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**HORIZONTAL AND VERTICAL  
TAX INTERACTIONS  
IN A COMMON AGENCY GAME**

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# HORIZONTAL AND VERTICAL TAX INTERACTIONS IN A COMMON AGENCY GAME

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11 août 2016

## Abstract

*The decisions made by one government affect the tax revenue that can be collected by the decisionmakers belonging to the same tier of government or by stacked jurisdictions : externalities arise, the existence and the magnitude of which are closely related to the nature of the tax, to the mobility of the base and to the distribution of tax competence among decisionmakers. Indeed, when same authorities belonging to a same level of government derive their receipts from a mobile tax base, a competition mechanism takes place among them that triggers externalities. Likewise, when different layers of decision-makers exert their taxing power upon a common base, the choices made by one tier affect the receipts that the other governments can collect.*

*As a by-product, this paper proposes a model where both horizontal and vertical interactions are tackled, first successively then simultaneously. Uncertainty concerning the base, that is, the amount of capital likely to be invested, is introduced and a generalization of taxation schemes is provided. The analysis shows that horizontal and vertical externalities point towards opposite directions : while horizontal competition leads to inefficiently low rates, the common pool problem arising from the stacking of decisionmakers taxing a same base gives rise to a phenomenon of over-taxation. Besides, the combination of both externalities yields to an intermediary tax rate : the outcome is brought closer to the social optimum.*

Keywords : Vertical and horizontal tax externalities, Informational asymmetry, Tax competition, Common Agency, Nonlinear taxes.

JEL Classification : D72, D82, H23, H30, H32, H71, H77.

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# 1 Introduction

The debate about the drawbacks of current tax systems is frequently fed with numerous scandals and the potential solutions give rise to lots of controversies.

Taxation is the cornerstone of intergovernmental fiscal relations and is especially at stake when authorities are vying for mobile tax bases. Indeed, Devereux, Maffini and Xing (2015) point the impact of marginal tax rates upon firms' choices in terms of capital structures and thus stress the importance of corporate tax incentives while Devereux (2007) shed the light on the "*influence of taxes on discrete location choices, capital expenditure decisions of affiliates, overall allocation of capital across countries, differences in the rates of profit across countries, financial and organisational form decisions*".

In traditional public finance literature, it has been shown that a unilateral rise in tax rate is an incentive for the mobile base to move towards another jurisdiction, so that the locality that raised taxes suffers a reduction of available receipts. As a result, same-level benevolent governments that noncooperatively make their decisions levy tax rates and provide a supply of public good that are inefficiently low (their valuation of the real marginal cost of public funds is wrong). Besides, the tax burden can be shifted onto less mobile tax bases, as supported by Bretschger and Hettich (2002), which means that tax competition may harm both efficiency and equity. Though results can be modified according the nature of decisionmakers<sup>1</sup>, the existence of competition through public good provision, the introduction of a political economy dimension..., many empirical papers have demonstrated the existence of strategic corporate tax competition, as Altschuler and Goodspeed (2002) or Devereux, Loretz and Rodeano (2008). Likewise, Auerbach, Devereux and Simpson (2007) highlights the empirical result of interdependence of tax rates between countries, which can be seen as an evidence of tax competition.

Profit shifting strategies also appear to depend to a great extent on tax policies and many countries are proved to have taken steps or concluded deals with MNEs (see for instance Egger, Eggert and Winner (2010) for an identification and a quantification of tax avoidance and profit shifting<sup>2</sup>). Actually, multinational companies are a main actor of such mechanisms as both their investments and the location of their profits react to taxation. Analysis show that the more mobile profit-makers, i.e. multinationals, are those who are targeted by decreasing tax rates<sup>3</sup>. A growing literature highlights the negative effects of this kind of mobility embodied through profit or location shifting strategies (Bartelsman and Beetsma (2003), Clausing (2003), Grueber and Mutti (1991), Hines and Rice (1994), Hines (1999)).

Another important aspect is the vertical dimension of intergovernmental relationships. Indeed, the very essence of both federal and unitary countries is multileveled governments, which typically involves some commonality of tax base between higher- and lower- level decision-makers. The issue of vertical tax externalities started being addressed by the end of the eighties, with the seminal papers of Flowers (1988) and Johnson (1988), and a real significant theoretical impulse was given with the works of Keen (1998), Keen and Kotsogiannis (2002, 2003, 2004),

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<sup>1</sup>When policymakers are envisaged as Leviathan, competition may act in a corrective way towards pre-existing distortions (Brennan and Buchanan (1977)).

<sup>2</sup>Many works deal more particularly with intangible assets, as Dischinger and Riedel (2011), Böhm, Karkinsky and Riedel (2012). Karkinsky and Riedel (2012).

<sup>3</sup>Devereux, Lockwood and Redoano (2008).

essentially. The main result emphasized by this literature is the excessively high level of taxation which can be explained as follows : when a decision-maker increases her tax rate, authorities that belong to different layers of government are inflicted a negative externality conveyed by a tax base drop and the social marginal cost of raising tax revenue from the common base results under-valued. The global rate is too high and tax receipts are too weak with respect to the socially optimal outcome of a unique tax rate.

Because very often the map of territorial organizations is fragmented and overlapping, both horizontal and vertical fiscal external effects come into play and the interactions between them are worth analysing.

Furthermore, informational issues may represent a key element in the relationship between tax-payers and governments. Asymmetric information may arise and create scope for a rent that the informed agents may get. Information constraints thus affect the choices public decisionmakers can implement.

As a matter of fact, this paper addresses the issue of strategic tax interactions not only between policymakers belonging to the same layer but also among different tiers of governments taxing a common base, in the light of two related new assumptions : the introduction of uncertainty over the amount of capital likely to be invested and a generalization of taxation schemes *via* instruments that make taxes depend on the level of capital invested. Indeed, in some cases, the agent may have a better knowledge than governments concerning one relevant parameter. As a result, we will consider that governments compete in tax schedules, that is, functions that link the level of taxes on capital to the amount of capital invested in each jurisdiction. Nonlinear instruments allow a better adjustment to uncertainty than do fixed tax rates when decision-makers cannot commit to strategic variables and allow a formulation of the tax problem that more closely corresponds to the actual tax systems<sup>4</sup>. Indeed, though corporate taxes are usually proportional, other tax advantages are offered that make them depart from mere proportional taxes and support the use of nonlinear instruments. The model analysed is a three-tier model of vertical tax competition.

