LEVIATHAN AND TAX COMPETITION IN FEDERATIONS

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Abstract

Federal systems commonly involve some co-occupation of the same tax base by both federal and state governments. This paper analyses a simple model of taxation in a federal system, within which fiscal externalities arise not only horizontally, across the 'states' (effects familiar from the tax competition literature) but also vertically between levels of government. Implications are developed for the case in which policy-makers are revenue-maximising Leviathans. The incorporation of both externalities results in excessively high taxation in the non-cooperative equilibrium. Intensifying horizontal competition, by increasing the number of states, unambiguously increases revenues (contrary to the Leviathan wisdom) but nevertheless enhance consumer welfare (consistent with the Leviathan wisdom). Revenue sharing arrangements between policy-makers are shown to be (contrary to the Leviathan wisdom) Pareto improving.

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1 Introduction

Two widely divergent views have dominated both the academic literature and the policy debate regarding the desirability of tax competition (by which is meant here simply non-cooperative tax-setting by distinct jurisdictions). According to the 'normative' public finance literature 'horizontal tax' competition, between welfare-maximising governments, typically[1] results in taxes being inefficiently low in the absence of coordination between policy-makers (as in Zodrow and Mieszkowski (1986) and Wildasin (1989)): for each jurisdiction neglects the benefit of an expanded tax base that it conveys on other jurisdictions when it raises its tax rate.

The second view, as mainly expressed in the writings of Brennan and Buchanan (1977, 1980), is radically different and is rooted in the vision of governments as revenue-maximising Leviathans. Brennan and Buchanan (1980) depart from the traditional public finance literature by rejecting the assumption that the policy-makers are benevolent despots. Instead they assert that the policy-makers (the so called Leviathans) are governed by monolithic principles and that the electoral process can appropriately constrain the natural proclivities of government only if it is accompanied by additional constraints and rules imposed at the constitutional level. The essence, therefore, of the problem, for Brennan and Buchanan, is how to constrain the natural proclivities of government so to achieve results that are consonant with those which are desired by the citizenry. As they most succinctly note,

> '[t]he very principle of constitutional government requires it to be assumed that political power will be abused to promote the particular purposes of the holder; not because it always is so, but because such is the natural tendency of things, to guard against which is the especial use of free institutions.'[2]

Following this perspective they argue that tax competition should be regarded not as a source of inefficiency and rationale for coordination but, on the contrary, as a welcome supplement to inadequate constitutional constraints on the intrinsic pressures towards excessively high tax rates implied by policy-makers' pursuit of their own interests. As Brennan and Buchanan (1980), most notably put it,

> '[i]intergovernmental competition for fiscal resources and inter-jurisdictional mobility of persons in pursuit of "fiscal gains" can offer partial or possibly complete substitutes for explicit fiscal constraints on the taxing power,'[3]

[1]Though not always, since there is typically also a motive of tax-exporting (pointing towards excessively high tax rates) at work in horizontal tax games: see Mintz and Tulkens (1986), and for this and other related issues regarding tax competition, Wilson (1999).

[2]J.S.Mill, cited in Brennan and Buchanan (1980), p.13.

[3]Brennan and Buchanan (1980), p.184.

and so, they conclude,

> '..tax *competition* among separate units rather than *tax collusion* is an objective to be sought in its own right.'[4]

It is surprising, though, to find that the tax implications of the above two views are analysed and articulated in frameworks within which the federal government is rarely present in any purposive form. Instead the analysis of tax matters often focuses on the interactions between a set of horizontally-related jurisdictions,[5] with the federal government finally introduced – if at all – as a *deus ex machina* to deal with, as in the seminal work of Gordon (1983), the fiscal externalities shown to arise between them. It is also true in the, equally seminal, work of Brennan and Buchanan (1977, 1980).

Federalism means multi-leveled government. And multi-leveled government typically means, in practice some commonality of tax base between central ('federal') and lower-level ('state') governments. And this is a common feature of fiscal arrangements in federations. In Canada, Switzerland and the U.S, for example, federal and state-level governments both levy excises; and in Canada both levels also levy general sales taxes. Even when, perhaps as result of constitutional restrictions, the distinct levels have formally different tax bases – income and sales taxes, for example – they may overlap in real terms. Surprisingly, though, this commonality has been – until very recently – been an unnoticed phenomenon.

The existence of a common tax base points towards the existence not only of horizontal fiscal externalities – familiar from the tax competition models – across states but also of vertical externalities between the – vertically related – levels of government. Vertical and horizontal externalities are thus at the heart of federal tax architecture. Recognising and understanding the interaction between them is of some importance to the theory of fiscal federalism.[6]

The purpose of this paper is to develop a simple model of federal tax arrangements, encompassing both horizontal and vertical fiscal externalities, within which some of the implications of the Leviathan view for the analysis and normative evaluation of fiscal federalism can be articulated. A word of clarification is in order here. This is not to suggest that the Leviathan view is the 'right' view of the world or even an especially attractive one. Certainly there are other and perhaps more appealing models of policy-making emphasising heterogeneity of preferences and the role of voting and lobby

[4] Brennan and Buchanan (1980), p.186. Second italics added.

[5] As for instance in, Zodrow-Mieszkowski (1986), Wilson (1986), Oates and Schwab (1988), and Wildasin (1989).

[6] The importance of vertical externalities in the theory of fiscal federalism is also emphasised in Keen (1998).

groups.[7] Whatever one's views on the Leviathan hypothesis, however, it has become sufficiently influential for its implications to deserve careful thought. The strategy here is, therefore, to see where pursuing a thoroughgoing view of policy-makers as revenue-maximising Leviathans leads on in thinking about fiscal federalism. In particular, two issues, at the heart of the Leviathan perspective of fiscal federalism, will be investigated.

First, what are the implications of the two kinds of externality for the equilibrium levels of federal and state taxation, and for the sum of the two? Analyses of 'horizontal' tax competition between revenue-maximising Leviathans shows that taxes will be inefficiently low in the absence of coordination between policy-makers, since each jurisdiction neglects the benefit of expanded tax base that it conveys on other jurisdictions when it raises its tax rate. But the vertical externality arising from co-occupancy suggests that, on the contrary, taxes may be too high in non-cooperative equilibrium: for then each level of government neglects the adverse effect it has on the other by raising its tax rate and thereby causing the common tax base to contract. Then the question arises: Will federal structures, in which both horizontal and vertical externalities potentially arise, result in state and/or federal taxes being too low in equilibrium or too high?

The second issue is the impact of intensified horizontal competition – brought about, in particular, by an increase in the number of lower level jurisdictions – on the levels of consumer welfare and tax revenue. This seemingly routine exercise in comparative statics touches directly on some of the central themes and concerns in the analysis of federalism: the argument that horizontal competition is intrinsically desirable as a means of disciplining policy-makers, on the one hand; and on the other the view that such competition can be socially damaging and create a case for policy coordination across jurisdictions. The importance of the issue is recognised in the recent empirical literature, stimulated by Oates (1985), which has presented itself as testing the hypothesis that policy-makers are revenue-maximising Leviathans in the fashion of Brennan and Buchanan (1977, 1980). Forbes and Zampelli (1989, p. 568), for example take it that

> '...[t]he Leviathan hypothesis predicts an inverse relationship between public sector size and fiscal decentralisation as measured by the number of competing jurisdictions.'

Clearly such prediction is entirely consistent with other models of government motivation, so that finding such a relationship would cast little light on the validity of the Leviathan hypothesis.[8] Here, however, we focus on the prior question of whether one would indeed expect to find such an inverse relationship within explicit federal structures. And what

[7] See, for instance, Persson and Tabellini (1992, 1994, 1996a,b), Chari, Jones and Marimon (1997), and Persson (1998).

