SELF-ENFORCING INTERNATIONAL AGREEMENTS AND DOMESTIC POLICY CREDIBILITY

PAOLA CONCONI
CARLO PERRONI

CESIFO WORKING PAPER NO. 988
CATEGORY 7: TRADE POLICY
JULY 2003

CESifo *Working Paper No. 988*

SELF-ENFORCING INTERNATIONAL AGREEMENTS AND DOMESTIC POLICY CREDIBILITY

Abstract

We explore the relationship between international policy coordination and domestic policy credibility when both must be self-supporting. Our arguments are presented in the context of a two-country, two-period model of dynamic emission abatement with transboundary pollution, where government policies suffer from a time-consistency problem. In the absence of repeated interaction, any form of coordination - between governments, and between governments and their respective private sectors - improves policy making. Nevertheless, under repeated interaction international policy spillovers can make it possible to overcome the domestic credibility problem; and, conversely, the inability to precommit to policy domestically can help support international policy cooperation.

Keywords: policy commitment, self-enforcing international agreements.

JEL Code: F42, C73, H20.

Paola Conconi
European Centre for Advanced Research in Economics and Statistics (ECARES)
Université Libre de Bruxelles
Ave F.D. Roosevelt 50, CP 114
1050 Brussels
Belgium
pconconi@ulb.ac.be

Carlo Perroni
Department of Economics
University of Warwick
Coventry CV4 7AL
United Kingdom
c.perroni@warwick.ac.uk

We wish to the thank the participants at the 2001 EURESCO Conference on the International Dimension of Environmental Policy, the Mid-West International Economics Group Spring 2003 Meeting at the University of Pittsburgh and seminar participants at the University of Bristol, Royal Holloway, and Free University of Brussels (ECARES) for helpful comments. We are also grateful to Mathias Dewatripont, Michael Finus, Patrick Legros, Arik Levinson, David de Meza, André Sapir, and John Whalley, for their valuable suggestions. The usual disclaimer applies. We gratefully acknowledge support from the University of Warwick and the ESRC.

1 Introduction

In the literature on rules versus discretion,[1] it is often informally argued that international agreements, by making domestic policy changes more difficult to reverse, could enhance the credibility of policymakers when domestic policy commitment devices are not available.[2] Figure 1, where we plot the World Bank indicator of institutional credibility[3] against membership (or not) in the World Trade Organization (WTO) for seventy countries, seems to support such a claim: on average, WTO members score a higher credibility index than non-members.[4] This argument, however, runs against the observation that international agreements are themselves not directly enforceable: absent a supranational authority with autonomous powers of enforcement, international agreements need to be sustained by the threat of credible punishment between the parties involved.[5] If international agreements are not automatically binding, one could actually conjecture a reverse linkage between domestic policy credibility and international agreements, namely that a lack of domestic commitment might make it more difficult to undertake commitments vis-à-vis international partners. Indeed, this is an alternative interpretation of the pattern shown in Figure 1.

---

[1] The idea that policy discretion might provide governments with an incentive to renege on earlier promises, that this incentive could undermine the sustainability of optimal government policies, and that the adherence to policy rules might restore the credibility and therefore lead to preferred outcomes, was introduced in the seminal paper by Kydland and Prescott (1977). The most influential applications of this idea have been in monetary and fiscal policy (see Persson and Tabellini [1994] for a review), but time inconsistency issues have been shown to arise in most areas of economics, including international trade (e.g. Staiger and Tabellini [1987], Matsuyama [1990], and Tornell [1991]) and environmental policy (e.g. Laffont and Tirole [1996]).

[2] For example, Staiger and Tabellini (1987) and Matsuyama (1990) suggest that time inconsistency problems in trade policy could be overcome if countries could undertake *binding* commitments through the GATT/WTO. In a more recent paper, Staiger and Tabellini (1999) find that GATT rules did indeed help the US government to make domestic trade policy commitments to its private sector.

[3] This index—which range from 1 (worst) to 6 (best)—captures the credibility of governments' policy announcements. It was constructed by the World Bank and the International Finance Corporation on the basis of a private sector survey conducted during 1996-1998 in seventy-four countries (see Brunetti *et al.* [1998]).

[4] The empirical evidence on this question is otherwise scant. There have been empirical studies focusing on the relationship between price inflation, central bank independence, and membership in a monetary union (e.g., Cukierman [1992]); but we are not aware of any systematic cross-country examination of the relationship between domestic policy credibility and membership in international agreements.

[5] For example, the WTO cannot directly punish violations and can only authorize member countries to retaliate against violators. The idea that international agreements must be self-enforcing has been repeatedly stressed in recent literature (see, for example, Bagwell and Staiger [1997], Maggi [1999], and Ederington [2001a,b]).

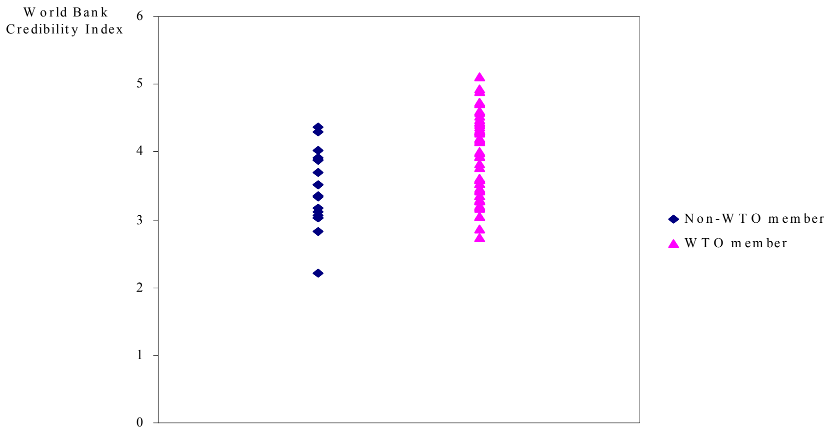

Figure 1: Domestic Credibility and WTO Membership

This paper explores the linkage between international agreements and domestic policy credibility when both must be self-supporting. The paper's main contribution is to show that the need to internalize international policy spillovers through a self-enforcing international agreement may help governments to overcome domestic policy credibility problems in policy choices, and, conversely, the need to sustain policy reputation with the private sector may help governments to support policy coordination with one another; consequently, reducing the scope for repeated strategic interaction by means of a binding partial coordination mechanism—such as a (hypothetically) binding international agreement or a domestic policy commitment device—may make it more difficult to support efficient policies. We also show that, when the international policy coordination problem and the policy credibility problem are not too severe, a simultaneous increase in the severity of both problems can be beneficial to self-enforcing policy coordination.

The general conclusion one can draw from these results is that when international agreements and domestic policy credibility must both be self-supporting, causation between them can flow in either direction: self-supporting international agreements can boost domestic policy credibility, and, *vice versa*, the need to sustain domestic policy reputation can help international cooperation. But co-causation is also possible: self-supporting international agreements and domestic policy credibility can complement each other, working together to help support efficient policies.

To the best of our knowledge, this is the first paper in the literature to analyze the two-way relationship between the credibility of domestic institutions and international policy cooperation under repeated interaction. Earlier related studies by Rogoff (1985a) and Kehoe (1989) have focused on the effects of binding (i.e. non self-enforcing) policy coordination between governments on time-consistent policy choices within a single round of interaction. What our analysis shows, however, is that the manner in which partial binding coordination affects cooperation under repeated strategic interaction does not mirror its effects within a single round of interaction. Thus, whether horizontal coordination—between governments—and vertical coordination—between governments and their respective private sectors—are binding or self-supporting matters a great deal for how they interact with each other.