Section 1 is dedicated to a survey of the diverse dimensions of tax competition. Section 2 presents the framework of the common agency game model used. Sections 3 and 4 respectively tackle the settings of horizontal competition and vertical tax externality, while the last section concludes on the simultaneous interplay of both kinds of tax competition.

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<sup>4</sup>Laussel and Lebreton (1992), Bierbraueur, Brett and Weymark (2013) used nonlinear taxes to address issues of tax competition.

## 2 What we already know about tax competition

Devereux and Loretz (2011) provide a clear-cut and very useful definition of tax competition : *'the uncooperative setting of source-based taxes on corporate income where the country is constrained by the tax setting behaviour of other countries'*. This definition encompasses the various forms tax competition can take (rate, base...) and the different strategic instruments implementable. It also allows envisaging several kinds of governments' objective function (welfare-maximisation or revenue-maximisation...).

### 2.1 Main results of literature on horizontal tax competition

#### 2.1.1 The public finance conventional approach of the tax competition issue

Mobile tax bases are at the root of strategic tax competition, both within and between countries. Indeed, the existence of mobile tax bases that seek to optimally localize in order to get the highest possible after tax return triggers some competition among policymakers. This mechanism induces horizontal tax externalities among same level governments.

A pioneer work by Bradford and Oates (1971) and Oates (1972) demonstrates that tax competition prevents benevolent governments from providing an efficient level of public good.

Extending this result, one strand of the normative literature based on the Pigouvian approach that sees the government as a benevolent social planner seeking to maximise social welfare in her jurisdiction shows that, in small open economies, vying for mobile tax bases puts downward pressure on the degree of taxation and tax rates end up being set at an inefficiently low level. Some of the major earliest papers providing important formal statements are Wilson (1986), Zodrow and Mieszkowski (1986), Wildasin (1988), Hoyt (1991) and Wilson (1999) presents the main findings. The underlying mechanism is as follows : in a framework involving a great number of jurisdictions eager to attract capital, when a decision-maker unilaterally and independently raises her tax rate, part of the mobile base will move into neighbouring jurisdictions (since the net capital return becomes lower), thereby reducing the amount of tax receipts to be collected in the locality that implemented a hike. If the first mover does not take this effect into account, her perceived marginal cost of public funds is higher than the real social cost, and the tax rates are set at a level lower than the level that would allow the provision of the optimal amount of local public good. The Nash tax equilibrium thus corresponds to a situation where the provision of local public good and tax rates are too low with respect to the levels likely to lead to the optimum that a coordinated government could reach. Besides, this race to the bottom can trigger a misallocation and induce an excessive burden over the less mobile factors. The number of countries involved is an important feature : when the number of countries is small, the race to the bottom does not necessarily appear, as well as the difference in size : for instance, Bucovetsky (1991) and Wilson (1991) show that the more aggressive tax cut behaviour is observed on behalf of the smaller countries.

Yet, when policymakers are considered to be Leviathan, competition may correct pre-existing distortions. Actually, the Public Choice theory regards governments as representatives

of self-interested agents likely to use the authorities so as to reach their private ends. Competition may thus act as a constraint and tame Leviathan governments, leading to an improvement in social welfare, as underlined by Brennan and Buchanan (1977).

### 2.1.2 Extending the traditional model

A wider set of outcomes may arise if some assumptions are added, especially with respect to the existence and the nature of public goods financed through these tax receipts. Indeed, it may lead governments to compete by increasing public good provision. For instance, starting from the standard Zodrow-Mieszkowski model (1986), Dhillon, Wooders and Zissimos (2007) introduce the provision of a public good that enters the production process and may enhance capital productivity. The result of this game can be either efficiency or over-taxation and over-provision of public good, i.e. a race to the top, depending upon such factors as the degree of complementarity between capital and the public good. The intensity of tax competition can also be modified by taking into account differentiated valuations by firms of the public good (Zissimos and Wooders, 2008).

This public good dimension also appears in analysis related to the the new economic geography which brought enriching insights to such issues, putting forward the role of agglomeration in the relationship between tax decisions and the potential link between economic integration and tax competition. The race-to-the-bottom phenomenon is shown not to be necessarily involved because firms may accept to pay higher taxes when they benefit from agglomeration rents since it means a greater market potential. The fact that agglomeration in the core country creates a higher market potential justifies a tax discrepancy in favour of small periphery EU countries. Yet, if the gap between core and periphery member states is too large, the core countries will lower their tax rates, which can induce losses of welfare for both of them<sup>5</sup>. Furthermore, when integration increases, agglomeration forces in the core are weaker and the role of the taxes differential in the settling choices of firms strengthens.

As far as economic issues are concerned, political economy works brought additional light. For instance, through a model involving a voting procedure, Persson and Tabellini (1992) highlights the positive link between economic integration and tax competition. These papers go beyond and investigate the impact of a higher capital mobility triggered by economic integration on the tax rates equilibrium, when voters concerned about redistribution have to elect a government that chooses taxes on capital. Persson and Tabellini (1992) shows that though a higher capital mobility induces more tax competition between the countries involved, it also modifies the preferences of the voters and leads them to appoint a new policymaker that will increase the degree of capital taxation. Haufler et al. (2008) stresses that the profitability of multinational enterprises is raised which may reverse the traditional conclusion as the redistributive benefit of taxation is enhanced.

With respect to the political economy dimension of tax competition, another strand of literature examines the role of interest groups in the observed trends of corporate income taxes. Authors as Lorz (1998) or Lai (2010) introduce lobbying, was it is considered to affect the

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<sup>5</sup>Besides, when tax receipts are used to finance public goods likely to influence localisation choices, this furniture acts as an agglomeration force.

determination of tax rates, in a redistributive capital taxation setting for the former whereas in the latter capital ownership matters since interest groups may be constituted by capitalists or workers. In the first paper, interest groups appear because of an unequal distribution of capital among the population and it is shown that lobbying is lessened when capital mobility increases, so that social welfare is improved (as lobbying, which represents a waste of resources for the economy, does not necessarily affect tax policies in a favorable way). In a model derived from Zodrow and Mieszkowski (1986), Lai (2010) demonstrates that because of interest groups, enhanced capital mobility does not necessarily lead to a race to the bottom in tax rates as some parties can prefer higher tax rates. Chirinko and Wilson (2010) confirm through an empiric study led in the US the role of campaign contributions upon tax rates decisions.