[8] This was pointed out by Richard Musgrave (see footnote 2 of Oates (1985)), and indeed is implicit in Oates' (1972) earlier work on the same empirical issue, which was not motivated in terms of the Leviathan hypothesis. The results of Hoyt (1991) confirm the point.

are the implications for consumer welfare of intensified horizontal tax competition once one recognises a purposive form for the federal government?

These issues have not been entirely neglected in the literature. Two important but apparently little-known paper – by Cassing and Hillman (1982) and Flowers (1988) – make the point that co-occupation by revenue-maximising governments could lead to such heavy taxation that the federation finds itself on the downward sloping part of its Laffer curve. Flowers (1988), in particular, provides a rich and perceptive account of the general issues at stake in the Leviathan case. Neither paper, however, explicitly incorporates horizontal tax competition, and hence neither considers either the interplay between horizontal and vertical externalities or the central question as to the welfare effects of intensifying horizontal tax competition.[9]

Keen (1995), and Keen and Kotsogiannis (2000), and Wrede (1996) do model simultaneously both dimensions of tax competition.The first two also consider welfare aspects. Dahlby (1994, 1996), and Boadway and Keen (1996), examine the implications of co-occupancy for the marginal cost of public funds and for the optimal pattern of inter-governmental grants. They all, though, assume welfare-maximising policy-makers[10] and more importantly they do not address the two issues raised above.

The plan of the paper is as follows. Section 2 describes the model. The basic strategy is to adapt a broadly familiar model of horizontal capital tax competition by superimposing a federal government on horizontally-related jurisdictions. Section 3 considers a federation of Leviathans while Section 4 considers Pareto-improving tax cuts. The role of inter-state competition is the subject of topic 5. The federal government as first mover is taken up in Section 6 and finally Section 7 concludes.

2 The model

This paper explores the tax implication of assuming all policy-makers – at both levels of government – to be pure Leviathans, modeled exactly as in Brennan and Buchanan (1977, 1980). It will help to begin by recalling the essence of the constitutional setting within which the Leviathan hypothesis is developed.

Brennan and Buchanan assume that each policy-maker maximises the surplus of tax revenues over some spending g_i (for a state policymaker) or G (for the federal policy-maker). They assume that the constitution defines minimum compulsory expenditures

[9] Flowers (1988) also implicitly assumes state and federal taxes to be strategic substitutes; this as will be seen below, may quite plausibly not be the case.

[10] Johnson (1988), Boadway, Marchant and Vigneault (1998) address related but distinct issues concerning the impact of co-occupation on the extent of redistribution in federal structures. Hoyt (1996), Sobel (1997), and Wrede (1998) also provide analyses that emphasise the effect of co-occupation on the level of taxation.

on public goods. Each policy-maker is assumed constrained – by some unspecified means, possibly constitutionally – to spend a fixed proportion $\lambda \in (0,1)$ of the tax revenues he receives on the public good for which he is responsible. Thus, if r_i is the state tax revenue and R is the federal tax revenues then the state Leviathan's expenditure on the state public good, g_i, is λr_i, while the federal Leviathan's expenditure on the federal public good, G, is λR. With λ fixed, maximising surplus, simply, reduces to maximising tax revenues.

The framework we use is a broadly familiar model of capital tax competition, along the lines of, for example, Zodrow and Mieszkowski (1986) and Wildasin (1989), but appropriately augmented to include an over-arching federal government and an endogenous aggregate supply of capital[11] as in Keen and Kotsogiannis (2000).

The economy consists of $N \geq 1$ identical lower-level jurisdictions, called 'states'.[12] The production side of the economy has a simple structure. Output in state i is $F(K^i)$, where K_i denotes the capital located in i; F is increasing, strictly concave and at least three times continuously differentiable. Capital, K^i, is freely and costlessly mobile across the states and so it relocates until it earns, in equilibrium, the same post–tax return ρ in each state. State i levies a source-based tax t_i on each unit of capital in its jurisdiction.[13] The federal government levies a unit tax at the rate T. This tax rate is common[14] to all states. We refer to $\tau_i \equiv t_i + T$ as the combined or consolidated tax rate[15] in state i, and similarly to the sum of federal and state tax revenues as consolidated revenues. The arbitrage condition[16]

$$F'\left(K^i\right) - \tau_i = \rho\,, \tag{1}$$

[11]For the issues that we want to address here, if the aggregate supply of capital were fixed, as in Zodrow and Mieszkowski (1986) and Wildasin (1989) for instance, the federal tax base would be completely inelastic and, therefore, the federal government would have access to a non-distorting tax, and a federal Leviathan of the kind we consider in here would be effectively unconstrained in the exercise of his greed. Such an extreme outcome would conceal the issues that we wish to raise.

[12]Although the analysis will be couched in terms of federal–state governments the concepts are obviously capable of re-interpretation in appropriate circumstances to apply to state–local governmental relationships. What is important for the analysis is the existence of different levels of decision making.

[13]Though the model has been chosen for basic familiarity and tractability rather than realism, the most prominent examples of corporate taxes levied at sub-central levels of government are indeed source-based. Many national capital taxes may also be approximated as source taxes.

[14]This uniformity reflects a realistic assumption since in practice the federal government is not allowed to discriminate between states in its tax setting.

[15]State taxes are often deductible or creditable against federal taxes, but modeling this would make the analysis more cumbersome and, more particularly, distract from the effects arising from the behaviour of the private sector that we seek to emphasise: see Dahlby, Mintz and Wilson (1999).

[16]Derivatives are indicated by primes for functions of a single variable, and by subscripts for functions of several.

then, implicitly, defines the equilibrium demand for capital in i as $K^i = K(\rho + \tau_i)$ with

$$K'(\rho + t_i + T) = \frac{1}{F''} < 0 \; . \tag{2}$$

Since the production function is strictly concave rents will be generated. Rents arising in state i are denoted by

$$\Pi^i \equiv F\left(K^i\right) - F'\left(K^i\right) K^i \; , \tag{3}$$

with, using (2),

$$\Pi'(\rho + \tau_i) = -K(\rho + \tau_i) \; . \tag{4}$$

Rents in i are taxed at the rate x_i by state i (and not taxed by any other state) and at the rate X by the federal government. To simplify matters whilst bringing out the irrelevancy to the main arguments of the allocation of rents between governments and consumers, we simply take these tax rates, X and x_i as given.

There is a single consumer in each state, and each has preferences of the form

$$U(C_1, C_2, g, G) = U(C_1) + C_2 + \Gamma(g, G) \; , \tag{5}$$

defined over first- and second-period consumption, C_1 and C_2, the level g of a local public good provided by the government of the state in which she lives and the level G of federal spending per state. Each consumer has a fixed endowment e of first-period income, and in the second she receives principal and interest on her first-period savings, S, plus the rents, net of combined state and federal taxes of $\chi_i \equiv x_i + X$, she earns in her jurisdiction. The preference restriction in (5) simplify matters by implying that savings are $S(\rho)$ with $S'(\rho) > 0$. Indirect utility is then

$$V(\rho, \tau, g, G) = U[e - S(\rho)] + (1 + \rho) S(\rho) + (1 - \chi) \Pi(\rho + \tau) + \Gamma(g, G) \; , \tag{6}$$

with, making use of (4),

$$\begin{aligned} V_\rho &= S - (1 - \chi) K \; , & (7) \\ V_\tau &= -(1 - \chi) K \; . & (8) \end{aligned}$$