2 Policy without Repeated Interaction

We develop our arguments by focusing on the case of environmental taxes. There is evidence both in the United States and in Europe suggesting that environmental policy suffers from a credibility problem: politicians have often pledged to introduce tough environmental policies but then adopted much softer policies.[6] There are also indications that this credibility problem stems from a tension between the goal of encouraging innovation and investment in environment-friendly technologies on the one hand and distributional concerns on the other: the prospect of future environmental taxes is instrumental to induce firms to undertake abatement-related investment; environmental taxes, however, produce unwanted distributional effects,[7] which are difficult to offset through compensation.[8] Then, once innovation has taken place, policymakers are driven to reduce environmental taxes in order to minimize their distributional effects.[9] As private investors recognize the ex-post incentives of policymakers, the promise of high future emission taxes is not credible.[10]

Our analysis focuses on an infinitely-repeated policy game between governments, where two symmetric countries are linked by transboundary pollution externalities and where pollution abatement requires investment by the private sector. In order to focus on the

[6] For example, according to the European Environmental Bureau (EEB) "there have been many words but little concrete change" in the EU taxation of energy products. A proposal to increase EU environmental taxes was put forward in 1997 has not yet been adopted and has been amended to introduce many exemptions for sectors which are more sensitive than others to energy prices (see www.eeb.org).

[7] Most energy and environmental taxes are well known to be regressive, since poorer people pay a disproportionate share of their income in these taxes relative to richer people (for example, see Poterba [1991], OECD [1995], and Metcalf [1999]).

[8] Compensation schemes typically run against incentive-compatibility problems. For example, grandfathering rules in the allocation of emission permits amongst firms can in principle neutralize distributional effects, but require verification of past emissions, which can generate ex-ante incentives for firms to increase emissions.

[9] In 2000, for example, truckers forced the UK government to roll back fuel taxes after successfully managing to disrupt automotive fuel distribution across the UK for almost a month.

[10] Much of the existing literature has focused on credibility problems arising from efficiency considerations only. An exception is Pearce and Stacchetti (1997), who analyze time-consistent taxation when a government cares about both efficiency and distribution.

environmental policy dimension, we assume that there is no trade.[11] The stage game consists of the following sequence: first the private sector selects levels of pollution-reducing investment on the basis of expected emission taxes; then governments choose emission taxes and pollution abatement decisions are finalized. Emission taxes are the only available policy instrument, and produce adverse distributional effects because different agents have different consumption requirements of the polluting good. Thus, when setting emission taxes governments trade off efficiency and distributional objectives; however, since taxes are chosen after investment decisions are made, effects on investment will not be accounted for. This gives rise to a domestic commitment problem: in the absence of repeated interaction, the taxes chosen ex post by each government will be below their unilaterally optimal levels.

In this model, policy formation suffers from a *vertical* coordination problem between government and private sector, stemming from governments' inability to precommit to a certain level of emission taxation, as well as from a *horizontal* coordination problem between governments, stemming from the presence of transboundary emission spillovers.

This section describes the stage game, and examines policy formation within a single round of interaction. Subsequent sections will focus on repeated interaction over an infinite horizon.

2.1 Pollution Abatement and Investment

In each country consumers consume a fixed amount X of a certain good, which can be produced by two alternative methods: a "dirty" technology, which produces one unit of the good at a constant marginal cost of unity while generating one unit of environmental emissions; and a clean technology, which generates no emissions but involves a marginal cost in excess of unity and requires some investment in the first period. If a total amount V of the good is produced using the clean technology, total domestic emissions are

$$E = X - V. \tag{1}$$

The government levies a tax t per unit of emissions, which makes the gross-of-tax price of the polluting good and the net-of-tax price of its clean substitute both equal to $p = 1 + t$. Revenues from environmental taxation, $R = tE$, are assumed to be returned to the consumers in equal shares in a lump-sum fashion.

There are n domestic firms having access to the clean technology. The long-run cost of producing an amount v for a certain firm through the clean technology is assumed to

[11] For an analysis of the interaction between trade and environmental policies in a game theoretical setting where international agreements are constrained to be self-enforcing, see Ederington (2001b).

be quadratic in v for all firms:

$$c(v) \equiv v + \frac{1}{2}\psi v^2. \tag{2}$$

The first component of $c(v)$ (the linear term) does not involve any capital costs for any of the firms. In contrast, for a fraction θ ($0 \leq \theta \leq 1$) of the abating firms, the second component (the quadratic term) represents input costs for a combination of abatement-specific capital inputs and other inputs.[12] We shall call these the *capital-intensive* firms. For these, the two inputs must be combined in fixed proportions: k units of capital for every $1-k$ units of other inputs, where $0 \leq k \leq 1$.[13] Thus the indirect demand for investment by one of these firms, for a given level of abatement, v, is

$$\frac{1}{2}k\psi v^2 \equiv i(v). \tag{3}$$

The remaining fraction $1-\theta$ of firms do not use capital inputs (i.e., for these firms, the quadratic component of costs only involves current inputs).

If the private sector foresees a tax t, the expected profits to a firm from producing an amount v of the clean good are

$$tv - \frac{1}{2}\psi v^2 \equiv s(v,t), \tag{4}$$

and the first-order condition for a profit-maximizing abatement choice is

$$t - \psi v = 0, \tag{5}$$

which implies that pollution abatement, v, by a firm will take place up to the point where marginal abatement costs equal marginal abatement benefits. This identifies a function $v(t) = t/\psi$ linking the privately optimal aggregate level of abatement by a firm to the tax. In spite of their different technologies, if firms of both types correctly foresee the tax, they will select the same level of abatement and obtain the same profits.

[12] Investment in R&D and new equipment is the principal means by which pollution abatement takes place. Examples are the development of energy-efficient engine designs to reduce emissions by vehicles, the construction of refinery equipment to produce unleaded gasoline, or the installation of water cleaning equipment by chemical manufacturers. Estimates presented by the European Commission from studies carried out by several research institutions show that a European Carbon tax can only be effective in reducing CO_2 emissions if accompanied by substantial investment and innovation (DRI, 1992). Also, investment in emission-reducing projects plays a central role in the Kyoto Protocol through the Joint Implementation mechanism (Art. 6.1) and the Clean Development Mechanism (Art. 12).

[13] This specification amounts to assuming Leontieff homothetic primal technologies.

2.2 Consumption, Damage, and Welfare

In each country, the population comprises h consumers of two types, A and B, each present in equal numbers ($h/2$), and individually endowed with exogenous income levels equal to m^A and m^B, respectively. Consumers all have equal stakes in production activities, implying that the total profits from abatement, S, are distributed uniformly in the population. Disposable income for each individual of type j is then $y^j = m^j + (S + tE)/h$, $j = A, B$. Consumption takes place in the second period and it is assumed that individuals spend a fixed amount of their income on the pollution generating commodity—$x^j = \gamma^j X/h$, $j = A, B$, with $\gamma^A + \gamma^B = 2$—and spend the rest of their income on other non-polluting goods, in amounts equal to $c^j = y^j - x^j$.[14] In the rest of our discussion, we shall assume $\gamma^A > \gamma^B$.[15]

Emissions are transboundary. The valuation of environmental damage by a representative domestic consumer is assumed to be linear in the global level of emissions:

$$d = \frac{\mu}{h}\left[(1-\alpha)E + \alpha E^*\right], \tag{6}$$

where E^* denotes emissions by foreign firms, and where α ($0 \leq \alpha \leq 1$) represents the extent to which environmental damage is transboundary. Environmental damage is assumed to be additively separable in preferences. The (indirect) utility of consumers of type j in the home country can then be written as

$$u^j = m^j + \frac{-(1+t)\gamma^j X + S + tE - \mu\left[(1-\alpha)E + \alpha E^*\right]}{h}, \qquad j = A, B. \tag{7}$$

We wish to represent a situation where environmental taxes have undesirable distributional effects, i.e., where the distribution of welfare under $t = 0$ is viewed by society as being desirable (so that emission taxes would not independently be used to pursue distributional objectives in the absence of environmental costs). This can be captured simply by specifying endowments as $m^A = m^B + (\gamma^B - \gamma^A)X/h$, so that $t = 0$ implies $u^A = u^B$ and $t > 0$ implies $u^A < u^B$; thus, any increase in t from zero will skew the distribution of welfare against group A.[16]

---

[14] Formally, such demand patterns are consistent with preferences that can be represented in terms of a utility function of the form $u(x^j, c^j) = \lambda \min\{x^j - \gamma^j X/h, 0\} + c^j$, $j = A, B$, for λ sufficiently large.

[15] For example, group A could be identified with the rural population, who consume comparatively more automotive fuel.