### **2.1.3 Empirical tests dedicated to EU**

First, some authors seek to materialize the link between reductions in tax rates and non cooperative tax policies. Thus, Riedl and Rocha-Akis (2012) test whether the downward corporate income taxes trend recorded from 1982 to 2005 could be explained by a process of tax competition on behalf of governments eager to attract mobile base. They find that this is the case but to a reduce extent and above all when only Western European countries are taken into account. Heinemann, Overesch and Rincke (2010) also show that the interaction among decisionmakers triggers reductions in corporate tax rates and add that the relative position of the member state in terms of corporate tax burden is decisive. Cassette and Paty (2008) test the existence of strategic corporate tax interdependence between the former EU15 countries and the new member states for the period 1995-2005 : they find that interactions are stronger for Western countries than among central and eastern Europe ones.

Other economists more specifically examine whether countries have more to face tax competition when they belong to EU. Krogstrup (2005) shows that a higher capital mobility has led to reduced corporate taxes (*"a decrease in corporate tax burdens of about one fifth between 1980 and 2001 on the average in the EU"*), particularly due to the capacity of MNEs to conclude tax deals with some EU countries' tax authorities. Through spatial econometric models, Davies and Voget (2008) confirm that EU expansion induces tax competition. Redoano (2014) uses a gravity model (with data selected for a period of thirty years) which enables her to show that *"the lower cost of cross-border"* flows of capital inside the EU reinforces interdependence and tax competition among member countries (*"the EU countries react more to each other than they do to non-EU countries"*). These conclusions are verified by Devereux and Loretz (2013) empirical review which concludes to the existence of tax competition in the EU and stresses the impact given by the arrival of new member states to this mechanism. Keuschnigg, Loretz and Winner (2014) agree on their role as *"a driving force of the tax competition process"*. Regis, Cuestas and Chen (2015) precise that club convergence have embodied such evolutions.

### **2.1.4 The role of information**

Several information issues may be at stake when dealing with tax competition.



When there is asymmetry of information between governments and citizens at the expense of the latter, voters may use the information on the tax burden they can observe in neighboring jurisdictions to draw inferences about the performance of their representatives and vote accordingly (in particular they may decide whether to re-elect them or not). This process is called political yardstick competition (Salmon, 2006)<sup>6</sup>. As it was proved by Buettner and von Schwerin (2016), some kind of collusion process may appear leading to a bunching in tax rates at a level sometimes higher<sup>7</sup>.

Informational issues can represent a key element in the relationship between tax-payers and governments, they may modify incentives and add new effects.

Since the early 1990's, models of common agency game have introduced informational asymmetries, starting with Laussel and Lebreton (1993, 1994) and extending traditional results through the introduction of new assumptions as the seminal papers from Olsen and Osmundsen (2001, 2011) did in settings allowing for instance decisionmakers to seek capturing the rents of a large investor partly owned by local shareholders, the introduction of a joint cost or again the existence of spillovers correlated to the firm's productivity... and that led to results quite novative with respect to traditional common agency outcomes (higher tax rates, differentiation in the levels of investment between efficient and inefficient types...). See annex for more details.

Becker and Davies (2015) use the theory of social experimentation and build a model taking into account government incomplete information concerning the elasticity of the tax base and allowing the decision-maker to progressively learn the real value of this parameter. They show that such imperfect knowledge modifies tax competition even if in the long run the traditional results remain valid. Indeed, a first information interaction appears, related to the fact that countries learn information about the other ones and update their beliefs according the data learned, which can lead to some convergence of the policies implemented. The authors add the possibility that only the choices of tax policies be observed. They stress the role of information externalities, which may trigger another kind of interdependence between tax rates, and the inefficiency that can derive from the learning process.

## 2.2 Main results of literature on vertical tax competition

Multilevel governments represent a common feature of fiscal arrangements, not only in federations or in unitary states, but also in areas of cooperation between countries such as EMU. The "potential dependence of the tax base of each level of government on the tax policies pursued by the other" (Keen, 1998) triggers vertical externalities. The mechanism of vertical tax externality stemming from the co-occupancy of tax bases between several tiers of government was first analysed by Cassing and Hillman (1982). The federal government of Australia levies taxes both on coal output and exports. Tax receipts are thus collected on the coal transported

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<sup>6</sup>based on yardstick competition in IO (Holmström (1982), Shleifer (1985)).

<sup>7</sup>Chirinko and Wilson (2013) "*Our results suggest that the secular decline in capital tax rates, at least among U.S. states, reflects synchronous responses among states to common shocks rather than competitive responses to foreign state tax policy*".

by train up to the harbour. Meanwhile, the state of Queensland holds a monopoly on railroads and taxes freight. With respect to a cooperative situation, the competition between these two Leviathan public decision-makers leads to a shrinkage in the potential amount of tax receipts and increases the deadweight losses as a same resource is taxed twice. These conclusions were highlighted by the pioneer work of Flowers (1988), based on Brennan and Buchanan (1980). Her model examines a situation in which two different layers of government eager to maximize their fiscal revenue tax a common mobile base. With respect to a unique government setting, the addition of a second authority endowed with tax powers induces an erosion of the common base. As each layer ignores the revenue losses incurred by the other policymaker when he raises his rate, the marginal cost of raising tax revenue from the common base is underestimated and the global tax rate is thereby excessively high. Besides, as demonstrated by Sobel (1997), the distortion is strengthened in a sequential framework, as the Stackelberg leader anticipates the revenue reduction and seeks to compensate for this effect through a hike in his tax level. The study by Keen (1998) in a framework of consumption taxes posts an exhaustive presentation of the main effects stemming from tax stacking<sup>8</sup>. These main conclusions were generalized by Flochel and Madiès (2002) in a context borrowed from industrial organization. With Leviathan governments and imperfect mobility of the taxed base, that is capital, the global tax rate to which the common base is subject results as an increasing function of stacked layers.