Taxing and public spending occur in the second period. It will be assumed throughout that there are no inter-governmental transfers, either vertically between the levels of government or horizontally across the states.[17] State and federal tax receipts (per state) are then, respectively,

$$r_i = t_i K(\rho + \tau_i) + x_i \Pi(\rho + \tau_i) \ , \tag{9}$$

$$R = \frac{1}{N} \sum_{i=1}^{N} \left[T K(\rho + \tau_i) + X \Pi(\rho + \tau_i) \right] \ . \tag{10}$$

At some points in the analysis we shall think of this economy as small in a wider world, and take ρ as given. For the most part, however, we take the federation to be closed. Denoting the N-vector of consolidated tax rates by $\vec{\tau} = (\tau_1, ..., \tau_N)$ the net return $\rho(\vec{\tau})$ is implicitly defined by the market clearing condition

$$NS(\rho) = \sum_{i=1}^{N} K(\rho + \tau_i) \ , \tag{11}$$

so that, on applying the implicit function theorem to (11),

$$\frac{\partial \rho}{\partial \tau_i} = \frac{K'(\rho + \tau_i)}{NS' - \sum_{j=1}^{N} K'(\rho + \tau_j)} \in (-1, 0) \ . \tag{12}$$

We confine attention throughout to symmetric equilibria: one, that is, in which all states set the same tax rate (so that $(\tau_i = \tau, \forall i)$). The net return in such an equilibrium is $p(\vec{\tau}) \equiv \rho(\tau, ..., \tau)$ so that

$$p'(\vec{\tau}) = \frac{K'(\rho + \tau)}{S'(\rho) - K'(\rho + \tau)} \in (-1, 0) \ , \tag{13}$$

so the net return depends only on the combined tax rate τ (being independent, in particular, of the number of states N). Comparing now (12) and (13) one obtains, in symmetric equilibrium,

$$p' = N \frac{\partial \rho}{\partial \tau_i} \ . \tag{14}$$

The strategic interaction between the state and federal Leviathans can be modeled in a number of ways. In many contexts, it is natural to conceive of a dominant federal government as a first mover relative to the states. In some other cases it may be more appealing to conceive of all governments moving simultaneously. The analysis here starts with the case in which all move simultaneously, building on this to deal finally with that

[17] Such transfers are hard to rationalise – other than by the intervention of some outside agency – when, as in most of the analysis below, all governments hold Nash conjectures as to each other's behaviour. The potential role of intergovernmental transfers in a context of benevolent policy-making with a federal leader is discussed in Boadway and Keen (1996).

in which the federal government is a Stackelberg leader.

3 A federation of Leviathans

The state policymakers, being Leviathans, choose t_i to maximise revenues as given by (9). In doing so, it is assumed throughout, they take as given the tax rates set by all other states and by the federal government. For the present, we take it that the federal government also has Nash conjectures, taking state taxes as given; Section 6 explores the alternative assumption that the federal Leviathan acts as a Stackelberg leader.

3.1 Equilibrium and best responses

Consider first the behaviour of the states. Using (14), the state first order condition, at the symmetric equilibrium, implies

$$K\left[p\left(\vec{\tau}\right)+\tau\right]+\left(tK'\left[p\left(\vec{\tau}\right)+\tau\right]-xK[p\left(\vec{\tau}\right)+\tau]\right)\left(1+\frac{1}{N}p'\left(\vec{\tau}\right)\right)=0\ , \tag{15}$$

which implicitly defines the equilibrium state tax as a function of the federal tax and the number of states in the federation, that is $b\left(T,N\right)$. A word of clarification is in order here. It is tempting to think of $b\left(T,N\right)$ as the states' 'best response' but it would be misleading to do so.[18] For outside the very special case in which there is only one state the common tax rate defined by (15) emerges not from any collective optimisation by the states in the setting of t but rather emerges as the equilibrium of a non-cooperative game between them, a game whose outcome will typically depend upon the federal tax in place and on the number of states. Thus, as will be seen, except in very special cases setting $t=b\left(T,N\right)$ would almost certainly not be the states' best response were they to cooperate with one another. To emphasise this, we refer to $b\left(T,N\right)$ as the states' 'equilibrium response'.

One feature of this equilibrium response that will prove of particular interest and importance in the analysis that follows is the sign of $dt/dT=b_T$: Does an increase in the federal tax rate lead to an increase in the equilibrium state tax or to a reduction?[19] As is evident from (15), the analytics of this question are cumbersome.[20] To develop some sense of the possibilities, however, consider the special case in which state rents are untaxed (so $x=0$) and $S'\rightarrow\infty$ or $K'\rightarrow 0$ (so that, from (13), $p'\rightarrow 0$ and the economy

[18] Similar treatment of this kind of comparative statics appear in Cournot type models: see Tirole (1988) and the references therein.

[19] Besley and Rosen (1996), and Keen (1998) discuss the analogous question in a commodity taxation framework while Boadway and Keen (1996) do so in a labour taxation framework.

[20] The details are provided in Appendix A.

is effectively small). Then the first order condition (15) reduces to the familiar inverse elasticity rule

$$t = -\left(\frac{1}{K'(p+\tau)/K(p+\tau)}\right) , \tag{16}$$

with the second order condition requiring that $E^K < 2$, where

$$E^K \equiv \frac{KK''}{(K')^2} , \tag{17}$$

is (minus) the elasticity of the slope of the marginal product schedule. Differentiating (16) shows the sign of the derivative of the best response function, dt/dT, to be the same as that of $E^K - 1$; and so to be ambiguous. Nor does intuition provide much guidance as to the likely sign or magnitude of the key quantity E^K. If $F(K)$ is quadratic, for example, then $E^K = 0$ and consequently state and federal taxes are strategic substitutes in the sense that $dt/dT < 0$; if on the other hand F is of the Cobb-Douglas form K^α, with $\alpha \in (0,1)$, then $E^K - 1 = 1 - \alpha > 0$ and they are strategic complements in the sense that $dt/dT > 0$. There can thus be no presumption as to the sign of b_T, and both possibilities will need to be borne in mind below.

There is though one simple property of b_T that will prove useful, it being shown in Appendix B that

$$1 + b_T > 0 . \tag{18}$$

That is, while the equilibrium state tax may fall in response to a higher federal tax it cannot fall by so much as to prevent the combined rate τ from rising.

The analytics for the federal government are similar, given our assumption, for the present, that it too plays Nash. Indeed the analysis is rather simpler, since there is no analogue to the distinction between best and equilibrium responses that arises at state level. In symmetric equilibrium, federal revenue per state is

$$R(T,t) = TK\left[p(\vec{\tau}) + \tau\right] + X\Pi\left[p(\vec{\tau}) + \tau\right] , \tag{19}$$

and so the necessary condition on the revenue-maximising T is

$$K\left[p(\vec{\tau}) + \tau\right] + \left(TK'\left[p(\vec{\tau}) + \tau\right] - XK\left[p(\vec{\tau}) + \tau\right]\right)(1 + p') = 0 . \tag{20}$$

This condition has the same general structure as (15) above, but with federal tax rates replacing the common state tax and N replaced by unity. We therefore omit the details, simply noting that the considerations that arise in signing $B' = dT/dt$ are broadly similar to those just discussed and that

$$1 + B' > 0 \, . \tag{21}$$

Nash equilibrium (indicated by asterisks) is characterised in the usual way by a mutual consistency of responses

$$\begin{aligned} t^* &= b\left(T^*, N\right) \, , & (22) \\ T^* &= B\left(t^*\right) \, , & (23) \end{aligned}$$

and we further assume

$$b_T\left(T^*, N\right) B'\left(t^*\right) < 1 \, , \tag{24}$$

so that equilibrium is in a natural sense locally stable.

