k_1 &= \frac{b_2 b_3 \left(2K - a_3 - a_2\right) + \left(b_1 a_1 - t_1\right)\left(b_3 + b_2\right) + b_2 t_3 + t_2 b_3}{2\left(b_2 b_1 + b_1 b_3 + b_2 b_3\right)} \\
k_2 &= \frac{b_1 b_3 \left(2K - a_1 - a_3\right) + b_1 t_3 + t_1 b_3 + \left(b_2 a_2 - t_2\right)\left(b_1 + b_3\right)}{2\left(b_2 b_1 + b_1 b_3 + b_2 b_3\right)} \\
k_3 &= \frac{b_1 b_2 \left(2K - a_1 - a_2\right) + b_1 t_2 + t_1 b_2 + \left(b_3 a_3 - t_3\right)\left(b_1 + b_2\right)}{2\left(b_2 b_1 + b_1 b_3 + b_2 b_3\right)} \\
r &= \frac{b_1 b_2 b_3 \left(a_1 + a_2 + a_3 - 2K\right) - t_3 b_2 b_1 - b_2 t_1 b_3 - t_2 b_1 b_3}{\left(b_2 b_1 + b_1 b_3 + b_2 b_3\right)}
\end{aligned}$$

[7] To our knowledge, no empirical study shows that $\beta_{ij} = \beta_{ji}$.

As can be seen, capital allocation and the world interest rate depend on all taxes and technological parameters.

2.2 Reaction functions

In each jurisdiction, the Government chooses the tax rate that maximises the utility of its consumer. Hence, the problem for jurisdiction i is:

$$\begin{aligned} Max_{t_i} U_i &= \alpha_i c_i + (1-\alpha_i)\left(g_i + \sum_{i=1; i\neq j}^{n} \beta_{ij} g_j\right) \qquad (8) \\ & s.t. \\ g_i &= t_i k_i \\ c_i &= b_i (a_i - k_i) k_i - (r + t_i) k_i + \theta_i r K \end{aligned}$$

The FOC of Problem (8) allows to calculate the reaction function of each jurisdiction to a change in the tax rate of the other local authorities (see appendix A). Table 1 shows the results.

$$\begin{aligned} t_{12} = \frac{\partial t_1}{\partial t_2} &= b_3 \frac{(b_1 b_3 + b_2 b_3 + b_2 b_1)(1-\alpha_1)(1+\beta_{12}) - \alpha_1 b_1 (b_3 + b_2)}{2(b_1+b_2)(b_2 b_3 + b_1 b_3 + b_2 b_1)(1-\alpha_3) + \alpha_3 b_3 (b_1 + b_2)} \\ t_{13} = \frac{\partial t_1}{\partial t_3} &= b_2 \frac{(b_1 b_3 + b_2 b_3 + b_2 b_1)(1-\alpha_1)(1+\beta_{13}) - \alpha_1 b_1 (b_3 + b_2)}{2(b_1+b_2)(b_2 b_3 + b_1 b_3 + b_2 b_1)(1-\alpha_3) + \alpha_3 b_3 (b_1 + b_2)} \\ t_{21} = \frac{\partial t_2}{\partial t_1} &= b_3 \frac{(b_1 b_3 + b_2 b_3 + b_2 b_1)(1-\alpha_2)(1+\beta_{21}) - \alpha_2 b_2 (b_3 + b_1)}{2(b_1+b_2)(b_2 b_3 + b_1 b_3 + b_2 b_1)(1-\alpha_3) + \alpha_3 b_3 (b_1 + b_2)} \\ t_{23} = \frac{\partial t_2}{\partial t_3} &= b_1 \frac{(b_3 + b_2 b_3 + b_2 b_1)(1-\alpha_2)(1+\beta_{23}) - \alpha_2 b_2 (b_3 + b_1)}{2(b_1+b_2)(b_2 b_3 + b_1 b_3 + b_2 b_1)(1-\alpha_3) + \alpha_3 b_3 (b_1 + b_2)} \\ t_{31} = \frac{\partial t_3}{\partial t_1} &= b_2 \frac{(b_1 b_3 + b_2 b_3 + b_2 b_1)(1-\alpha_3)(1+\beta_{31}) - \alpha_3 b_3 (b_1 + b_2)}{2(b_1+b_2)(b_2 b_3 + b_1 b_3 + b_2 b_1)(1-\alpha_3) + \alpha_3 b_3 (b_1 + b_2)} \\ t_{32} = \frac{\partial t_3}{\partial t_2} &= b_1 \frac{(b_1 b_3 + b_2 b_3 + b_2 b_1)(1-\alpha_3)(1+\beta_{32}) - \alpha_3 b_3 (b_1 + b_2)}{2(b_1+b_2)(b_2 b_3 + b_1 b_3 + b_2 b_1)(1-\alpha_3) + \alpha_3 b_3 (b_1 + b_2)} \end{aligned}$$