[16] Much of the debate on the redistributive costs of environmental taxation revolves around the differential impacts these taxes can have across productive sectors, rather than consumers. A structure analogous to the one described here arises if ownership of the factors associated with the production of either the dirty or clean variety is concentrated within the economy. Then an increase in the tax would alter factor returns and would be distributionally nonneutral.

If we then assume the government's objective to be a weighted linear combination of individual utilities, $W(u^A, u^B) = h(w^A u^A + w^B u^B)$, we can represent inequality aversion by attaching a premium ρ to the utility of the less favored group (type A if we assume $\gamma^A > \gamma^B$) and specifying normalized weights as $w^A = (1+\rho)/(2+\rho), w^B = 1/(2+\rho)$.[17] The government's payoff, as a function of the domestic tax and of the foreign level of abatement, can thus be expressed as

$$\Pi(t, V^*) \equiv -\beta t + \mu\left[(1-\alpha)V(t) + \alpha V^*\right] - \frac{1}{2}\phi V(t)^2, \tag{8}$$

where $V(t)$ and V^* are total domestic and foreign abatement when all firms correctly forecast the tax and $\beta = -\rho X(1-\gamma^A)/(2+\rho) > 0$ is a constant.[18] The term βt in (8) represents the distributional cost of emission taxes; we shall assume that this effect cannot be neutralized by any available compensation mechanism.[19]

2.3 Second-Best and Time-Consistent Emission Taxes

If the government can credibly precommit to a level of emission tax in the second period, it will select a tax t which maximizes (8). This yields

$$t = (1-\alpha)\mu - \beta\phi. \tag{9}$$

In this unilateral second-best solution, the concern for reducing the environmental damage associated with emissions is weighed against the distributional cost of higher emission taxes.[20] Notice that this ex-ante optimal tax is independent of k and θ.

If, however, the government cannot credibly precommit to a certain level of emission taxation, the tension between efficiency and distributional goals combines with the dynamic dimension of pollution abatement to give rise to a time-inconsistency problem in

[17] This formulation can be derived from a hybrid Utilitarian/Rawlsian symmetric social welfare (or political support) function of the form $W(u^1, ..., u^h) = \min_i\{(1+\rho)u^i + \sum_{l\neq h} u^l\}$.

[18] The full expression for social welfare also includes a constant term $\Lambda = h(w^A m^A + w^B m^B) - (\gamma^A w^A + \gamma^B w^B)X + \mu((1-\alpha)X + \alpha X^*)$. For the sake of notational simplicity, we renormalize payoffs omitting the constant Λ; this has no implications for our subsequent analysis, which only involves payoff differences.

[19] A consumption subsidy lowering the price of both the dirty good and its clean substitute could in principle neutralize the effects of the emission tax. Such a scheme, however, would not be feasible if the level of consumption of the clean substitute (reflecting how consumers substitute away from the polluting good) is either unobservable or nonverifiable; or it may not be viable if the social opportunity cost of the public funds required for such a subsidy is prohibitively high (e.g., because of high marginal efficiency costs from raising revenues through other taxes).

[20] In the discussion that follows, we shall restrict our attention to scenarios featuring an interior unilateral solution where $(1-\alpha)\mu - \beta\phi > 0$.

the choice of emission taxes. The reason is that, once capital-intensive firms have installed a certain amount of investment, private abatement choices become less responsive to changes in the tax than they are ex ante; then, because of the adverse distributional costs of taxation, the government will be induced ex post to select a tax which is less than the one it would have committed to ex ante.

Formally, suppose that investors foresee a tax $\tilde{t}$. Then each capital-intensive firm would install an amount of capital, $i(\tilde{t}) = (1/2)k\psi(v(\tilde{t}))^2 = k(\tilde{t})^2/(2\psi)$. Once $i = i(\tilde{t})$ is installed, the cost of capital investment will be sunk, and the maximum possible level of abatement for a capital-intensive firm will be $[2i(\tilde{t})/(k\psi)]^{1/2} = \tilde{t}/\psi$. Thus, for any level of abatement less than $\tilde{t}/\psi$ the marginal cost of abatement to a capital-intensive firm will be reduced to $(1-k)\psi v$; on the other hand, the marginal cost of abatement for $v \geq \tilde{t}/\psi$ will be infinity. Thus, capital-intensive firms will each choose a level of abatement for which $t = (1-k)\psi v$, i.e. $v = t/[(1-k)\psi]$, if this level is less than or equal to $\tilde{t}/\psi$; and will choose $v = \tilde{t}/\psi$ otherwise.[21] So the short-run abatement response by each of the capital-intensive firms—as a function of the tax $\tilde{t}$ on which investment choices were based and of the tax actually selected by the government in the second period—can be expressed as[22]

$$\min\left\{\frac{t}{(1-k)\psi}, \frac{\tilde{t}}{\psi}\right\} \equiv \hat{v}_k(t, \tilde{t}). \tag{10}$$

The remaining firms, which do not use capital as an input, will each choose an abatement level $v(t) = t/\psi$. What the above implies is that the ex-post abatement choice by capital-intensive firms is constrained by the installed capacity, but a lower tax is required to induce a given abatement level by capital intensive firms, if this level is below the installed capacity. Then, if the government selects a tax that maximizes welfare after a level of investment $i = i(\tilde{t})$ is installed by each capital-intensive firm, it will be tempted to lower the tax so as to reduce its distributional effects.

In the Appendix, we derive the solution for the government's ex-post optimal choice of tax, as a function of the tax that was expected by investors ex ante:

$$\hat{t}(\tilde{t}) = \min\left\{t', \max\{t'', t'''\}\right\}; \tag{11}$$

where

$$t' \equiv (1-\alpha)\mu - \frac{\beta\phi}{(1-\theta) + \theta/(1-k)}; \quad t'' \equiv (1-k)\tilde{t}; \quad t''' \equiv (1-\alpha)\mu - \frac{\beta\phi}{1-\theta}. \tag{12}$$

---

[21] Since profits are concave and since they reach an unconstrained maximum at $v = t/[(1-k)\psi]$, if the latter is greater than $\tilde{t}/\psi$ we must have that profits are increasing at $v = \tilde{t}/\psi$, and this choice will therefore be a constrained optimum for the firm.

[22] In what follows, we use a "hat" ("^") to denote a divergence between the taxes expected by capital-intensive firms and the taxes chosen by the policymakers.

The optimum ex-post choice thus falls under one of three possible regimes: (i) regime $\hat{t}(\tilde{t}) = t'$ corresponds to an optimum where neither firm type is capacity-constrained; (ii) in regime $\hat{t}(\tilde{t}) = t''$, the tax is set at a level that is just high enough to induce capital-intensive firms to operate at capacity, i.e. such that capital-intensive firms would respond to a marginal tax reduction but not to a marginal tax increase; (iii) in regime $\hat{t}(\tilde{t}) = t'''$, capital-intensive firms operate at capacity and their abatement choices are fully unresponsive to marginal tax changes in either direction.

>From (11) it can be immediately seen that, if the anticipated tax, $\tilde{t}$, is equal to the second-best choice, i.e. $\tilde{t} = (1-\alpha)\mu - \beta\phi$, then the ex-post optimal tax will be less than $\tilde{t}$ (t', t'', and t''' are all less than $(1-\alpha)\mu-\beta\phi$ in that case); thus, the ex-ante second-best tax cannot constitute a credible promise. In a perfect-foresight equilibrium, where investors correctly anticipate the ex-post optimal choice of the government, we must have $\tilde{t} = \hat{t}(\tilde{t})$. It is easy to verify that the only value of $\tilde{t}$ that satisfies the above fixed-point condition—the time-consistent level of taxation—for $k > 0$ is $\tilde{t} = t''' = (1-\alpha)\mu - \beta\phi/(1-\theta)$ if this expression is positive, and $\tilde{t} = 0$ otherwise.[23] Therefore, the unilateral second-best level of emission taxation cannot be sustained in the absence of a commitment mechanism.[24]

2.4 One-Shot Uncoordinated and Coordinated Policy Outcomes

If $\theta = 0$ no policy credibility problem arises. We can interpret this case as representing a scenario where all firms use only current inputs in abatement, or, alternatively, a scenario where the government can rely on a commitment technology, i.e. where taxes are chosen, and credibly committed to, prior to investment taking place. Similarly, a value of zero for the parameter α can be interpreted either as representing a scenario with no pollution spillovers between countries or a scenario where the two governments manage to internalize the spillovers by choosing taxes in a coordinated manner. Then, the policy choice obtained for $\theta = \alpha = 0$ represents the "global" second-best optimal tax, which will be denoted by t^C:[25]

$$t^C = \mu - \beta\phi; \tag{13}$$

this is the tax for which the common payoff of the two countries is maximized.