However, the results are very sensitive to the assumptions taken into account, as it can be seen when examining the different empirical works led. Indeed, in order to check the existence of such effects in a hierarchically nested governments framework, Besley and Rosen (1998) propose an empirical analysis on excise taxes in United States. They estimate the impact of changes in federal tax policy on states tax decisions. Four kinds of reaction can appear : a revenue effect that describes the local government reaction to maintain his revenue when the federal government raises his tax rate, the deadweight loss effect related to the fact that, all things equal, the marginal disutility of tax increases with the rate (that is taxes are complement), the tax complement or substitution effect when demand cannot be differentiated, and a spending effect according to which tax receipts decrease when the federal tax rate is raised. An increase of 10% in the unitary federal tax rate on cigarettes triggers an increase of 2.8% of the local unitary tax rate ; the same increase for gasoline induces a 4.1% rise of the local tax. Esteller-Moré and Solé-Olé (2001) analysed personal income and general sales taxes. They found that US state taxes reacted positively to increases in federal taxes. Likewise, examining Canadian income taxes, Esteller-Moré and Solé-Olé (2002) stressed a positive response of provincial tax rates to changes in the federal tax rates. On the other hand, Hayashi and Boadway (2001) found a negative correlation, also stressed by Goodspeed (2000) in a panel of OECD countries. When a political economy dimension is introduced, for instance through the addition of lobbying with two different pressure groups, if policymakers seek not only to maximise tax receipts but also are interested about receiving campaign contributions, Esteller-Moré, Galmarini and Rizzo (2012) show that conclusions can be reversed : taxation by two layers may be more efficient

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<sup>8</sup>The author shows that when the lower level is Leviathan, federal and local taxes are strategic complements if the price-elasticity of the good demand is constant. If local decision-makers are benevolent, two additional effects appear : the decrease in demand for the good because of the consumer price rise (which lessens the loss of consumer welfare), and the reduced production of the local public good due to the shrinkage of the tax base (which makes the increase of local public good through higher tax rates more attractive).

than taxation by only one.

## 2.3 Simultaneous horizontal and vertical tax competition

Because both horizontal and vertical tax external effects come into play in territorial organizations, it appears relevant to take them into account simultaneously and to analyse the interactions between them.

Keen (1995) shows that when a tax base overlap is combined with horizontal tax competition, both externalities exert countervailing effects and the economy may end up on the downward sloping side of the Laffer curve. However, the net impact of the interaction between horizontal and vertical externalities appears quite ambiguous and assumption-dependent.

Keen and Kotsogiannis (2002), (2004) tackle this issue through an amended version of Zodrow and Mieszkowski (1986) introducing the addition of a higher level of policymaker and an endogeneized supply of capital. They show that the final effect depends on the elasticity of savings supply, capital demand, the level of income taxation, households' preferences for local or national public goods, and the degree of mobility of the tax base...

In a Leviathan policymakers framework, Keen and Kotsogiannis (2003) prove that receipts are strictly higher for both local and federal governments if the tax rate is reduced by at least one of them and that social welfare improves when the public goods provided by different layers of governments are substitute. Brühlhart and Jametti (2004) adopt a similar approach in an international setting and confirm this latter effect. Besides, they show that the domination of the vertical externality depends on the way the local public good enters the utility function, on the relative elasticity of capital... If the decision-maker is not benevolent, one tier of government at least must reduce his rate in order to raise receipts.

Similarly to horizontal tax competition analyses, some authors have shown that the conclusions could be greatly modified if productivity-enhancing public goods were introduced. For instance, Dhalby and Wilson (1998, 2003) demonstrate that an insufficient supply of public good can emerge if state and federal governments apply a tax on wages and produce a public good that improves labour productivity. Thanks to a model based on Keen and Kotsogiannis (2002), Madiès (2004) highlights that if states provide such a public good whereas the central government provides a residential public good, a fiscal feed-back effect may arise and the resulting dominant effect is not clear-cut. Pi and Zhou (2014), through an extended model of Keen and Kotsogiannis (2002, 2004), show that both horizontal and vertical externalities are modified when all-purpose goods are introduced.

To put it in a nutshell, no clear-cut result emerges as far as the net impact of the interaction between horizontal and vertical externalities is considered. This is also what we can infer from the empirical works performed.

Indeed, Revelli (2003) analyses the UK local structure, made of two stacked levels of governments that share spending and taxing responsibilities and demonstrates that the horizontal effect is in fact a reaction to the actions of the upper level. Leprince, Madiès, Paty (2003), for the French case, show that a strategic complementarity between départements and municipalities arises. Goodspeed (2000) examines how a federation tax structure is affected by both a

vertical externality and a horizontal one. The second effect is controlled through the choice of a poverty index that may represent a measure of mobility. The estimation realized on a thirteen OECD countries sample over the period 1975-84 indicates that a rise in the federal tax triggers a decrease in the local tax rate. Besides, a reduction in the poverty rate induces a cut in income tax as horizontal competition is strengthened. Goodspeed (2002) shows that a higher national tax rate can reduce tax base disparities and, via the horizontal interaction, and indirectly lead to higher local tax rates. In their adaptation of Keen and Kotsogiannis (2002), Brülhart and Jametti (2004) study the Swiss case for income taxes and take into account states asymmetry. They show that the vertical externality dominates, but if the analysis is led on business taxes, the horizontal effects is stronger. Rizzo (2003) examines which effect results from the interaction between horizontal and vertical externalities when the cigarettes and the retail markets are considered, in the US and Canada, for the period 1984-1994. States are supposed identical in terms of population. Results show that a rise in federal taxes reduces the external effect induced by the mobility of the tax base. Complementary to this work, the study of Devereux, Lockwood and Redoano (2004) shows that when the demand price-elasticity is weak and horizontal competition strong, the horizontal externality dominates and the link between federal and state taxes is not significant.

### 3 A common agency game of taxation : framework and main assumptions.

Two kinds of asymmetries of information can be examined. On the one hand, adverse selection which corresponds to the fact that the base, i.e. the firm, possesses an informational advantage upon the government with respect to an exogenous feature such as the amount of capital available for investment. The second type of informational problem that may arise and create a gap between the firm and the policymaker stems from a moral hazard process according to which some endogenous variables of the firm cannot be observed by the government : for instance the firm may choose to allocate capital towards another use than local investment. These asymmetries of information create scope for a rent that the principals have to give up to the better informed agent, i.e. the firm.

In this paper, we analyse a model taking information asymmetries into account and we study tax interactions both between same level governments and among different layers of decisionmakers. The firm - the agent - holds a private information concerning the amount of capital she can locally invest, whereas the governments are the imperfectly informed principals.

In such settings, the Revelation Principle cannot be used as externalities arise and truthful equilibria are no more possible (one principal may induce the firm to misrepresent to the other ones). As a result, the Delegation Principle, which is an extension to multiprincipals frameworks of the Taxation Principle (Guesnerie, 1981, 1995, and Rochet, 1986) and stipulates that there is no loss of generality in confining to strategically decentralized menus of relevant contracting parameters is applied.