4 Pareto-improving tax cuts

There are two kinds of fiscal externalities at work in this federation. The first is a fiscal horizontal externality between the states of a kind familiar from Zodrow-Mieszkowski (1986), Wildasin (1989) and others: each state optimises 'locally' ignoring the beneficial effect that raising its tax rate has on the other states by inducing capital flight into them and thereby expanding their tax bases. This mutually damaging horizontal tax competition in itself tends to lead to the equilibrium state tax being lower than the states would set if they acted cooperatively.

Denote the revenue of the typical state in symmetric equilibrium by

$$r\left(t^*, T^*\right) \equiv t^* K\left[p\left(\vec{\tau}\right) + \tau\right] + x\Pi\left[p\left(\vec{\tau}\right) + \tau\right] \, , \tag{25}$$

one finds that

$$\begin{aligned} r_{\vec{t}}\left(t^*, T^*\right) &= K + \left(t^* K' - xK\right)\left(1 + p'\right) \, , & (26) \\ &= \frac{-Kp'\left(N-1\right)}{N + p'} \geq 0 \, , & (27) \end{aligned}$$

the second equality following on (15). Condition (27) states that each state-level policymaker would indeed gain – strictly not lose – if all were to raise their tax rate strictly above the Nash equilibrium level, with the federal rate remaining unchanged. Naturally, this horizontal externality vanishes, as an envelope property, if $N = 1$. It also vanishes, in the limit, following (13), if $p' \to 0$, which as noted earlier can be if $S' \to \infty$ or $K' \to 0$: For in the former case savings are infinitely elastic and so even a small increase in the state's tax will dramatically diminish savings, whereas in the latter the elasticity of capital is infinitely inelastic and so states are isolated from each other.

The other and much less familiar fiscal externality operates vertically between the two levels of government, and arises from the common pool property of the same tax base. For in weighting the case for an increase in its own tax rate each policy-maker ignores the loss that the other level of government will suffer from the induced contraction of the common tax base. Differentiating state revenues (25) with respect to the federal tax rate and using again the equilibrium condition (15) one thus finds that at the Nash equilibrium

$$r_T\left(t^*, T^*\right) = \left(t^* K' - xK\right)\left(1 + p'\right) < 0 \; , \tag{28}$$

and similarly differentiating federal revenues in (19) gives, on using the federal first order condition (20), that

$$R_{\vec{t}}(T^*, t^*) = T^* K' \left(1 + p'\right) = -K < 0 \; . \tag{29}$$

With each government neglecting an adverse impact that raising its own tax has on the other level, these vertical externalities tend towards the emergence of excessively high taxes.

The two kinds of externality thus point in opposite directions: horizontal to taxes being too low – too low, that is, in terms of the policy-makers' objective of maximised revenue – while vertical externalities point to their being, in the same sense, too high. In the setting of the federal tax, only the vertical externality in (28) is at work, since $R_T = 0$ (as an envelope property) in the Nash equilibrium. However, both kinds of externality are at work at state level. Notice though, from (26) and (29), that

$$r_{\vec{t}}(t^*, T^*) + R_{\vec{t}}(T^*, t^*) = (t^* K' - xK)(1 + p') < 0 \tag{30}$$

so that at the Nash equilibrium a small increase in the state tax reduces federal revenues by more than it increases state revenues and thus, strikingly, the vertical externality, in the setting of t, dominates (the horizontal).[21] Intuitively, a reduction in the common state tax has three effects, the first two of which (the loss of Kdt at unchanged base, and the indirect reduction of federal revenues by $TK'(1 + p')dt$) cancel out as a consequence of federal optimisation (20), leaving only the third, beneficial effect on state revenues of an expanded tax base, $(t^* K' - xK)(1 + p')dt$. Summarising:

[21] This is as in Flowers (1988), who provides a diagrammatic treatment of the case in which the equilibrium state tax t and T are strategic substitutes. The result here establishes the point more formally and generally.

Proposition 1 *Starting from the Nash equilibrium, consolidated revenue is strictly increased by a small cut in any or all of:*

(a) the federal tax rate;

(b) the state tax rate;

(c) the combined tax rate $\tau \equiv t + T$.

Proof of Proposition 1 Part (a) of the Proposition follows from the observations above, (28) - that an increase in the federal tax contracts the state tax base, and an application of the envelope theorem on (19) that $r_T(t^*, T^*) < R_T(T^*, t^*) = 0$ and part (b) from (30); that is from the fact that an increase in the state tax reduces federal revenues by more than it increases state revenues. For part (c) denote consolidated revenues in symmetric equilibrium by $\theta(\tau) \equiv r(t, T) + R(T, t) = \tau K + \chi \Pi$. Then

$$\theta'(\tau) = K + (\tau K' - \chi K)(1 + p'). \tag{31}$$

Now evaluating (31) from (15) and (20) gives $\theta'(\tau^*) = \frac{-NK(1+p')}{N+p'} < 0$. □

The Nash equilibrium finds the federation on the downward-sloping part of its Laffer curve or, more precisely, on the downward-sloping parts of both the Laffer curves showing consolidated revenue as a function of the tax levied by one level of government – conditional on the tax set by the other – and the Laffer curve showing consolidated revenue as a function of the consolidated tax rate.

Proposition 1, it should be emphasised, concerns only with effects on tax revenues consolidated across state and federal governments. Recalling that in the absence of intergovernmental transfers, what matters for the self-interest of the policy-makers themselves, however – and also, as we shall shortly see, for the welfare of the citizenry – are rather the distinct effect of taxes on revenues at state and federal levels. Consider then the effects on state and federal revenues of consolidated small cuts in both the federal tax and the common state tax. Federal revenue certainly increases: as an envelope property, the change in T itself has no effect on R, whilst from (29) a cut in the state tax increases federal revenues. The effect on state revenues, however, is in general ambiguous: for while the cut in the federal tax raises state revenue (from (28)), the cut in the state tax reduces it (from (27)) in consequence of the horizontal externality. A coordinated tax cut is thus unambiguously beneficial to the federal Leviathan, but may harm those at the state level. Nevertheless, it is a simple matter to design a coordinated tax cut that will strictly increase revenues at both levels: all that is needed is to make the cut in the state tax sufficiently small relative to the cut in the federal tax.

Consider next the effects of a small cut in both federal and state taxes on the welfare of the typical citizen. Perturbing indirect utility $V(\rho, \tau, g, G)$, using (8) and recalling that at each level of government the fixed proportion λ is spent on the public good, the welfare effect of an arbitrary tax reform is given by

$$dV = V_\rho d\rho - (1-\chi) K d\tau + \lambda \left(\Gamma_G dR + \Gamma_g dr \right) \ . \tag{32}$$

For the first term in (32), evaluating (7) at a symmetric equilibrium, gives $V_\rho = \chi K \geq 0$, so that since the net return to capital is negatively related to the tax cuts, $d\rho > 0$ for any tax cuts in Proposition 1, the effect on this score is beneficial: consumers gain from the increased net return induced by a tax cut.[22] The second term, reflecting increased rents, is also beneficial; $(1-\chi) K$ in the form of rents will go to the citizen. The third and forth terms reflect the impact on expenditures at the two levels of government, and so turn on exactly the considerations discussed in the preceding paragraph. Federal revenues, we saw there, unambiguously increase if taxes are cut at both levels of government: the citizen thus benefits from an increase in federal expenditure. But state revenues may not increase. In general, the net impact on the citizen's welfare of the induced changes in public expenditures then depends on the relative marginal valuations of state and federal spending, Γ_g and Γ_G. This dependence is something of an irritation, since these valuations are extraneous to the matters in hand, and their relative magnitude in equilibrium are consequently not in general tied down by the model being used.