[23] For $k > 0$, a solution with $\tilde{t} = (1-\alpha)\mu - \beta\phi/[(1-\theta)+\theta/(1-k)] > (1-\alpha)\mu - \beta\phi/(1-\theta) > 0$ would imply $\tilde{t} = (1-k)\tilde{t}$ and $\tilde{t} > 0$, an impossibility.

[24] Trivially, in a scenario where the second-best choice is $t = 0$ (i.e., where $(1-\alpha)\mu - \beta\phi \leq 0$) no credibility problem arises.

[25] In the rest of our analysis, we shall often refer to t^C as the optimal tax. However, the reader show keep in mind that this is a constrained (second-best) optimum; the unconstrained (first-best) optimum—a Pigouvian tax equal to μ—could only emerge in the absence of distributional effects (i.e. $\beta = 0$).

In the absence of any form of coordination, the symmetric policy outcome will involve a suboptimal tax choice:

$$t^{NC} = (1-\alpha)\mu - \beta\phi/(1-\theta) < t^C, \tag{14}$$

where the superscript NC stands for "no coordination" (between the two governments and between each government and its investors). Two types of miscoordination are responsible for the inefficiency: (i) vertical miscoordination between government and domestic investors, resulting in an ex-post optimal choice of taxes below the ex-ante second-best choice; (ii) horizontal miscoordination between governments, resulting in taxes that fail to internalize the transboundary emission spillovers. The vertical coordination problem exaggerates the impact of the distributional costs of taxes on the choice of t^{NC}: θ only appears in the second term and has no impact on t^{NC} if $\beta = 0$; the horizontal coordination problem understates the effect of taxes on global environmental damage.

If governments can rely on a commitment technology, i.e. $\theta = 0$, the uncoordinated outcome will feature a tax $t = (1-\alpha)\mu - \beta\phi \geq t^{NC}$; and since payoffs are monotonically increasing in t for $t < t^C$, this will result in a (weak) Pareto improvement. Analogously, if governments can coordinate their choices ($\alpha = 0$), the coordinated, no-commitment outcome will feature a tax $t = \mu - \beta\phi/(1-\theta) \geq t^{NC}$, which will also result in a (weak) Pareto improvement. Thus, within a single round of interaction, any form of coordination is beneficial, for it leads to the adoption of higher taxes:

Proposition 1 *With a single round of interaction, partial coordination—either between governments or between governments and investors—results in a higher level of taxation and higher welfare.*

In this model, the two forms of miscoordination operate in the same direction: both bias policies downwards, and can never offset each other as they do, for example, in the problems studied by Rogoff (1985a), and Kehoe (1989).

3 Policy Reputation and International Cooperation under Repeated Interaction

The literature on policy credibility has appealed to the well-known idea that repeated interaction creates incentives to maintain reputation[26] and can therefore help overcome

[26] Here the term "reputation" is used—somewhat loosely, but consistently with the use in some of the literature—to refer to policy credibility in the context of a game of complete information. (For a discussion of reputation in games of incomplete information, see, for example, Fudenberg and Tirole [1996].)

policy credibility problems, or at least mitigate them.[27] As described in Stokey (1989), when the interaction between each government and its domestic investors is repeated indefinitely, time-inconsistency policy problems can be solved by the use of "trigger" punishment strategies involving a permanent reversion by the private sector to the expectation of future inefficient policies:[28] the idea is simply that, if reneging on a policy promise—even only once—entails a permanent loss of credibility, the prospect of future losses can be sufficient to prevent a forward-looking government from going back on its promises.

The notion that, under repeated interaction between countries, the threat of punishment can be used in support of international cooperation has also been independently invoked in the international economics literature to rationalize the existence of international policy coordination agreements, which, in the absence of exogenous enforcing mechanisms, must be interpreted as being self-enforcing. Intuitively, an agreement to bind policy at the efficient level can be enforced if the one-time gain from cheating on the agreement is sufficiently small relative to the discounted future cost of a "policy war" that would be triggered as a consequence.[29]

In the problem we are analyzing, if repeated interaction takes place, both of the above reputation mechanisms are at work. In order to examine the two-way relationship between the domestic policy credibility problem and the international cooperation problem under repeated interaction, we shall focus on a dynamic version of the problem, namely a repeated game where the sequence of choices described in the previous section is repeated indefinitely. We want to study the conditions under which a common choice of the optimal tax level, t^C, can be supported as part of a subgame-perfect equilibrium in Nash-reversion punishment strategies, whereby any deviation from a common tax is followed by permanent reversion to the Nash equilibrium level of tax of the stage game.[30]

Consider then a situation where both governments select a tax t^C and punish deviations from t^C by permanent reversion to t^{NC}. If they both keep to this choice of strategy, the tax level in both countries will be t^C in all periods. If now the government in one country contemplates a deviation from t^C in a certain period, such deviation would lie off the path of play anticipated by all the other players; thus, unlike in the static analysis

[27] This argument was first formulated by Selten (1975).

[28] Since investment projects are assumed to last only one period, private agents are effectively finitely-lived players; nevertheless, their investment choices can be made to depend on past history.

[29] The first paper to apply this idea to model international policy cooperation is Dixit (1987).

[30] We follow, among others, Bagwell and Staiger (1997), Maggi (1999), and Ederington (2001a,b) in focusing on Nash-reversion punishment. In the Appendix, we also discuss the use of alternative, non-stationary, subgame-perfect punishment schemes that can support more severe punishment (as in Abreu [1988]).

of Section 2, a deviation from t^C in a certain period would not have been anticipated by investors in the previous period. This implies that the ex-post optimal tax by a deviating government would be equal to $\hat{t}(t^C)$. Therefore, if the government deviates optimally from t^C, it will experience a payoff $\hat{\Pi}(\hat{t}(t^C), t^C, V(t^C))$, which exceeds the cooperative payoff $\Pi(t^C, t^C, V(t^C)) = \Pi(t^C, V(t^C))$. The source of the temptation to deviate is twofold: (i) since a fraction α of the benefits from emission abatement accrue to the other country, deviating from the optimal tax generates a resource savings in excess of the associated environmental cost for the deviating country; moreover, (ii) since private abatement responses are constrained by the installed capacity, the government can lower the tax—and thus reduce the associated distributional cost—with little effect on abatement.

A deviation from t^C by the government, however, would trigger indefinite reversion to noncooperation, i.e. the other government would cease to select polices cooperatively and, at the same time, investors in each country would mistrust their governments forever. This course of action—with tax levels in the reversion phase being fully anticipated by investors—results in the lowest possible equilibrium level of taxation in all periods of the continuation game; since payoffs are monotonically increasing in the tax, this represents the worst punishment that can be administered through a stationary punishment strategy in the continuation game. The associated payoff is $\Pi(t^{NC}, V(t^{NC}))$, which is less than the cooperative payoff $\Pi(t^C, V(t^C))$.