Table 1: Reaction functions

The sign of reaction functions can be either positive or negative: this depends on the relative strength of α and β. The interesting feature of these reaction functions is that the presence of the spillovers allows jurisdictions to have asymmetric responses in two dimension: a) reciprocal (i.e., t_{ij} may be different from t_{ji}); b) across jurisdictions (i.e., the signs of t_{ij} may be different from the signs of t_{iz} and $t_{jz}$and at the same time the signs of t_{iz} and t_{jz} may also be different).

To show this, let us first consider the case without spillovers, i.e., with $\beta_{ij} = 0$. In this case, the relative magnitude of the effect can be different, although the sign, which depends on the relative weight that the jurisdiction i attaches to public goods, is the same. In appendix B we show that:

$$t_{ij} \gtrless 0 \quad if \quad \frac{\alpha_i}{1-\alpha_i} \lesseqgtr \frac{\varepsilon}{\upsilon_i} \tag{9}$$

where $\nu_i = b_i \left(\sum_{j=1,3;j\neq i} b_j\right)$ and $\varepsilon = (b_1 b_3 + b_2 b_3 + b_2 b_1)$. Since the inequality $\varepsilon > \nu_i$ always holds, strategic complementarity is compatible only with values of $\alpha < \frac{1}{2}$, i.e., the jurisdiction should weight more public goods than private consumption for its reaction function being positive. The intuition behind this result is simple: with positive (negative) spillovers the potential gain from attracting foreign capital is at least partially offset (amplified) by the loss from an international reduction in public goods supply.

Provided that these three economies are asymmetric (i.e., the productivity parameter is not the same), the sign in equation (9) is the same: if for instance we focus on jurisdiction 1, we can see that if $t_{12} < 0$, then the inequality $t_{13} < 0$ holds. Without spillovers, the reactions may have a different magnitude (see equation 9). However, they have the same sign.

When we introduce spillovers, the slope of the reaction turns to be ambiguous and depends on the combined effect of α and β. To show this, let us consider the reaction function of jurisdiction 1 to change in t_2 and t_3. In appendix B we show that the following conditions

$$\begin{aligned} t_{12} \gtrless 0 \quad if \quad \beta_{12} \gtrless \frac{\alpha_1}{1-\alpha_1}\frac{\nu_1}{\varepsilon} - 1, \\ t_{13} \gtrless 0 \quad if \quad \beta_{13} \gtrless \frac{\alpha_1}{1-\alpha_1}\frac{\nu_1}{\varepsilon} - 1, \end{aligned} \tag{10}$$

hold. If therefore spillover effects are heterogeneous across jurisdictions, strategic complementarity and substitutability can co-exist.

If, for instance, $\beta_{12} > \frac{\alpha_1}{1-\alpha_1}\frac{\nu_1}{\varepsilon} - 1 > \beta_{13}$, we obtain $t_{12} > 0 > t_{13}$. In other words, jurisdictions 1 and 2 are strategic complements, whereas jurisdiction 1 and 3 are strategic substitutes. Our model allows to interpret the results of the previous literature in a new light. For example, Vrijburg and de Mooij (2016) concludes that with a linear welfare function, strategic complementary always holds; our model shows that results are quite different if spillovers are accounted for. Using (10) we can in fact determine the following threshold

$$\overline{\beta_{ij}} \equiv \frac{\alpha_i}{1-\alpha_i} \cdot \frac{v_i}{\varepsilon} - 1$$

Since $\frac{v_i}{\varepsilon} < 1$, the sign depends on the combined effect of $\frac{\alpha_i}{1-\alpha_i}$ and $\frac{v_i}{\varepsilon}$. For $\frac{\alpha_i}{1-\alpha_i} < 1$ ($\alpha_i < \frac{1}{2}$) strategic substitution is compatible only with negative spillovers. For higher values of α, strategic substitution may emerge even with positive spillovers. The intuition behind this results is straightforward: if public expenditure is relatively more important than private consumption (low α), only a negative spillover is compatible with strategic substitution. If however, private consumption is relatively more important (α is high enough), even positive spillovers can lead to strategic substitutability.