One natural case to take as a benchmark is that in which, at the margin, consumers are indifferent between federal and state spending. It is sufficient for this that $\Gamma(g, G) = \Gamma(g+G)$, so that public expenditures at the two levels are perfect substitutes. This is clearly an extreme case, but does transparently remove effects arising from differences in the marginal valuation of state and federal spending that are not the essence for the issues at stake. In this case it is only the impact of reform on consolidated revenues that matters for the third and fourth terms of (32). Recalling from Proposition 1(b) that a state tax cut increases federal revenues by more than it diminishes state revenues, the citizen then clearly gains from a coordinated tax cut. Summarising:

Proposition 2 *Starting from the Nash equilibrium*:

(a) A small cut in the federal tax rate is strictly Pareto-improving: that is, no citizen or policy-maker loses from such a tax cut and some strictly gain;

(b) A small cut in the state tax rate (or any small cut in the consolidated tax rate) is strictly beneficial for the federal policy-maker, and if g and G are perfect substitutes is also strictly beneficial for the citizenry.

Proof of Proposition 2 The proof of Proposition 3 follows directly from the discussion of the preceding paragraphs. □

Note too the implication that one can specify the cut in the state tax to be sufficiently

[22] Assumptions on the pattern of endowments will guarantee that savings are positive in equilibrium.

small relative to that in the federal tax to ensure that r rises, and hence that all – both policy-makers and citizens – gain from a coordinated tax cut.

In one sense these results strengthen the arguments of Brennan and Buchanan (1980) confirming that equilibrium tax rates are too high from the citizen's perspective when policy-makers are Leviathans. The novelty that arises with the explicit recognition of a federal structure is, however, twofold: while tax rates are *too high*, tax revenues are *too low*; and tax rates proves too high even from the perspective of the Leviathans themselves.

The analysis here points to quite different conclusions, however, in respect of the proper role of inter-governmental transfers. Brennan and Buchanan argue against such transfers on the grounds that they may provide a device whereby policy-makers can avoid competing with one another. As they notably put it

> [R]evenue sharing is undesirable, because it subverts the primary purpose of federalism, which is to create competition between jurisdictions. Each jurisdiction must have responsibility for raising its own revenue and should be precluded from entering into explicit agreements with other jurisdictions..[23]

Here, however, the absence of cooperation between policy-makers is itself a source of loss for the citizen, since it is this that gives rise to the vertical externality underlying over-taxation. Measures of 'fiscal cartelisation', enabling the policy-makers to internalise (part or all of) the fiscal externalities between themselves, may thus be in the citizenry's best interest. Suppose for example that aggregate revenue $r + R$ is strictly concave in the combined tax rate τ. Then it would be entirely to the citizenry's advantage if the federation of Leviathans were to organise themselves into a single Leviathan: tax rates would fall, the economy would move to the peak of the Laffer curve, public expenditures would rise and so too would the net return ρ. Fiscal cartelisation, far from damaging the citizen, would be Pareto improving. Summarising:

Corollary *With the form of tax coordination in the sense of Proposition 2, appropriate revenue-sharing arrangements between the state-level and federal Leviathans are Pareto improving.*

Proof of Corollary The proof follows from the preceding discussion. $\square$

5 The role of inter-state competition

Consider now the effects of increasing the number of states, N. This will intensify competition between the states, since each has less monopoly power to exploit in taxing capital.

[23]Brennan and Buchanan (1980), p.183.

For the same reason that they distrust fiscal cartelisation, Brennan and Buchanan (1980) thus refer to the

> 'efficacy of a large number of subordinate government units.'[24]

But having just seen that explicit modelling of a federal structure places fiscal cartelisation in a much more favourable light than has been argued, the question arises as to the implications of such explicit modelling for evaluating an increase in N. The following shows that there are indeed profound: far from reducing tax revenues, under a very weak condition increasing the number of lower-level jurisdictions actually *increases* revenue per state.

Proposition 3 *An increase in N, the number of states, strictly increases equilibrium consolidated tax revenue per state.*

Proof of Proposition 3 By Proposition 1(c), it suffices to show that $d\tau < 0$. For this, note first, again denoting the left of (15) by $h(t, T, N)$ that

$$h_N = \frac{Kp'}{N(N + p')} < 0 , \tag{33}$$

so that (again assuming $h_t < 0$) $b_N < 0$. Perturbing (22)-(23) gives

$$\begin{bmatrix} dt \\ dT \end{bmatrix} = \frac{b_N dN}{1 B' b_T} \begin{bmatrix} 1 \\ B' \end{bmatrix} , \tag{34}$$

and thus

$$\frac{d\tau}{dN} = \frac{(1 + B' b_T)}{(1 - B') b_N} , \tag{35}$$

which is strictly negative by (21) and the stability condition (24). □

The result is illustrated in Figure 1 for the case in which t and T are strategic substitutes at both levels of government.

The best response of the federal government is BB and bb is the equilibrium response of the states; RR, which has slope[25] -1, is the locus along which the combined tax rate – and hence also consolidated revenue – is the same as at the initial equilibrium at A. Since, following the proof of Proposition 3, $b_N < 0$, increasing N shifts bb to the left. Thus if the federal tax rate was to remain at T^*, the state tax would fall to $\hat{t}$: this is the effect of intensified inter-state competition, as the number of states increases

[24] Brennan and Buchanan (1980), p 180.

[25] The locus RR must lie between BB and bb. This follows from (18) and (21). (18) implies that $\frac{1}{b_T} < -1$ while (21) implies that $B' > -1$.

Figure 1: Federal and state taxes as strategic substitutes.