Then a common choice of t^C can be supported by Nash-reversion punishment strategies as long as

$$\hat{\Pi}(\hat{t}(t^C), t^C, V(t^C)) - \Pi(t^C, V(t^C)) \leq \frac{\delta}{1-\delta}\left[\Pi(t^C, V(t^C)) - \Pi(t^{NC}, V(t^{NC}))\right], \quad (15)$$

where δ is the factor by which both governments discount future payoffs.[31]

The above inequality yields a minimum critical discount factor, δ^{NC}, above which t^C can be supported ("NC" stands for "no coordination"):

$$\delta^{NC} = \frac{\hat{\Pi}(\hat{t}(t^C), t^C, V(t^C)) - \Pi(t^C, V(t^C))}{\hat{\Pi}(\hat{t}(t^C), t^C, V(t^C)) - \Pi(t^{NC}, V(t^{NC}))}. \quad (16)$$

It is useful to examine first the limiting cases where only one type of miscoordination is present: (i) $\alpha = 0$, $\theta > 0$, where the only coordination problem is between each

[31] An alternative way of looking at how partial coordination affects repeated strategic interaction is to focus on the most cooperative tax level that can be supported for a given δ. In our model, due to the monotonicity properties of the deviation and punishment payoffs, the two approaches are equivalent: a fall in the critical discount factor, for a given cooperative tax, implies that governments would be able to support a higher cooperative tax, for a given discount factor. However, solving for the minimum discount factor that can support full cooperation greatly simplifies the analysis when strategies must satisfy a renegotiation-proofness requirement (which is the focus of the next section).

government and its investors; and (ii) $\alpha > 0$, $\theta = 0$, where the only coordination problem is between governments.

In case (i), it can be shown that the minimum discount factor δ^{HC} for which t^C can be supported by the use of Nash-reversion punishment strategies ("HC" stands for "horizontal coordination" between governments) lies between zero and unity (Lemma 1 in the Appendix). Thus, policy credibility can be supported by repeated interaction between the government and the investors without relying on international agreements, as long as the government places a sufficiently high weight on the future.

In case (ii), due to the linearity of environmental damage function and the quadratic abatement costs, one can verify that the one-period deviation gain, $\hat{\Pi}(\hat{t}(t^C), t^C, V(t^C)) - \Pi(t^C, V(t^C))$, and the loss experienced in every period thereafter, $\Pi(t^C, V(t^C)) - \Pi(t^{NC}, V(t^{NC}))$, are both equal to $\alpha^2\mu^2/(2\phi)$. Therefore (15) gives

$$\delta^{VC} = \frac{1}{2}, \tag{17}$$

(where "VC" stands for "vertical coordination" between government and investors). Thus, in the absence of a domestic commitment problem, the sustainability of international cooperation does not depend on the size of the pollution spillovers, as long as these are nonzero. This feature of our model makes it easier to identify how the two different coordination problems interact with each other: if, for $\theta > 0$, a change in α produces a certain effect on δ^{NC}, this effect can be attributed to the interaction between α and θ rather than to a direct effect of α on the sustainability of international policy coordination.

In both cases (i) and (ii), where only one form of miscoordination is completely absent, eliminating the other makes it always possible to support t^C without restriction on the degree of impatience (i.e. even for $\delta = 0$). However, this is not generally the case when some degree of miscoordination remains—as can be seen by comparing cases (i) and (ii) with a case where both forms of miscoordination are present, i.e. $\alpha > 0$, $\theta > 0$ (we shall refer to this as case (iii)).

Consider, first, the comparison between cases (i)—$\alpha = 0$, $\theta > 0$—and (iii)—$\alpha > 0$, $\theta > 0$. It can be shown that, when vertical miscoordination cannot be fully eliminated ($\theta > 0$), the relationship between the critical discount rate, δ^{NC}, and the spillover parameter, α, is ambiguous:

Proposition 2 *When $\theta > 0$, the minimum discount factor for which a globally optimum level of taxation, t^C, can be supported interaction in a subgame-perfect equilibrium by the threat of Nash reversion for $\alpha > 0$ can be greater than or smaller than the corresponding value for $\alpha = 0$.*

Proof: see Appendix.

In some cases eliminating the spillover—or equivalently, a binding horizontal coordination agreement, represented by a move from $\alpha > 0$ to $\alpha = 0$—reduces each country's temptation to lower its taxes, free riding on the other country's policies, and thus helps to support optimal levels of taxation; then an international binding agreement ($\alpha = 0$) makes it easier to sustain efficient policies; and conversely, the need to support international cooperation through a self-enforcing agreement ($\alpha > 0$) would make it more difficult to do so. In other cases the presence of a positive level of spillover ($\alpha > 0$) can make it easier to support efficient policies. A positive α makes defections more tempting, but this effect is partially offset by the fact that some of the costs associated with achieving a globally optimal level of abatement along the equilibrium path of play are sunk. At the same time, a positive α can also make the punishment for defecting more severe, and this latter effect can dominate the former. When this happens, it is the very need to support international cooperation by repeated interaction that can help sustain efficient policies.[32] In these cases, the presence of transboundary spillovers can help solve the domestic policy credibility problem; we can then say that an international self-supporting international agreement ($\alpha > 0$) would make it easier to sustain optimal levels of taxation, whereas a binding agreement ($\alpha = 0$) would not.

If we restrict our attention to a neighborhood of the limiting case $\alpha = 0$, $\theta > 0$, the conditions under which a self-enforcing agreement can be helpful to overall cooperation have a simple characterization:

Proposition 3 *For $\theta > 0$, a necessary and sufficient condition for δ^{NC} to be decreasing in α, for α approaching zero, is $kt^C/(kt^C + \beta\phi) < \theta < 1 - \beta\phi/\mu$.*

Proof: see Appendix.

Under the conditions stated in Proposition 3, if the spillover is sufficiently small (α is sufficiently close to zero), we have $\delta^{NC} < \delta^{HC}$—horizontal miscoordination can help support efficient policies. For this to occur, θ must lie within a certain range, i.e. the policy credibility problem must be significant but not too severe.

Similarly, if we compare cases (ii)—$\alpha > 0$, $\theta = 0$—and (iii)—$\alpha > 0$, $\theta > 0$—we can show that, for $\alpha > 0$, increasing θ from $\theta = 0$ has an ambiguous effect on the prospects for supporting efficient policies:[33]

Proposition 4 *When $\alpha > 0$, the minimum discount factor for which a globally optimum level of taxation, t^C, can be supported under repeated interaction in a subgame-perfect*

[32] This can occur even when the international cooperation problem, when looked at in isolation, is more difficult to overcome than the policy credibility problem, i.e. when $\delta^{HC} > \delta^{VC} = 1/2$.

[33] Notice that in our model any positive value of θ produces a discrete jump in comparison with the case $\theta = 0$: with $\theta = 0$ and $\alpha = 0$, the minimum value of δ that makes supporting t^C possible is always $\delta = 0$. Thus, for $\alpha = 0$, a move from $\theta = 0$ to $\theta > 0$ always results in a higher minimum δ.

equilibrium by the threat of Nash reversion for $\theta > 0$ can be greater than or smaller than the corresponding value for $\theta = 0$.

Proof: see Appendix.

In some cases binding domestic policy commitment—represented by a move from $\theta > 0$ to $\theta = 0$—can help support efficient policies because it reduces the short-run temptation to deviate to lower taxes in order to meet distributional objectives; then, binding mechanisms of domestic policy commitment ($\theta = 0$) can make it easier to sustain efficient policies; and, conversely, the need to sustain policy reputation ($\theta > 0$) would make it more difficult to do so. In other cases a positive θ can make it easier to support optimal levels of taxation, both because it makes the punishment for deviations more severe and because it disrupts coordination between each government and its domestic investors: under repeated interaction defections to unilateral optimal tax choices from a cooperative path are not anticipated by investors; some of costs associated with the cooperative level of abatement the efficient level of tax are thus sunk, which can make defections less attractive. Here, it is the very need to sustain policy reputation by repeated interaction with the investors ($\theta > 0$) that can help sustain efficient policies. In these cases, the presence of a domestic policy credibility problem can help to solve the international policy coordination problem; we can then say that self-supporting, domestic policy reputation ($\theta > 0$) would make it easier to sustain international cooperation, whereas binding policy commitment ($\theta = 0$) would not.

If we focus on a neighborhood of the limiting case $\theta = 0$, we obtain a sharper prediction:

Proposition 5 *For $\alpha > 0$ and for θ approaching zero, δ^{NC} is decreasing in θ.*

Proof: see Appendix.

If the size of the capital-intensive sector spillover is sufficiently small (θ is sufficiently close to zero), vertical miscoordination always helps support efficient policies.