2.3 Symmetric productivity parameters

In order to get a better understanding of the impact of spillovers, let us consider a symmetric case where $b_i = b$. In this case, the reaction function exists if $\alpha_i \neq \frac{3}{4}$. For $\alpha_i > \frac{3}{4}$, the reaction function is always positive in this linear setting, whereas for $\alpha_i < \frac{3}{4}$:

$$t_{ij} = \frac{3\,(1+\beta_{ij})\,(1-\alpha_i) - 2\alpha_i}{6\,(1-\alpha_i) - 2\alpha_i}. \tag{11}$$

Using (11) and setting $t_{ij} = 0$ gives the values of β_{ij} and α_i such that the reaction function is zero:

$$\beta_{ij} = \frac{2}{3}\frac{\alpha_i}{1-\alpha_i} - 1.$$

Accordingly, if $\beta_{ij} > \frac{2}{3}\frac{\alpha_i}{1-\alpha_i} - 1$ the reaction function is positive; otherwise it is negative. Figure 1 provides a graphical explanation. The blue line is the place of the points where the slope of reaction functions is nil. Above (below) this line, the slope of reaction functions is positive (negative).

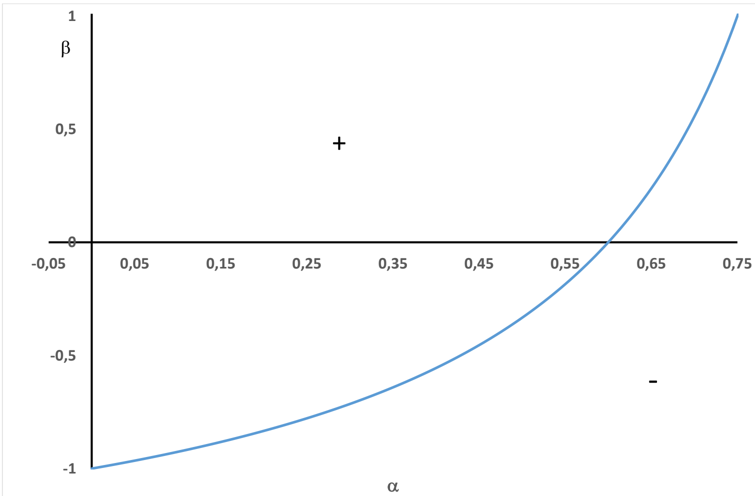

Figure 1: Sign of the tax change for alternative combinations of β and α

If we allow spillovers to be positive ($\beta \geq 0$) a change in the tax rate of other jurisdictions usually produces strategic complementarity unless α is sufficiently high; on the other hand if spillovers can also be negative the number of possible combinations of (α, β) for which the reaction can be negative increases. All the points along the blue line foresees a case where the tax in a jurisdiction is set independently from the behaviour of another jurisdiction (this result is in line with Bjorvatn and Schjelderup, 2002). If however we look at points on the horizontal axis, we can compare our results with Vrijburg and de Mooij (2016) (who set $\beta = 0$): as can be seen, strategic complementarity (substitutability) holds if α is low (high) enough. Outside the horizontal axis and the blue line, we can find heterogeneous reaction functions where strategic complementarity and substitutability can co-exist even if technology is the same across jurisdictions.