We consider two hierarchically identical governments and an upper-tier decision-maker. All are supposed to be Leviathan. The agent, a unique firm, can locally invest a part of her capital and thus contracts with local authorities on this base. Besides, she faces a global tax on the whole amount of capital invested, levied by the higher-level government. Capital,  $\theta$ , is a private information of the firm.  $\theta$  is a continuous parameter on the support  $\Theta = [\underline{\theta}; \bar{\theta}]$ . The continuous distribution function  $G(\theta)$ , with strictly positive density function  $g(\theta)$ , represents the common knowledge law that describes the prior of the government on  $\theta$ . The hazard rate of this distribution is monotonic and  $\frac{d}{d\theta}(g(\theta))$  is nonnegative.

$f(k_i(\theta))$  designs the output produced in  $i$  with the amount of capital invested.  $f(\cdot)$  is three times continuously differentiable,  $f'(\cdot) > 0$ ,  $f(0) = 0$ ,  $f''(\cdot) < 0$ . We denote  $M(\theta - k_i(\theta) - k_j(\theta))$  the opportunity benefit of dedicating some part of capital to another use.  $M(\cdot)$  is exogenous, increasing, strictly concave and satisfies  $M'''(\cdot) > 0$ .

Timing :

1. Nature determines  $\theta$  and the agent learns his private parameter.
2. Contracts are offered by the principal(s).
3. The firm simultaneously accepts or rejects the contracts.

The firm profit writes

$$U(\theta) = \{f(k_i) - T(k_i) + f(k_j) - T(k_j) - \tau(k_i + k_j) + M(\theta - k_i - k_j)\}. \quad (1)$$

where  $T(k_i)$  represents local government  $i$  tax and  $\tau(\cdot)$  the tax set by the higher level of government on the total amount of capital locally invested. Marginal taxes are supposed to be nonnegative.

We restrict to twice differentiable nonlinear deterministic transfers<sup>9</sup> and use the First-Order Approach, developed by Martimort and Stole (2002), to compute the best response of the principals to pure-strategy nonlinear contracts offered by their rival in a differentiable equilibrium. In such a setting, different contracts proposed by a principal do not affect the same way the firm's incentives to invest in the jurisdiction of the other principal. An externality is created by the fact that a local government's decisions affect the design of the contracts the rival principal proposes to firms since they introduce a change in firms' incentives to behave with respect to the principal.

The game is an intrinsic common agency game, i.e. a all-or-nothing game where the agent does not have the option to contract exclusively with a single principal (Bernheim and Whinston (1986), Martimort and Stole (2004)).

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<sup>9</sup>In this common agency framework, it appears more relevant to use indirect mechanisms instead of directly applying the Revelation Principle (actually,  $\theta$  is unobservable to the principals and they cannot discriminate among the different possible types of firms in such a private information setting), and implement the Taxation Principle.

## 4 Horizontal tax externality

We consider there is only one level of governments made of two jurisdictions. We assume that policymakers behave as Nash players (they choose their tax rates to maximise revenues taking as given the tax rates set by the other governments and the alternative opportunity of capital use).

The horizontal externality at work stems from capital mobility : when a government unilaterally increases its tax base, the tax base of other states will be broadened and firms will be enhanced to dedicate capital to the alternative possible use.

First, let's characterize the best-response of one local government, say  $i$ , to any contract proposed by the other policymaker, say  $j$ .

The indirect profit function gives the maximal gain of a  $\theta$ -type firm for a given amount of capital invested in jurisdiction  $i$  ( $k_i$ ) when the firm chooses optimally her level of investment in the second jurisdiction and the amount of capital invested in jurisdiction  $j$  which satisfies the first-order condition associated to the maximization problem,  $\hat{k}_j(\theta, k_i)$ , are :

$$\begin{cases} \hat{\pi}(\theta, k_i) = \max_{k_j > 0} \{f(k_j) - T_j(k_j) + M(\theta - k_i - k_j)\} \\ \hat{k}_j(\theta, k_i) = \arg \max_{k_j > 0} \{f(k_j) - T_j(k_j) + M(\theta - k_i - k_j)\} \end{cases} \quad (2)$$

From principal  $i$ 's point of view, it is as if the firm had a total benefit

$$U(\theta) \equiv \max_{k_i > 0} \{f(k_i) - T_i(k_i) + \hat{\pi}(\theta, k_i)\} \quad (3)$$

Then, in order to find principal  $i$ 's best-response to the contract proposed by the rival principal (that will satisfy local incentive compatibility), we apply the standard methodology of single principal-agent contracting problem.

**Lemma 1** *A pair  $\{U(\theta); k_i(\theta)\}$  is implementable by principal  $i$  if and only if,  $\forall \theta \in \{\underline{\theta}; \bar{\theta}\}$ , the following first-order and second-order local conditions are satisfied.<sup>10</sup>*

$$\frac{\partial U(\theta)}{\partial \theta} = \frac{\partial \hat{\pi}(\theta, k_i)}{\partial \theta} = M'(\theta - k_i - k_j) \quad \text{and} \quad \frac{\partial^2 \hat{\pi}(\theta, k_i)}{\partial k_i \partial \theta} \frac{\partial k_i}{\partial \theta} \geq 0$$

As the Spence-Mirrlees condition is  $\frac{\partial^2 \hat{\pi}(\theta - k_i)}{\partial k_i \partial \theta} \leq 0$ , the single-crossing condition leads to the local second-order condition reducing to  $\frac{\partial k_i}{\partial \theta} \leq 0$ .

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<sup>10</sup>Local incentive conditions are sufficient for global incentive compatibility.

As underlined by Martimort and Stole (2002), the implementability conditions of principal  $i$ 's best-response are better expressed in terms of a pair informational rent (i.e. profit of the firm) and amount of capital invested (instead of a pair tax - investment).