It is well understood that in noncooperative games partial coordination amongst a subset of players can give rise to a more inefficient noncooperative outcome.[34] Here we focus on cooperation rather than noncooperation; nevertheless, self-supporting cooperation is the result of noncooperative interaction. Thus, our analysis can be thought of as providing a counterpart of that general principle in a setting with repeated interaction, where cooperative choices must be supported by noncooperative equilibrium strategies: partial coordination does not necessarily improve prospects for overall coordination.

[34] Krugman (1991), for example, applies this idea to preferential international trade policy coordination, and shows that the simultaneous formation of customs unions lowers welfare.

In the policy game we are analyzing, the two different forms of miscoordination operate in the same direction, and thus partial coordination always results in more efficient policies within a single round of interaction. Nevertheless, when the game is repeated indefinitely, partial binding coordination can become counterproductive. Under repeated interaction, lack of domestic policy commitment can facilitate international cooperation because it can make deviations by a country less tempting. International policy spillovers can help because they can generate a larger vertical miscoordination cost during deviations and because they make it possible to leverage on this vertical miscoordination effect by way of horizontal punishment.[35] Note that it is even possible for both effects to operate simultaneously in the same scenario, i.e. for both an increase in α and an increase in θ to result in a lower δ^{NC}.[36]

4 Renegotiation-Proof Equilibria

Although Nash reversion represents a credible threat—since playing t^{NC} indefinitely is always an equilibrium strategy in the continuation game—it may be considered implausible: if players can support a more efficient tax, then, following an act of defection, why would they not choose to forgo punishment and instead re-coordinate to an equilibrium of the continuation game that gives them all a higher continuation payoff?[37] The potential lack of plausibility of Nash-reversion punishment becomes particularly apparent when we simultaneously consider two different forms of miscoordination—as we do here—making it possible for punishment to be cross-linked.[38] Such cross-punishment can imply implau-

[35] The effect of vertical miscoordination on deviations applies not just to first-round deviations but also to deviations from a stated course of punishment, if cooperation between the punisher and the defector is required during the punishment phase. Nash-reversion punishment strategies do not rely on this type of cooperative punishment, but other types of punishment strategies might do so in order to maximize the punishment that can be administered (e.g., the renegotiation-proof strategies described in Section 4, or Abreu's [1988] "optimal penal codes"); with this type of strategies, a larger spillover is even more likely to help. See the Appendix for a discussion of the case of non-stationary punishment strategies.

[36] For example, for α close to zero, it is always possible to find a θ and a k small enough that the conditions of Propositions 3 and 5 are met, so that δ^{NC} is decreasing in both α and θ.

[37] In international trade, countries have sometimes chosen to forgo retaliation even when this was sanctioned by international trade institutions. For example, the US did retaliate against the EU in the case of measures concerning meat and meat products, where the WTO had fixed sanctions to the relatively small amount of US\$116.8 million per year; however, it seems unlikely that the EU will retaliate against the US in the case of the tax breaks granted to foreign sales corporations, where the WTO has allowed the record amount of retaliation of US\$4 billion per year. This is because—as the US trade representative Robert Zoellick puts it—carrying out the threat "would be like dropping a nuclear bomb on the trade system".

[38] In this respect, our analysis presents some similarities with Ederington (2001a), who looks at the

sible threats: if, for example, the policy credibility problem, when taken in isolation, is comparatively less severe than the international cooperation problem, then, when the two problems are combined, the comparatively more severe punishment associated with the loss of policy credibility can be used to boost prospects for international cooperation. Yet, such linked threat does not appear plausible precisely because, in such a scenario, policy reputation can easily be sustained.

In order to deal with this type of objection, Farrell and Maskin (1989) have proposed the notion of renegotiation-proof equilibrium for infinitely repeated games. The argument underlying this refinement is that the only plausible equilibrium strategies are those that yield Pareto-undominated continuation equilibria in all relevant subgames, thus eliminating incentives for players to jointly renegotiate a switch to different strategies upon entering the punishment phase. This means that the only punishment strategies that are plausible are those which give some of the players a higher continuation payoff, once punishment is triggered, than the payoff they would obtain by renegotiating a reversion to cooperation jointly with the defector.

In the problem under analysis, the set of players includes the two countries' governments as well as private investors; the effect of punishment strategies on investors' payoffs must thus also be taken into account in the characterization of renegotiation-proof strategies. This rules out punishment strategies involving a reversion to the no-commitment tax, t^{NC}: if the government can sustain reputation to begin with, why would it not choose to revert to the "reputation" tax level $t^{VC} = (1-\alpha)\mu - \beta\phi$ given that this gives all players (the investors as well as both governments) a higher continuation payoff?

It can be shown that the following strategy profile is renegotiation proof: each country plays t^C as long as the other country does the same; if country i defects in a given period (and country j does not), then country j (the punisher) will play t^{VC} until the defector country i (the defector) reverts to t^C; as soon as country i has repented by playing t^C, country j forgives the initial defection and returns to playing t^C.[39] The conditions for such a strategy to be a subgame perfect, renegotiation-proof equilibrium strategy are:

$$\hat{\Pi}(\hat{t}(t^C), t^C, V(t^C)) - \Pi(t^C, V(t^C)) \leq \delta(\Pi(t^C, V(t^C)) - \Pi(t^C, V(t^{VC}))), \tag{18}$$

$$\hat{\Pi}(\hat{t}(t^C), t^C, V(t^{VC})) - \Pi(t^C, V(t^{VC})) \leq \delta(\Pi(t^C, V(t^C)) - \Pi(t^C, V(t^{VC}))), \tag{19}$$

$$\Pi(t^{VC}, V(t^C)) \geq \Pi(t^C, t^C). \tag{20}$$

linkage between two policy instruments affecting one dimension of horizontal strategic interaction (trade), and with Ederington (2001b), who looks at the linkage between two dimensions of horizontal strategic interaction (trade and environment).

[39] This characterization of renegotiation-proof punishment strategies calls into play a number of technical issues, which are discussed in the Appendix.

The first condition states that the one-shot gain from defection must be less than the discounted one-shot punishment cost that will be experienced by the defecting country. The second condition states that reversion must be optimal for the defecting country after a single period of punishment, i.e. it must not be tempting to postpone repentance.[40] The last condition states that the punisher must be better off during punishment than under cooperation. This last condition is what especially distinguishes a renegotiation-proof equilibrium. As in the Nash-reversion case, unilateral deviations from the stated strategies "surprise" domestic investors; however, in the case of renegotiation-proof punishment strategies, two types of such deviations are relevant: deviations from t^C during the cooperative phase (represented by the defection payoff $\hat{\Pi}(\hat{t}(t^C), t^C, V(t^C))$ in (18)), and deviation from "repentance" during in the punishment phase (represented by the "no-repentance" payoff $\hat{\Pi}(\hat{t}(t^C), t^C, V(t^{VC}))$ in (19)).

Condition (20) is always trivially satisfied, so we can restrict our attention to conditions (18) and (19). Notice that, with linear damage the difference $\hat{\Pi}(\hat{t}(t^C), t^C, V) - \Pi(t^C, V)$ is independent of V. It follows that (18) and (19) are equivalent. We can thus directly use condition (18) to solve for the minimum discount factor that allows the two countries to sustain cooperation:

$$\delta^{NC} = \frac{\hat{\Pi}(\hat{t}(t^C), t^C, V(t^C)) - \Pi(t^C, V(t^C))}{\Pi(t^C, V(t^C)) - \Pi(t^C, V(t^{VC}))}. \tag{21}$$

Renegotiation-proofness imposes a more stringent plausibility requirement on punishment threats than subgame perfection alone does: it removes the non-credible threat of indefinite reversion to the no-reputation tax, t^{NC}, and only allows for a less severe but more plausible punishment strategy between countries. As a consequence, it can be shown that the minimum discount factor for which a globally optimum level of taxation can be supported under repeated interaction by renegotiation-proof punishment strategies is always smaller than the corresponding minimum discount factor for the case of Nash-reversion strategies (Lemma 2 in the Appendix).