3 Conclusions

While most of the traditional literature on fiscal federalism (Oates, 2008) tends to associate spillovers with a positive effect, the empirical literature has shown many instances of negative externalities. Moreover, spillovers may not be reciprocal and may also have a different sign, as in health care. For this reason, this article has studied tax competition under spillover effects. We show that in this case tax strategies may be heterogeneous. In particular, if spillover effects are negative (as in the case of health services trade, transportation and pollution), taxes are more likely to be strategic substitutes. In other terms, with negative spillovers, the potential gain from attracting foreign capital is at least partially amplified by the loss from an international reduction in public goods supply. This means that if a jurisdiction levies a higher tax rate, other competing jurisdictions can find it optimal to react in different ways, by either cutting or increasing rates. Hence, strategic complementarity and substitutability can co-exist.

It is worth noting that our results have important policy implications, in that they explain the lack of tax convergence among jurisdictions. Moreover, if at least some tax reaction functions have a negative slope, there are no symmetric equilibria, and the so-called tax-cut-cum-base-base-broadening policy would fail to hold. For this reason, policymakers should carefully account for spillovers when deciding their own tax strategies.

Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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A Derivation of the reaction functions

Let us consider the problem for jurisdiction 1

$$\begin{aligned} Max_{t_1} U_1 &= \alpha_1 c_1 + (1-\alpha_1)(g_1 + \beta_{12} g_2 + \beta_{13} g_3) \\ & s.t. \\ g_1 &= t_1 k_1 \\ g_2 &= t_2 k_2 \\ g_3 &= t_3 k_3 \\ c_1 &= b_1(a_1 - k_1)k_1 - (r + t_1)k_1 + \theta_1 r K \end{aligned}$$

The FOC for the problem can be written as:

$$\begin{aligned} \frac{\partial U}{\partial t_1} &: \frac{(b_3+b_2)}{2} \frac{-2(b_2b_3 + b_1b_3 + b_2b_1)(1-\alpha_1) + \alpha_1 b_1 (b_3+b_2)}{(b_2b_1 + b_1b_3 + b_2b_3)^2} t_1 \\ &+ b_3 \frac{(b_2b_3 + b_1b_3 + b_2b_1)(1-\alpha_1)(1+\beta_{12}) - \alpha_1 b_1 (b_3+b_2)}{2(b_2b_1 + b_1b_3 + b_2b_3)^2} t_2 \\ &+ b_2 \frac{(b_2b_3 + b_1b_3 + b_2b_1)(1-\alpha_1)(1+\beta_{13}) - \alpha_1 b_1 (b_3+b_2)}{2(b_2b_1 + b_1b_3 + b_2b_3)^2} t_3 \\ &+ b_2b_3 \frac{(b_2b_3 + b_1b_3 + b_2b_1)(1-\alpha_1(1+\theta_1)) - \alpha_1 b_1 (b_2+b_3)}{(b_2b_1 + b_1b_3 + b_2b_3)^2} K \\ &- \frac{(b_3b_2(a_2+a_3) - b_1a_1(b_2+b_3))((b_2b_3 + b_1b_3 + b_2b_1)(1-\alpha_1) - \alpha_1 b_1 (b_2+b_3))}{2(b_2b_1 + b_1b_3 + b_2b_3)^2} = 0 \end{aligned}$$

The optimal level of t_1 conditional on the choices of t_2 andt_3 can be written as:

$$\begin{aligned} t_1 &= b_3 \frac{\alpha_1 b_1 (b_3+b_2) - (b_1b_3 + b_2b_3 + b_2b_1)(1-\alpha_1)(1+\beta_{12})}{-(b_3+b_2)(2(b_2b_3 + b_1b_3 + b_2b_1)(1-\alpha_1) - \alpha_1 b_1 (b_3+b_2))} t_2 \\ &+ b_2 \frac{\alpha_1 b_1 (b_3+b_2) - (b_1b_3 + b_2b_3 + b_2b_1)(1-\alpha_1)(1+\beta_{13})}{-(b_3+b_2)(2(b_2b_3 + b_1b_3 + b_2b_1)(1-\alpha_1) - \alpha_1 b_1 (b_3+b_2))} t_3 \\ &- 2b_2b_3 \frac{((b_2b_3 + b_1b_3 + b_2b_1)(1-\alpha_1(1+\theta_1)) - \alpha_1 b_1 (b_2+b_3))}{(b_3+b_2)(2(b_2b_3 + b_1b_3 + b_2b_1)(1-\alpha_1) - \alpha_1 b_1 (b_3+b_2))} K \\ &+ \frac{(b_3b_2(a_2+a_3) - b_1a_1(b_2+b_3))((b_2b_3 + b_1b_3 + b_2b_1)(1-\alpha_1) - \alpha_1 b_1 (b_2+b_3))}{(b_3+b_2)(2(b_2b_3 + b_1b_3 + b_2b_1)(1-\alpha_1) - \alpha_1 b_1 (b_3+b_2))} \end{aligned} \tag{12}$$