Principal i's programme writes

$$\begin{aligned} & \max_{\{k_i; U(\theta)\}} \{f(k_i) + \widehat{\pi}(\theta - k_i) - U(\theta)\} \\ & \text{st } U(\theta) \geq 0, \quad \frac{\partial U(\theta)}{\partial \theta} = \frac{\partial \widehat{\pi}(\theta, k_i)}{\partial \theta}, \quad \frac{\partial^2 \widehat{\pi}(\theta, k_i)}{\partial k_i \partial \theta} \frac{\partial k_i}{\partial \theta} \geq 0. \end{aligned}$$

We apply the First-Order Approach to compute the best response of each principal to pure-strategy nonlinear contracts offered by the other level of government in a differentiable equilibrium. The resulting marginal tax rate defined by a local government is

$$\frac{\partial T_i(k_i)}{\partial k_i} = -\frac{1 - G(\theta)}{g(\theta)} \left[ \frac{\partial^2 M(\theta - k_i - k_j)}{\partial \theta \partial k_i} + \frac{\partial^2 M(\theta - k_i - k_j)}{\partial \theta \partial k_j} \frac{\partial \widehat{k}_j}{\partial k_i} \right] \quad (4)$$

Besides, the investments made by the firm are substitutes as

$$\frac{\partial \widehat{k}_j}{\partial k_i} = \frac{g(\theta) \left[ \frac{\partial f(k_i)}{\partial k_i} + \frac{\partial \widehat{\pi}(\theta - k_i)}{\partial k_i} \right] - [1 - G(\theta)] \frac{\partial^2 M(\theta - k_i - k_j)}{\partial \theta \partial k_i}}{[1 - G(\theta)] \frac{\partial^2 M(\theta - k_i - k_j)}{\partial \theta \partial k_j}} \leq 0 \quad (5)$$

Applying the same methodology for both jurisdictions leads to a similar equation and thus gives a system of partial differential equations that characterize the equilibrium investment profiles in a common agency game under incomplete information

$$\begin{cases} \frac{\partial T_i(k_i)}{\partial k_i} = -\frac{1 - G(\theta)}{g(\theta)} \left[ \frac{\partial^2 M(\theta - k_i - k_j)}{\partial \theta \partial k_i} + \frac{\partial^2 M(\theta - k_i - k_j)}{\partial \theta \partial k_j} \frac{\partial \widehat{k}_j}{\partial k_i} \right] \\ \frac{\partial T_j(k_j)}{\partial k_j} = -\frac{1 - G(\theta)}{g(\theta)} \left[ \frac{\partial^2 M(\theta - k_i - k_j)}{\partial \theta \partial k_j} + \frac{\partial^2 M(\theta - k_i - k_j)}{\partial \theta \partial k_i} \frac{\partial \widehat{k}_i}{\partial k_j} \right] \end{cases}$$

If there were only one government, the tax would be

$$\frac{\partial T_i(k_i)}{\partial k_i} = -\frac{1 - G(\theta)}{g(\theta)} \frac{\partial^2 M(\theta - k_i)}{\partial \theta \partial k_i}$$

This means that the local tax rates implemented when there are at least two decisionmakers competing for firms are lower than in the benchmark case since  $\frac{\partial^2 M(\theta - k_i - k_j)}{\partial \theta \partial k_j} \frac{\partial \widehat{k}_j}{\partial k_i} \geq 0$ .

**Proposition 2** *When, in a framework of imperfect information, several competing local governments want to attract firms on their territory, tax rates are lower than in the socially optimal outcome which corresponds to only one policymaker being assigned the tax competence.*



## 5 Vertical tax externalities

We now consider that two layers of governments tax a same tax base, each level being represented by one policymaker only. The same methodology as previously is applied.

First, we define in a similar way as we did for horizontal tax competition the indirect profit function that yields the maximal gain of a  $\theta$ -type firm for a given amount of capital invested in the jurisdiction ( $k$ ). Then, we can derive the firm total benefit from the local government's point of view

$$\begin{aligned}\widehat{\pi}(\theta, k) &= \max_{k>0} \{-\tau(k) + M(\theta - k)\} \\ U(\theta) &\equiv \max \{f(k) - T(k) + \widehat{\pi}(\theta, k)\}\end{aligned}\tag{6}$$

In order to find principal i's best-response to the contract proposed by the rival principal (that will satisfy local incentive compatibility), we apply the standard methodology of single principal-agent contracting problem :

$$\begin{aligned}\max_{\{k; U(\theta)\}} &\{f(k) + \widehat{\pi}(\theta, k) - U(\theta)\} \\ \text{st } U(\theta) &\geq 0, \quad \frac{\partial U(\theta)}{\partial \theta} = \frac{\partial \widehat{\pi}(\theta, k)}{\partial \theta}, \quad \frac{\partial k}{\partial \theta} \leq 0\end{aligned}$$

We find that the local tax rate amounts to

$$T'(k) = -\frac{1 - G(\theta)}{g(\theta)} \frac{\partial^2 M(\theta - k)}{\partial \theta \partial k}\tag{7}$$

Second, we can likewise consider the problem of the upper-layer government

$$\begin{aligned}\widehat{\pi}(\theta, k) &= \max_k \{f(k) - T(k) + M(\theta - k)\} \\ U(\theta) &\equiv \max_{k>0} \{-\tau(k) + \widehat{\pi}(\theta, k)\}\end{aligned}\tag{8}$$

Which yields to the marginal federal tax

$$\tau'(k) = -\frac{1 - G(\theta)}{g(\theta)} \frac{\partial^2 M(\theta - k)}{\partial \theta \partial k}\tag{9}$$

As a result, the global level of taxation is

$$\tau'(k) + T'(k) = -2 \times \frac{1 - G(\theta)}{g(\theta)} \frac{\partial^2 M(\theta - k)}{\partial \theta \partial k}\tag{10}$$

**Proposition 3** *When two governments belonging to different layers tax a common base, both decisionmaker levy the same tax rates and the global level of taxation is higher than in the socially optimal issue. Though softened by the informational rent induced by the introduction of information asymmetry, the vertical external effect triggers excessive taxation.*

## 6 Concurrent horizontal and vertical tax interactions

Now, we consider both a local level made of two competing jurisdictions and a hierarchically superior government. The upper-level and the lower-tier define their tax scheme upon a common base that policymakers belonging to the same layer are eager to attract.

We define

$$\pi(\theta, k_i) = \max_{k_j > 0} \{f(k_j) - T_j(k_j) - \tau(k_i + k_j) + M(\theta - k_i - k_j)\}$$

The indirect profit function gives the maximal gain of a  $\theta$ -type firm for a given amount of capital invested in jurisdiction i ( $k_i$ ) when the firm chooses optimally her level of investment in the second jurisdiction.  $\widehat{k}_j(\theta, k_i)$  is the amount of capital invested in jurisdiction j which satisfies the first-order condition associated to the problem above.