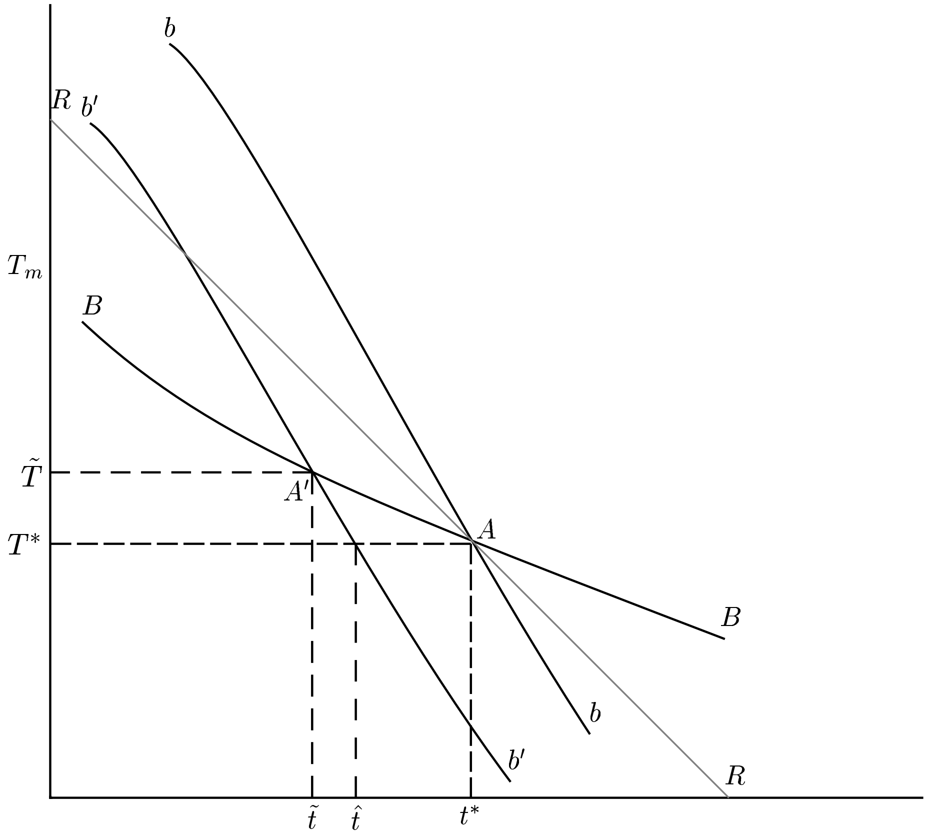
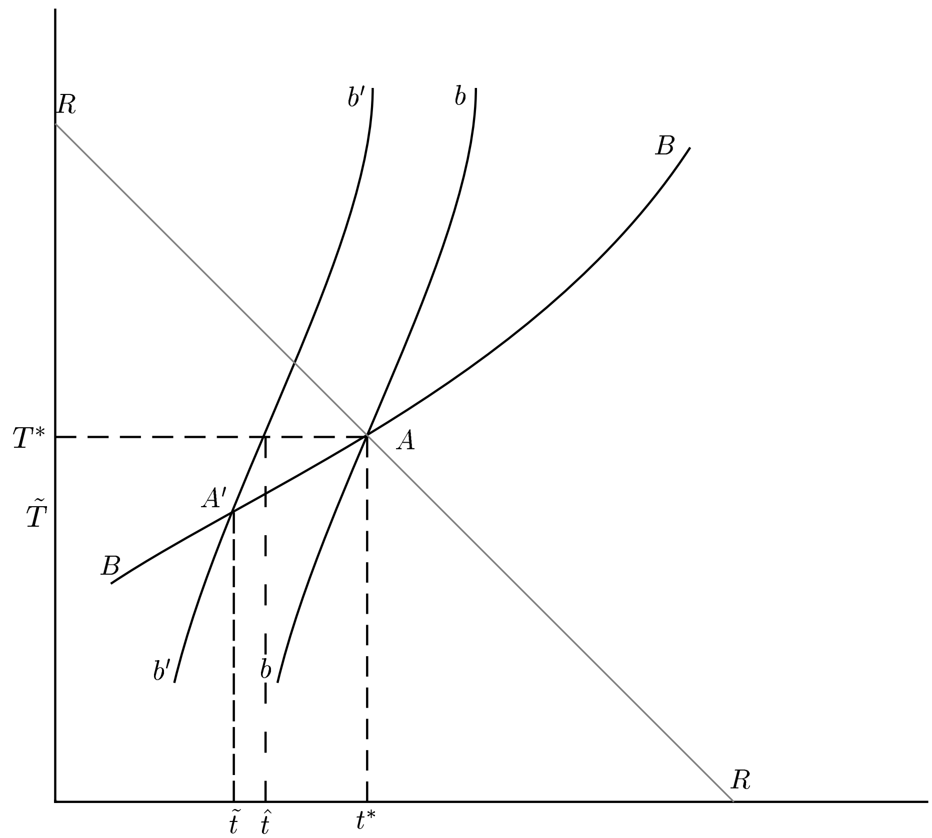


Figure 2: Federal and state taxes as strategic complements.



the equilibrium level of taxes decreases, and it would seem to be this effect that those who welcome intensified competition as a constraint on Leviathan would seem to have in mind. But the federal tax typically will not remain unchanged. In Figure 1, the new Nash equilibrium will be at A' with the taxes being $\tilde{T}$ and $\tilde{t}$. This must clearly lie along BB to the left of A, and so must lie beneath RR: thus consolidated revenue must increase.

Figure 2 – to which we return shortly – verifies that the same conclusion holds if instead t and T are strategic complements at both levels of government. Indeed the Proposition makes it clear that no restriction on the strategic relationship between the taxes are needed for the result. Proposition 3 runs counter to the intuition that increased inter-state competition will lead to lower taxes. Once seen, however, the reason is clear: intensified inter-state competition transforms the situation into one in which the federal Leviathan is more akin to a monopolist. As noted before, in the limit, one can conceive of N increasing to the point at which state taxes are eliminated and the field left entirely clear for the federal policy-maker to act as an archetypal revenue-maximiser. In Figure 1 that would correspond to the best response function bb shifting to the left until crossing

the T axis, point T_m.

This then raises the intriguing possibility that increasing N may benefit the citizen precisely because it *raises* tax revenues. For we have already seen that the emergence of a fiscal cartel tends to be in the interest of the consumer, and now also that one way of bringing this about is precisely by intensifying inter-state competition. That is, it may be that the policy preference for a large number of lower-level jurisdictions is correct not for the reason usually given, that this will moderate tax revenues, but for precisely the *opposite* reason, that it will increase them.

One other feature of the Leviathan case deserves emphasis. As noted in the introductory section, following Oates (1985), there has emerged a sizeable empirical literature – including Nelson (1987), Zax (1989) and Anderson and Van den Berg (1998) – seeking to test the hypothesis that policy-makers are revenue-maximising Leviathans. In fact Proposition 3 means that these empirical attempts to identify Leviathan by testing the 'Leviathan hypothesis' are ill-conceived in federal settings:[26] an inverse relationship would actually be a powerful evidence *against* the existence of Leviathan not for it.

The question then is whether an increase in N might raise consumer welfare. As shown in the proof of Proposition 3, an increase in N will lead to a fall in τ and hence, by (13), to an increase in p. Recalling (32), it thus suffices for the consumer to gain that the third and forth terms are positive, $\lambda\left(\Gamma_g dr + \Gamma_G dR\right) > 0$. But while we have seen in Proposition 3 that an increase in N will increase consolidated revenue, it need not be the case that both components r and R also rise. Federal revenue certainly will: as is evident from Figures 1-2, an increase in N leads to a lower state tax whatever the sign of the slope of the equilibrium responses, and thus - since $R_t < 0$ and, as an envelope property, the change in T itself has no first-order effect on R - it also leads to increased federal revenue. State revenue, however, may well fall: the direct effect of the induced fall in t points to such a reduction, recalling that the horizontal externality implies that $r_t < 0$ at the Nash equilibrium, and, recalling both Figure 1 and that $r_T < 0$ in the Nash equilibrium, this is reinforced by an increase in T when t and T are strategic substitutes. When they are strategic complements on the other hand, state revenue may increase if the effects of a reduced federal tax outweigh those of a reduced state tax. Thus the sign of dr is ambiguous. As a consequence, the overall effect on welfare again typically depends on the relative marginal valuations of state and federal public goods: as N increases, the gain from a higher net return and increased federal spending may be offset by a loss through reduced state spending. Once again it helps fix ideas to consider the special case in which g and G are perfect substitutes. With this further assumption the welfare effects of increasing N become unambiguous. For the argument, following (32), implies that it is sufficient for welfare to rise that consolidated revenue rise, and it then

[26]This is not the only difficulty with the hypothesis: for example the inverse relationship posited is also implied by standard models of horizontal tax competition with benevolent policy-makers.

follows from Proposition 3 that :

Proposition 4 *If state and federal spending are perfect substitutes, then an increase in N increases the citizen's welfare.*

Proof of Proposition 4 The proof of the Proposition follows directly from the discussion of the preceding paragraphs. □

6 The federal government as first mover

The intrinsic asymmetry between the single federal government at one level and the many state governments at the other leads one to consider the possibility that the federal government may act as first-mover relative to the states.[27] That is, in making its own tax policy the federal government might act as a Stackelberg leader, taking into account the reaction this will induce from the states. That is the case we now consider. To simplify, we assume in this section that the federation is small in world capital markets, and so take ρ as given.[28] The federal government now chooses T to maximise $R(T, b(T, N))$ in (19), giving the necessary condition

$$K + (TK' - XK)(1 + b_T) = 0 \, . \tag{36}$$

The equilibrium is illustrated in Figures 3-4, being characterised by tangency between an iso-revenue curve for the federal government, denoted by FF, and the equilibrium response of the states. When t and T are strategic substitutes, as in Figure 3, the Stackelberg equilibrium at S lies above the line RR through the Nash equilibrium at A and thus, as noted by Flowers (1988), the combined tax rate τ is higher in the Stackelberg than in the Nash equilibrium. Notice though that the opposite is true in the case of strategic complementarity, shown in Figure 4: here the combined tax rate is lower in the Stackelberg equilibrium than in the Nash. Since, by Proposition 1, the combined tax rate in the Nash equilibrium exceeds that which maximises collective revenues, it is intuitively apparent that in the case of strategic substitutes the Stackelberg equilibrium will also lie on the downward-sloping part of the aggregate Laffer curve. Using (15), (36) and $p' = 0$ in (31), one does indeed find that the effect on consolidated revenues of an

[27]Indeed there is evidence that this is the case for Canada. Boadway and Hayashi (1999) have found some evidence that, with Canadian corporate taxes, the federal government acts as Stackelberg leader.