The first derivatives of this equation allow to find the reaction functions presented in table 1. An analogous procedure allows to determine the reaction functions for t_2 and t_3.

B Sign of the derivative

B.1 Sign for the case without spillovers

Let us first consider the case without spillovers. From (12) we can write that:

$$t_{ij} = \frac{\partial t_i}{\partial t_j} = b_s \frac{(b_1 b_3 + b_2 b_3 + b_2 b_1)(1 - \alpha_i) - \alpha_i b_i \left(\sum_{j=1,3;j \neq i} b_j\right)}{2(b_3 + b_2)(b_2 b_3 + b_1 b_3 + b_2 b_1)(1 - \alpha_1) + \alpha_1 b_1 (b_3 + b_2)}$$

The denominator is always positive, i.e. $(b_3 + b_2)(2(b_2 b_3 + b_1 b_3 + b_2 b_1)(1 - \alpha_1) + \alpha_1 b_1 (b_3 +$
The sign of the derivative is determined by $(b_1 b_3 + b_2 b_3 + b_2 b_1)(1 - \alpha_i) - \alpha_i b_i \left(\sum_{j=1,3;j \neq i} b_j\right)$

Let us define $\nu_i = b_i \left(\sum_{j=1,3;j \neq i} b_j\right)$ and $\varepsilon = (b_1 b_3 + b_2 b_3 + b_2 b_1)$ we can write

$$t_{ij} \gtreqless 0 \; if \; \varepsilon (1 - \alpha_i) - \alpha_i \nu_i \gtreqless 0$$

which can be written as:

$$t_{ij} \gtreqless 0 \quad if \quad \frac{\alpha_i}{1 - \alpha_i} \lesseqgtr \frac{\varepsilon}{\upsilon_i}$$

B.2 Sign for the case with spillovers

Let us write the marginal effects

$$t_{12} = \frac{\partial t_1}{\partial t_2} = b_3 \frac{(b_1 b_3 + b_2 b_3 + b_2 b_1)(1 - \alpha_1)(1 + \beta_{12}) - \alpha_1 b_1 (b_3 + b_2)}{2(b_3 + b_2)(b_2 b_3 + b_1 b_3 + b_2 b_1)(1 - \alpha_1) + \alpha_1 b_1 (b_3 + b_2)}$$

$$t_{13} = \frac{\partial t_1}{\partial t_3} = b_2 \frac{(b_1 b_3 + b_2 b_3 + b_2 b_1)(1 - \alpha_1)(1 + \beta_{13}) - \alpha_1 b_1 (b_3 + b_2)}{2(b_3 + b_2)(b_2 b_3 + b_1 b_3 + b_2 b_1)(1 - \alpha_1) + \alpha_1 b_1 (b_3 + b_2)}$$

In order to have the same effect we need both numerators to be positive or negative. On the other hand when one is positive and the second is negative we will have opposing effects.

Let us study the sign of t_{12} and t_{13}. Defining $\nu_1 \equiv b_1 (b_3 + b_2)$ and $\varepsilon \equiv (b_1 b_3 + b_2 b_3 + b_2 b_1)$, we can therefore obtain:

$$t_{12} \gtreqless 0 \; if \; \beta_{12} \gtreqless \frac{\alpha_1}{1-\alpha_1} \frac{\nu_1}{\varepsilon} - 1$$

$$t_{13} \gtreqless 0 \; if \; \beta_{13} \gtreqless \frac{\alpha_1}{1-\alpha_1} \frac{\nu_1}{\varepsilon} - 1$$

By defining $\nu_i = b_i \left(\sum_{j=1,3; j \neq i} b_j \right)$ it is possible to find the conditions for all the other marginal derivatives.