Proceeding as we did in Section 4 for the Nash-reversion case, we can first focus on situations where only one form of miscoordination is present. When only the domestic commitment problem is present ($\alpha = 0$ and $\theta > 0$), it is straightforward to see that there are no credible punishment strategies giving investors (the punisher) a higher continuation payoff, once punishment is triggered, than the payoff they would obtain by renegotiating a reversion to cooperation jointly with the government (the defector). It follows that no degree of patience is high enough to solve the domestic policy credibility problem

[40] This condition is required for the strategy followed by the punished player to be subgame perfect in the continuation game. Notice that, if t^C can actually be sustained in a subgame-perfect equilibrium of the continuation game, reversion to anything higher or lower could not be part of a renegotiation-proof strategy.

(i.e. $\delta^{HC} = \infty$). On the other hand, when only the international coordination problem is present (i.e., $\alpha > 0$ and $\theta = 0$), we obtain, as in the Nash-reversion case, $\delta^{VC} = 1/2$.[41] Thus, imposing a renegotiation-proofness requirement does not affect conclusions with respect to the sustainability of international cooperation, when this is considered in isolation from the policy credibility problem.

In light of the above, if we compare a scenario where both coordination problems are present ($\theta > 0$, $\alpha > 0$) with a situation where only vertical miscoordination remains ($\theta > 0$, $\alpha = 0$), then we conclude that binding horizontal coordination always makes the efficient policies more difficult to sustain (since, for $\alpha = 0$, t^C cannot be supported by any level of patience). With respect to a neighborhood of the limiting case $\alpha = 0$, Proposition 2 above established that, when equilibrium taxes can be enforced by the use of Nash-reversion punishment strategies, an increase in transboundary spillovers *might* help to solve to the domestic commitment problem. The same conclusion applies to a scenario punishment strategies must satisfy the renegotiation-proofness requirement; however, it can be shown that in this case, an increase in the spillover from $\alpha = 0$ will *always* have such an effect:

Proposition 6 *For $\theta > 0$ and α approaching zero, the minimum discount factor for which a globally optimum level of taxation, t^C, can be supported in equilibrium by the use of renegotiation-proof punishment strategies is always decreasing in α.*

Proof: see Appendix.

Thus, unlike in the Nash-reversion case, for α sufficiently small, an increase in α *always* raises the punishment more than it does the temptation. The intuition for this result is that for $\theta > 0$ a larger spillover involves comparatively larger costs of surprising investors—as in the Nash-reversion case. At the same time, in the renegotiation-proof case, reversion to the no-commitment, tax t^{NC}, is not a plausible threat, and therefore the positive effect of a larger α on the punishment plays a comparatively more important role than it does in the Nash-reversion case.

If we next compare a scenario where both coordination problems are present ($\theta > 0$, $\alpha > 0$) with a situation where only horizontal miscoordination remains ($\theta = 0$, $\alpha > 0$), we find that the comparison is ambiguous (see Proposition 8 in the Appendix)—a result analogous to Proposition 4: as in the Nash-reversion case, domestic policy commitment can make it harder to sustain the efficient tax. Notice, however, that, unlike in the Nash-reversion case, the punishment from deviating from cooperation is now the same in the

[41] The single-period punishment $\Pi(t^C, V(t^C)) - \Pi(t^C, V(t^{VC}))$ is greater than the Nash-reversion punishment $\Pi(t^C, V(t^C)) - \Pi(t^{VC}, V(t^{VC}))$, but the latter is applied indefinitely. In the model, the former payoff difference is equal to twice the latter, and the latter difference is equal to the deviation gain. This implies $\delta^{VC} = 1/2$ as the in the trigger-strategy case.

commitment and no-commitment case. Thus, lack of commitment does not raise the punishment as it does in the Nash-reversion case. Nevertheless, as discussed above, lack of policy commitment implies that unilaterally optimal defections from cooperation can be larger but less effective, due to the costs of miscoordinating with the investors. Since such costs increase in α, it follows that if the international spillovers are high enough, it is easier to enforce an international environmental agreement in the absence of domestic commitment.

If θ is small enough, it can be shown that an increase in θ always lowers δ^{NC}—by the same arguments used to establish Proposition 5 for the Nash-reversion case. Together with Proposition 5, this result implies that, as long as vertical and horizontal miscoordination are not too severe (α and θ are both small but positive), they will work hand-in-hand to help support efficient policies, i.e. δ^{NC} is decreasing in both α and θ. Renegotiation proofness rules out vertical punishment, but not the effect of vertical miscoordination on horizontal punishment; in other words, with renegotiation-proof strategies, vertical miscoordination cannot be used as a direct threat, but must operate indirectly through the international spillover.

Imposing a plausibility requirement (renegotiation proofness) on the punishment strategies not only makes efficient policies more difficult to sustain, but also affects conclusions qualitatively. In the absence of spillovers—i.e. if a government faces its investors alone—no plausible form of punishment is available; this means that, as long as a vertical coordination problem is present, a binding international agreement will always be detrimental, whereas a self-enforcing agreement will make it easier to sustain efficient policies. Thus, imposing renegotiation proofness tends to skew results towards the conclusion that international spillovers can make it easier to overcome policy credibility problems, i.e. that policy credibility can be "imported" by a government from a self-enforcing agreement with a foreign partner, rather than the reverse.

5 Institution Design

Our previous discussion allows us to draw implications for the structure of institutions—not necessarily in a normative sense, but rather in the sense of what institutions would arise through the free choice of independent governments. There are, for example, a number of institutional commitment devices that governments could rely upon to achieve some degree of binding policy commitment—such as policy delegation or budgeting rules—many of which have been discussed in the literature.[42]

[42] The role of delegation of authority in monetary policy was first studied by Rogoff (1985b). Lucas and Stokey (1983) were first to study debt structure as a commitment device. Hence, the choice of whether or not to adopt a commitment technology may be viewed as being, to a certain extent, endogenous.

Suppose that in each period governments have the option of adopting a binding procedure by which taxes will be credibly committed to prior to investment decisions being made; alternatively, they can forgo commitment and leave the choice of tax to follow private investment choices.

Also suppose that the decisions of adopting such a procedure precede each round in which tax choices and investment decisions are made (i.e., countries can fully observe each other's institutional choice before selecting taxes). Then, focusing on Nash reversion, the one-shot no-commitment Nash equilibrium cannot be part of a subgame-perfect equilibrium punishment strategy, because in the case of a full breakdown of cooperation, unilateral commitment is a best response for both countries. This will limit the punishment that can be credibly administered to a defector.

Nevertheless, countries may adopt strategies which involve no commitment along the path of equilibrium play, and doing so may make it easier to support cooperation if it reduces the one-shot gain from reneging on cooperation. In turn, the adoption of the more effective procedure may be endogenously supported in equilibrium by punishment strategies dictating that, if one country deviates to the "wrong" procedural choice prior to selecting taxes, Nash reversion immediately ensues—even before taxes are selected.

As we have discussed earlier, the one-shot deviation gain with commitment can be greater or smaller than the corresponding deviation gain without commitment. If the former is larger than the latter; then, cooperation will be more easily supported by punishment strategies featuring policy commitment in the cooperation phase, whereas if the reverse is true, forgoing commitment will make it easier to support cooperation, and may endogenously be chosen in equilibrium. Since the Nash-reversion punishment is always the same independently of which procedure is used along the equilibrium path of play, the comparison between commitment and no commitment—in terms of their relative effectiveness at supporting efficient policies—only depends on the effect that commitment has on the one-shot deviation gain:

Proposition 7 *A necessary and sufficient condition for binding policy commitment to outperform policy discretion in supporting t^C is* $\Pi(t^C, V(t^C)) > \hat{\Pi}(\hat{t}(t^C), t^C, V(t^C))$.[43]

Such condition applies not only to Nash reversion but also to the renegotiation-proof case, since even then commitment only affects the minimum δ through its effect on the deviation incentives. Thus, even when a commitment technology is feasible, we may expect that in the presence of international spillovers, governments may willingly forgo policy commitment in order to maximize international cooperation chances.