[28]The substantial loss from this is that we are unable to address issues concerning the number of states N, since this then ceases to affect the equilibrium: see the next footnote.

Figure 3: Strategic substitutes taxes and the federal government as a first-mover.

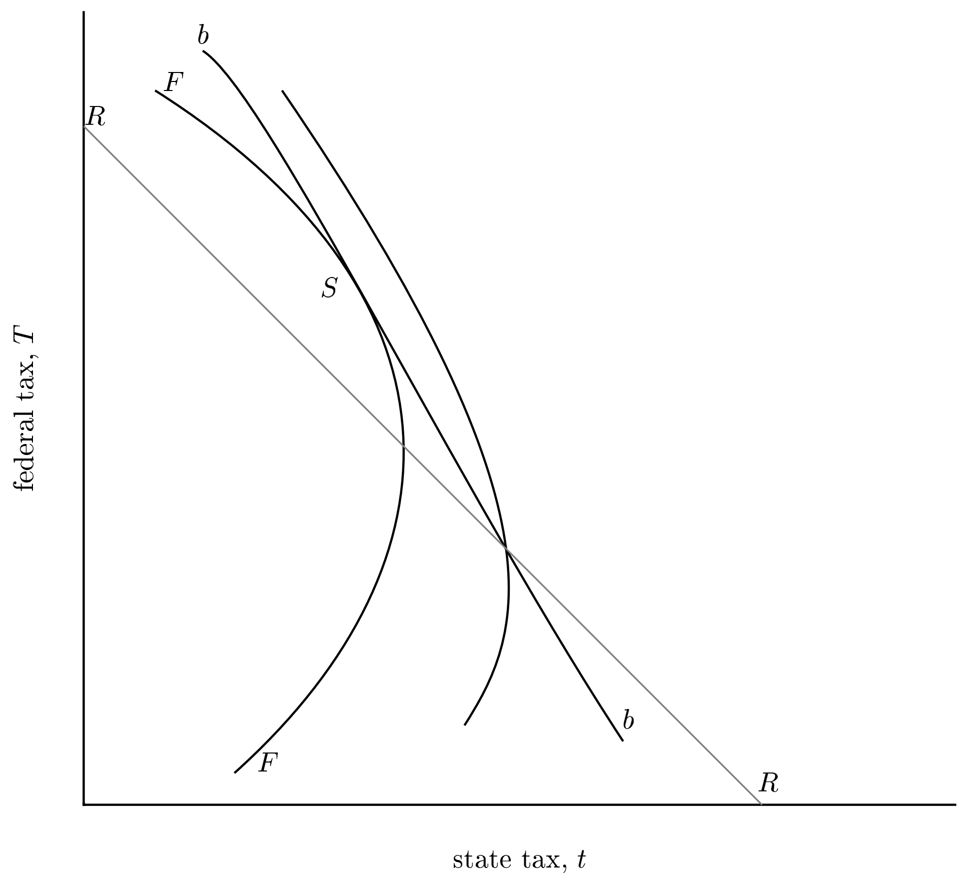
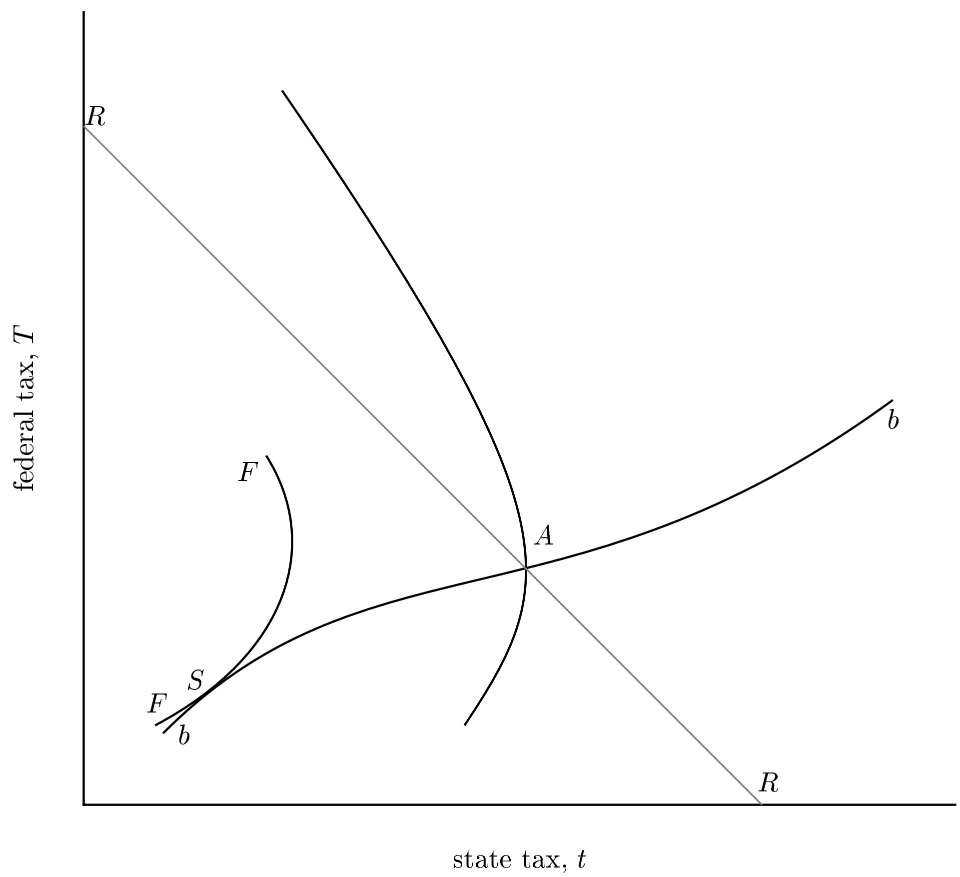


Figure 4: Strategic complements taxes and the federal government as a first-mover.



increase in τ is

$$\theta' = -\left(\frac{K}{1+b_T}\right) < 0 \,, \tag{37}$$

which confirms this intuition whilst also showing that the same conclusion holds even in the case of strategic complements: though lower than in the Nash equilibrium, the combined tax rate is still above its revenue-maximising level. More precisely:

Proposition 5 *Starting from the Stackelberg equilibrium, a small reduction in the combined tax rate strictly increases consolidated revenues.*

Proof of Proposition 5 Follows from the discussion of the preceding paragraphs. □

The key result of the Nash case thus carries over essentially unchanged to the Stackelberg case.[29]

7 Concluding remarks

The simple model of a genuinely federal tax structure developed here has proved rich in its implications. At some risk of over-simplification, the most important of these in relation to the two sets of issues raised at the outset can be summarised as follows:

- There does emerge a tendency, in the absence of cooperation between the policy-makers, towards over-taxation when policy-makers are Leviathans. For then consolidated – federal plus state – tax revenue is unambiguously increased by a small cut in either the federal or the state tax. It is especially striking that even the state tax emerges as excessively high in terms of the policy-makers' objectives: the horizontal externality typically emphasised in discussions of tax competition, and present here in undiminished force, is dominated by a less familiar vertical externality. Moreover, the equilibrium federal tax is too high even in terms of consumer welfare: a cut in the federal tax would benefit the citizen through higher state spending, higher net rental income and a higher return on savings. And the state tax is also high in the natural benchmark case in which federal and state spending are perfect substitutes: because a reduction in the state tax base will reduce state revenues by less than it will increase federal revenues.