From principal i's point of view, the firm has a total benefit given by the following expression

$$U(\theta) \equiv \max_{k_i > 0} \{f(k_i) - T_i(k_i) + \widehat{\pi}(\theta, k_i)\} \quad (11)$$

The programme of local government i is

$$\max_{\{k; U(\theta)\}} \{f_i(k_i) + \widehat{\pi}(\theta, k_i) - U(\theta)\} \text{ st } U(\theta) \geq 0, \text{ FOLC, SOLC}$$

The application of the same methodology as previously leads to the following expression of the local tax rates in jurisdictions i (similarly in j)

$$\frac{\partial T_i(k_i)}{\partial k_i} = -\frac{1 - G(\theta)}{g(\theta)} \left[ \frac{\partial^2 M(\theta - k_i - k_j)}{\partial \theta \partial k_i} + \frac{\partial^2 M(\theta - k_i - k_j)}{\partial \theta \partial k_j} \frac{\partial k_j}{\partial k_i} \right] \quad (12)$$

Then, we can consider the problem of the higher tier of government and define

$$\begin{aligned} \widehat{\pi}(\theta, k) &= \max_k \{f(k_i) - T_i(k_i) + f(k_j) - T_j(k_j) + M(\theta - k_i - k_j)\} \\ U(\theta) &\equiv \max_{k > 0} \{-\tau(k_i + k_j) + \widehat{\pi}(\theta, k_i)\} \end{aligned} \quad (13)$$

Which yield to the upper level marginal tax rate

$$\tau'(k_i + k_j) = -\frac{1 - G(\theta)}{g(\theta)} \left[ \frac{\partial^2 M(\theta - k_i - k_j)}{\partial \theta \partial k_i} + \frac{\partial^2 M(\theta - k_i - k_j)}{\partial \theta \partial k_j} \frac{\partial k_j}{\partial k_i} \right] \quad (14)$$

The resulting global tax rate is

$$-2 \times \frac{1 - G(\theta)}{g(\theta)} \left[ \frac{\partial^2 M(\theta - k_i - k_j)}{\partial \theta \partial k_i} + \frac{\partial^2 M(\theta - k_i - k_j)}{\partial \theta \partial k_j} \frac{\partial k_j}{\partial k_i} \right] \quad (15)$$

Thus, it appears that each level of government sets the same tax rate, as in the vertical case. Nevertheless, the existence of competition at the lower level acts as a downward force and reduces each tax rate to the level observed in the horizontal case. As a result, global taxation establishes at an intermediary level between the inefficiently low horizontal tax rate and the socially suboptimal high vertical rate.

What's more, the global tax rate is higher than the tax rate corresponding to the benchmark case if

$$\frac{\partial k_j}{\partial k_i} < \frac{\frac{\partial^2 M(\theta - k)}{\partial \theta \partial k} - 2 \frac{\partial^2 M(\theta - k_i - k_j)}{\partial \theta \partial k_i}}{\frac{\partial^2 M(\theta - k_i - k_j)}{\partial \theta \partial k_j}} \quad (16)$$

The combination of horizontal and vertical tax competition leads to a higher tax rate if the degree of substitutability between local investments is not too high. If  $k_i$  and  $k_j$  are weak substitutes, then the global rate is inefficiently high. On the other hand, if they are strong substitutes, horizontal tax competition drives the global rate to the bottom and limits the magnitude of the vertical externality.

**Proposition 4** *The final tax rate resulting from the interaction between horizontal and vertical tax competition is closer to the socially optimal tax rate of the cooperative case. Indeed, the vertical externality is lessened by the competition that takes place between local governments. As a downward pressure is already exerted by both the existence of information asymmetry and the presence of an outside option for the firm, if the social outcome is considered to be the tax rate set by a unique government in a perfect information context, the combination of horizontal and vertical externalities brings the outcome closer to the optimum.*

**Criterion 5 Corollary 6** *The global tax rate is higher than the benchmark tax rate for low degrees of substitutability between local investments.*

## 7 Conclusion

Two kinds of fiscal externalities appear at work in a multi-level territorial organization. The horizontal externality that arises from competition among same level governments and corresponds to an inefficiently low equilibrium local tax and the vertical externality that stems from the co-occupancy of a tax base by different tiers of government and triggers too high tax rates in non-cooperative equilibrium. These effects have been highlighted in this common agency game with hidden information and a type-dependent alternative opportunity investment. The informational effect related to the lack of knowledge of a relevant parameter of the firm by decisionmakers has also been stressed, as it constrains the latter to give her up a rent and thus reduce their taxation. The interest of this paper is to allow analysing in this framework the interplay of simultaneous horizontal and vertical tax competition. We have shown that the combination of both externalities lessened the magnitude of each one and brought the outcome closer to the social optimum. Another crucial point that has been highlighted is that the impact of territorial organization and intergovernmental fiscal relationships significantly depends on the nature of the taxed base. Indeed, it has appeared that as far as mobile tax bases are concerned, the simultaneity of horizontal tax competition and governments stacking results positive and socially desirable, say otherwise when same level decisionmakers wish to attract a mobile base the addition of another level of governments allows restoring social efficiency as with only competing jurisdictions endowed with tax competence the resulting degree of taxation would be sub-optimally low.

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## 9 Annexes

### 9.1 Annex 1

In Laussel and Lebreton (1993), the agent is a single large investor who does not reside in the jurisdictions where he can invest, and the setting is a delegated common agency game : capital can be allocated in one or both jurisdictions or in none of them. In Laussel and Lebreton (1994), there is a continuum of small investors. The net profit of the agent equals the output yield by investment less the local taxes. The agent has a private information about his amount of capital available, whereas the jurisdictions' policymakers only have *a priori*s concerning this parameter. Each jurisdiction is inhabited by a representative household whose utility function depends on the satisfaction derived from the private good and from the public good which is produced *via* the unique input, capital, according to a production function twice continuously differentiable, identical whatever the jurisdiction, and financed through taxes on capital. The governments, i.e. the principals, are assumed to maximise their tax income. They choose simultaneously and non cooperatively the tax schedules they want to implement. The problem of the investor consists in deciding which levels of capital he is willing to invest in each jurisdiction, given the tax schedules proposed to him and provided that the amount of capital invested does not exceed the amount he owns. The equilibrium appears as the outcome in which the firm optimally determines her investment choices, considering that diversification is the best strategy, and two competing governments choose simultaneously the tax schedules that will maximize their tax revenues. This equilibrium is unique<sup>11</sup> and all capital ends up being invested and equally divided among both jurisdictions.