[29] One might expect that if ρ were endogenous one would again find that an increase in N leads to higher consolidated revenues; but we have been unable to prove this. Certainly federal revenues will rise: the federal Leviathan can always increase his own revenue when N increases by raising T so as to leave the combined tax τ unchanged. But that does not preclude the possibility that the federal Leviathan could do even better for himself by changing T in such a way that consolidated revenue falls. Diagrammatically, it seems conceivable, for example, that as the equilibrium response bb shifts left in Figure 3 the new point of tangency with a federal iso-revenue curve lies above a line with slope -1 through the initial equilibrium.

- The relationship between consolidated revenue per state and the number of lower level jurisdictions is precisely the opposite to that conventionally associated with the Leviathan hypothesis, as indeed was argued, somewhat informally by Flowers (1988): rigorously formulated and embedded in a federal structure, the hypothesis implies, other things equal, a *positive* coefficient in a regression of consolidated revenues, not the negative one usually looked for. Though this standard presumption thus proves incorrect, the central policy conclusion drawn from it by those who view policy-makers as Leviathans – that increasing the number of states may benefit the citizenry – may still be right. Indeed we have seen that – assuming federal and state spending to be perfect substitutes – welfare is increased by an increase in the number of states. But the reason for this is very different from that usually given. Increasing the number of states does indeed reduce the equilibrium state tax. But the reason this gives rise to a welfare gain in the Leviathan case is not because it reduces tax revenues and hence waste; quite the opposite, the welfare gain comes precisely from an increase in tax revenues.

APPENDIX

A. Comparative Statics at State Level

In this appendix we provide more details on the comparative statics of state-level behaviour in the setting of Section 3.1. To simplify matters throughout this appendix we assume rents to be untaxed and so $x_i = 0$.

Note first that differentiation of the first order condition

$$K_i + (t_i K_i' - x_i K_i)\left(1 + \frac{\partial \rho}{\partial \tau_i}\right) = 0 \ ,$$

gives the second order condition, that is

$$2K_i'\left(1 + \frac{\partial \rho}{\partial \tau_i}\right) + t_i K_i''\left(1 + \frac{\partial \rho}{\partial \tau_i}\right)^2 + t_i K_i' \frac{\partial^2 \rho}{\partial \tau_i^2} < 0 \ . \tag{A.1}$$

Evaluating now (A.1) at the symmetric equilibrium, using (14), gives

$$\begin{aligned} 0 &> 2K\left(1 + \frac{1}{N}p'\right) + tK''\left(1 + \frac{1}{N}p'\right)^2 + tK'\frac{\partial^2 \rho}{\partial \tau_i^2} \ , \\ &= K'\left(1 + \frac{1}{N}p'\right)\left[2 - E^K - \frac{K}{K'\left(1 + \frac{1}{N}p'\right)^2}\left(\frac{\partial^2 \rho}{\partial \tau_i^2}\right)\right] \ , \end{aligned} \tag{A.2}$$

with the second inequality following from (7) and the definition in (15). For the final term in (A.2), differentiating in (12) and evaluating at a symmetric equilibrium gives

$$\left(\frac{\partial^2 \rho}{\partial \tau_i^2}\right) N\left(S' - K'\right) + \left(\frac{\partial \rho}{\partial \tau_i}\right)\left(NS''\frac{\partial \rho}{\partial \tau_i} - K''\left(1 + N\frac{\partial \rho}{\partial \tau_i}\right)\right) = K''\left(1 + \frac{\partial \rho}{\partial \tau_i}\right) \ . \tag{A.3}$$

Multiplying (A.3) by N and using both (13) and (14) gives

$$\left(\frac{\partial^2 \rho}{\partial \tau_i^2}\right) = \left(\frac{1}{S' - K'}\right)\left(\frac{K'}{N}\right)^2\left(\frac{1}{K}\right)\left[\left(\frac{S'}{S' - K'}\right)^2\left(E^K - E^S\right) - (N-1)\,E^K\right] \ , \tag{A.4}$$

where $E^S \equiv \frac{SS''}{(S')}$. Using (7) in (A.2) and recalling that

$$K'\left(1 + \frac{1}{N}p'\right) < 0 \ ,$$

one finds

$$2 - E^K - \left(\frac{K'}{S'-K'}\right)\left(\frac{1}{N+p'}\right)^2 \left[\left(\frac{S'}{S'-K'}\right)^2 \left(E^K - E^S\right) - (N-1)\,E^K\right] > 0\ . \tag{A.5}$$

Letting now $S' \to \infty$ or $K' \to 0$, this reduces - as claimed in the text - to $2 > E^K$. $\square$

B. Slope of the states' equilibrium response

Consider next the slope of the states' equilibrium response. Denoting the left of (15) by $h(t,T,N)$, this is by

$$b_T = -\frac{h_T}{h_t},$$

where

$$h_t = K'\left[2 + p'\left(1+\frac{1}{N}\right) - (1+p')\,E^K - \left(\frac{K}{K'(N+p')}\right)p''\right] . \tag{B.1}$$

Differentiating in (13) shows

$$p'' = \left(\frac{1}{S'-K'}\right)^3 \frac{(K'S')^2}{K}\left(E^K - E^S\right) , \tag{B.2}$$

which, used in (B.1), implies that h_t has the opposite sign to

$$2 - E^K - \left(\frac{K'}{S'-K'}\right)\left[\left(\frac{S'}{S'-K'}\right)^2\left(\frac{1}{N+p'}\right)\left(E^K - E^S\right) - \left(1+\frac{1}{N} - E^K\right)\right] . \tag{B.3}$$

We assume $h_t < 0$, a condition related to, but in general distinct from, the second order condition for the typical state's problem: for while the second order condition relates to a tax change by just one state h_t refers to a simultaneous change by all. Thus while the two conditions coincide if $N = 1$, in general they differ. The condition $h_t < 0$ may be thought of as a stability condition, ensuring that if the states were collectively forced to reduce their common tax rate then each acting in isolation would wish to raise its own tax in response. Given this, differentiating (15) shows b_T to have the same sign as

$$h_T = h_t - K'\left(1 + \frac{1}{N}p'\right) . \tag{B.4}$$

From (B.1), (B.4) implies that

$$h_T = K'(1+p')\left[1 - E^K - \left(\frac{K}{K'(N+p')}\right)\frac{p''}{1+p'}\right] . \tag{B.5}$$

Noting from (B.2) and (B.5) that

$$\frac{p''}{1+p'} = \left(\frac{1}{S'-K'}\right)^2 \frac{(K')^2 S'}{K}\left(E^K - E^S\right) . \tag{B.6}$$

use of (B.6) in (B.5) implies, recalling (13), that B_T has the same sign as

$$E^K - 1 + \left(\frac{1}{S' - K'}\right)\left(\frac{1}{NS' - (N-1)\,K'}\right) K'S'\left(E^K - E^S\right) \ , \tag{B.7}$$

which reduces to $E^K - 1$ as $S' \to \infty$ or $K' \to 0$.

Finally, (18) follows on noting from (B.4) that

$$1 + b_T = K'\left(1 + \frac{1}{N}p'\right)(h_t)^{-1} > 0 \ . \tag{B.8}$$

□

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