Olsen and Osmundsen (2001) analyses a model based upon a process of tax competition between two localities eager to capture the rents of a large investor partly owned by local shareholders. Hence, the multinational plays a significant paper in local welfare not only *via* the tax receipts collected by local authorities but also through the dividends distributed to local investors. The firm has private information about the efficiency of her operations in both jurisdictions, whereas governments can only observe the levels of investment in each one. The investor can divide capital among two jurisdictions and redirect a part of the investment made in one locality towards the other one. The interaction between the two governments is modelled through a joint cost and modifies the outcome with respect to what would emerge in a cooperative game. The net profit of the firm is equal to her operational profits minus a joint cost and local taxes. Policymakers are assumed to maximise expected domestic social welfare and thus integrate in their objective function the firm's profits, a part of which accrues to local shareholders. As a result, a new countervailing effect must be taken into account : an equity externality. In the end, the net effect is ambiguous. Tax competition may lead to results rather different from traditional common agency outcomes : lower investment levels and higher tax rates.<sup>12</sup>

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<sup>11</sup>A necessary and sufficient condition for a differentiable equilibrium to emerge is provided.

<sup>12</sup>The importance of taking into account the ownership structure has also been stressed by Calzolari (2000, 2002) who show that when the firm ownership is distributed among local and foreign entities, the firm can exert some kind of bargaining power or lobbying vis-à-vis governments. The emergence of a contractual externality is underlined.

Likewise, Olson and Osmundsen (2011) introduce some information asymmetry in a model of tax competition through the private knowledge MNEs have about one efficiency parameter. Besides, the existence of an alternative to locally investing capital, which is called an outside option, is allowed. The authors show that this outside options acts as a disciplining device for the governments and thus mitigates the negative externalities induced by tax competition.

## 9.2 Annex 2 : Horizontal external effect in a Delegated common agency game

The second possible type of common agency game is a delegated common agency game in which the firm may choose to settle in one jurisdiction only, if the profit she can get by doing so is greater than the profit she would obtain by being active in both localities or in none of them.

Common agency endogenously emerges in equilibrium through the chose made by the agent.

As in Diaw and Pouyet (2004), we can indifferently consider either that the firm chooses to be active in one jurisdiction only, or that she can credibly threaten to leave one of both localities if this strategy proves more profitable than being settled in both or than dedicating capital to another use. The effect of this threat appears through the outside opportunity of the firm.

As precised in Calzolari and Scarpa (2001), both outside opportunities cannot be simultaneously positive.

We consider the relation between the firm and the government of jurisdiction  $i$ , and we make the assumption that the outside option of the firm, if she accepts only the proposition of government  $j$ , is positive.

We define

$$\pi^{out}(\theta) = \max_{k_j > 0} \{f(k_j) - T_j(\theta, k_j) + M(\theta, k_i = 0, k_j)\}$$

The indirect profit function gives the maximal gain of a  $\theta$ -type firm when the firm chooses optimally her level of investment in the other jurisdiction.

$k_j^{out}(\theta, k_i)$  is the amount of capital invested in jurisdiction  $j$  which satisfies the first-order condition associated to the problem above

$$\begin{aligned} \frac{\partial f(k_j^{out})}{\partial k_j} - \frac{\partial T_j(\theta, k_j^{out})}{\partial k_j} + \frac{\partial M(\theta, k_i, k_j^{out})}{\partial k_j} &= \frac{\partial M(\theta, k_i, k_j^{out})}{\partial k_j} - \frac{\partial M(\theta, 0, k_j^{out})}{\partial k_j} \\ &= \int_0^{k_i} \frac{\partial^2 M(\theta, x, k_j^{out})}{\partial k_j \partial k_i} dx \end{aligned}$$

If we consider that

$$\Phi(k_j) = \frac{\partial f(k_j)}{\partial k_j} - \frac{\partial T_j(\theta, k_j)}{\partial k_j} + \frac{\partial M(\theta, k_i, k_j)}{\partial k_j}$$

then  $\Phi(\cdot)$  is a decreasing function and, as a result,  $k_j^{out} < \widehat{k}_j$ .

Likewise, 
$$\frac{d}{d\theta} [\pi(\theta) - \pi^{out}] = - \int_{\widehat{k}_j}^{k_j^{out}} \left( -\frac{\partial^2 T_j(\theta, x)}{\partial \theta \partial k_j} + \frac{\partial M(\theta, k_i, x)}{\partial \theta \partial k_j} \right) dx \leq 0$$

which confirms that the outside relation of the firm with principal j is not profitable.

### 9.3 Annex 3

The Hamiltonian associated to the local government i's problem is

$$H(\theta) = g(\theta) [f(k_i) + \widehat{\pi}(\theta - k_i) - U(\theta)] + \mu(\theta) \frac{\partial \widehat{\pi}(\theta - k_i)}{\partial \theta}$$

Applying the Maximum Principle yields

$$\frac{\partial H(\theta)}{\partial k_i} = 0, \quad \dot{\mu}(\theta) = -\frac{\partial H(\theta)}{\partial U(\theta)} = g(\theta), \quad \dot{U}(\theta) = \frac{\partial H(\theta)}{\partial \mu(\theta)} = \frac{\partial \widehat{\pi}(\theta - k_i)}{\partial \theta}$$

Optimization with respect to  $k_i$  (the first equation) gives

$$\begin{aligned} \frac{\partial H(\theta)}{\partial k_i} &= g(\theta) \left[ \frac{\partial f(k_i)}{\partial k_i} + \frac{\partial \widehat{\pi}(\theta - k_i)}{\partial k_i} \right] + [1 - G(\theta)] \frac{\partial^2 \widehat{\pi}(\theta - k_i)}{\partial \theta \partial k_i} \\ \text{where } \frac{\partial^2 \widehat{\pi}(\theta - k_i)}{\partial \theta \partial k_i} &= \frac{\partial^2 M(\theta - k_i - k_j)}{\partial \theta \partial k_i} + \frac{\partial^2 M(\theta - k_i - k_j)}{\partial \theta \partial \widehat{k}_j} \frac{\partial \widehat{k}_j}{\partial k_i} \end{aligned}$$