A similar argument can be made with respect to the endogenous choice of a binding

[43] The relevant conditions on the parameters are the same as those described in the proof of Proposition 8 in the Appendix.

horizontal coordination arrangement.[44] But drawing such a parallel could be deceptive: while institutional devices for achieving domestic policy commitment may be available, no analogous institutional devices (short of political union) are available in the international arena, and self-enforcing agreements are arguably the only available mechanism for supporting policy coordination between countries.[45]

6 Conclusion

In this paper we have explored the two-way linkage between domestic policy credibility and international policy coordination. We have found that repeated interaction between countries can add a credible source of punishment that would otherwise not be available, making it possible to overcome the domestic commitment problem: thus, if policy discretion is retained, internationally uncoordinated policymaking can do better than a single decisionmaker can. At the same time, the need to maintain policy reputation through repeated interaction with the private sector can help support international cooperation, implying that not "tying one's hands" by means of binding commitment mechanisms can boost prospects for international cooperation.

We have developed our arguments with specific reference to environmental policies—a case where policy spillovers have a particularly simple structure—but they demonstrate a more general principle: under repeated interaction, partial binding coordination can be an obstacle to supporting efficient policies, independently of whether or not coordination is beneficial when interaction is not repeated. As a consequence, when policies must be self-enforcing, countries may voluntarily forgo the use of institutional mechanisms for achieving partial binding coordination even if these are available.[46]

[44] Under Nash-reversion punishment strategies, countries will always have an incentive to choose a horizontal coordination agreement, since lack of coordination can never result in lower deviation incentives (and the Nash-reversion payoff will be independent of institutional choices made along the equilibrium path of play). In the case of renegotiation-proof strategies, on the other hand, if countries cannot rely on a commitment technology, they may have an incentive to forgo binding horizontal coordination in equilibrium, since repeated interaction with a foreign partner is the only mechanism by which efficient policies can be sustained, and may be able to support such a choice.

[45] The majority of proposals for a World Environmental Organization—as reviewed by Lodefalk and Whalley (2002)—describe it as an institution for facilitating cooperation rather than as a binding arrangement.

[46] In relation to the specific debate on environmental policy and international environmental treaties, our analysis suggests that, although domestic environmental policy may suffer from a credibility problem, international environmental treaties—if they ever come into compliance—could also serve to help domestic policy making, reducing the need for direct commitment mechanisms, and possibly even making them undesirable. On the other hand, if international environmental policy cooperation fails to emerge, direct means of commitment might be called for and might be expected to arise; and once these are in place,

Is policy credibility imported or exported? The results of our theoretical analysis suggest that it can flow in both directions, but that whether domestic credibility is achieved by commitment mechanisms or is the result of reputation, and whether international agreements are binding or self-supporting are both crucial for how we answer this question. Thus, our interpretation of the pattern shown in Figure 1 hinges on how we interpret domestic policy credibility and international cooperation—as binding or as self-supporting. Under the latter interpretation, our analysis has shown that credibility can both be imported from a self-enforcing international agreement and exported from a government's ability to sustain reputation at home. Moreover, importing and exporting credibility are not reciprocally exclusive possibilities: self-enforcing international agreements and the need to sustain policy reputation can complement each other in helping to support overall coordination.

A number of issues are raised but not addressed by our analysis. For example, if international cooperation is multilateral, rather than bilateral, then the manner in which partial binding coordination affects countries' ability to support cooperative policies depends also on how it affects countries' ability to support coordinated punishment strategies—an aspect that is absent in our two-country analysis. Also, our analysis has not addressed the implications of asymmetries between countries with respect to policy spillovers or with respect to the severity of the policy credibility problem they face.

References

Abreu, D. (1988). "On the Theory of Infinitely Repeated Games with Discounting" *Econometrica* 56, 383-396.

Bagwell, K., and R. Staiger (1997). "Multilateral Tariff Cooperation During the Formation of Regional Free Trade Areas," *International Economic Review* 38, 291-319.

Brunetti, A., G. Kisunko, and B. Weder (1998): "Credibility of Rules and Economic Growth: Evidence from a Worldwide Survey of the Private Sector," *World Bank Economic Review* 12, 353-384.

Cukierman, A. (1992). *Central Bank strategy, credibility and independence: Theory and evidence*, MIT Press, Cambridge, MA.

Dixit, A. (1987). "Strategic Aspects of Trade Policy," in Bewley, T. (ed.) *Advances in economic theory: Fifth World Congress*, Cambridge University Press, Cambridge, MA, 329-362.

DRI (1992). *Impact of a package of EC measures to control CO_2 emissions on European industry*, European Commission (DGXI).

Ederington, J. (2001a) "International Coordination of Trade and Domestic Policies," *American Economic Review* 91, 1580-1593.

international cooperation could be more difficult to secure.

Ederington, J. (2001b) "Global Environmental Agreements and Trade Sanctions," University of Miami, mimeo.

Farrell, J., and E. Maskin (1989). "Renegotiation in Repeated Games," *Games and Economic Behavior* 1, 327-360.

Fudenberg, D., and J. Tirole (1996). *Game theory*, MIT Press, Cambridge, MA., and London, UK.

Kehoe, P. (1989). "Policy Cooperation Among Benevolent Governments May Be Undesirable," *Review of Economic Studies* 56, 289-296.

Krugman, P. (1991). "Is Bilateralism Bad?" in Helpman, E., and A. Razin (eds.) *International trade and trade policy*, MIT Press, Cambridge, MA.

Kydland, F., and E. Prescott (1977). "Rules Rather Than Discretion: The Inconsistency of Optimal Plans," *Journal of Political Economy* 85, 473-491.

Laffont, J.-J., and J. Tirole. (1996) "Pollution Permits and Environmental Innovation," *Journal of Public Economics* 62, 127-140.

Lodefalk, M., and J. Whalley (2002). "Reviewing Proposals for a World Environmental Organisation," *The World Economy* 25, 601-617.

Lucas, R., and N. Stokey (1983). "Optimal Fiscal and Monetary Policy is an Economy without Capital," *Journal of Monetary Economics* 12, 53-93.

Maggi, G. (1999). "The Role of Multilateral Institutions in International Trade Cooperation," *American Economic Review* 89, 190-214.

Matsuyama, K. (1990). "Perfect Equilibria in a Trade Liberalization Game," *American Economic Review* 80, 480-492.

Organisation for Economic Co-operation and Development (1995). *Climate change, economic instruments and income distribution.* OECD, Paris.

Pearce, D., and E. Stacchetti (1997). "Time Consistent Taxation by a Government with Redistributive Goals," *Journal of Economic Theory* 72, 282-385.

Persson, T., and G. Tabellini (1994). *Monetary and fiscal policy, Volume I: Credibility*, MIT Press, Cambridge, MA.

Poterba, J. (1991). "Tax Policy to Combat Global Warming: On Designing a Carbon Tax, " in Dornbusch, R., and J.M. Poterba, (eds.), *Global warming : Economic policy responses*, MIT Press, Cambridge, MA.

Rogoff, K. (1985a). "Can International Monetary Policy Cooperation Be Counterproductive?" *Journal of International Economics* 14, 199-217.

Rogoff, K. (1985b). "The Optimal Degree of Commitment to an Intermediate Monetary Target," *Quarterly Journal of Economics* 100, 1169-1190.

Selten, R. (1975). "Reexamination of the Perfectness Concept for Equilibrium Points in Extensive Games," *International Journal of Game Theory* 4, 22-55.

Staiger, R.W. and G. Tabellini (1987). "Discretionary Trade Policy and Excessive Protection," *American Economic Review* 77, 823-837.

Stokey, N. (1989). "Reputation and Time Consistency," *American Economic Review, Papers and Proceedings* 79, 134-139.

Tornell, A. (1991). "On the Effectiveness of Made-to-Measure Protectionist Programs," in Helpman. E., and A. Razin (eds.), *International Trade and Trade Policy*, MIT Press, Cambridge, MA.

Van Damme, E. (1989). "Renegotiation-Proof Equilibria in Repeated Prisoners' Dilemma," *Journal of Economic Theory* 47, 206-217.

Appendix

Unilateral Ex-post Optimal Policies

The government's payoff, as a function of the current choice of tax, t, and of the tax foreseen ex ante by the private sector, $\tilde{t}$ (i.e. once $i = i(\tilde{t})$ is installed), can be written as

$$\begin{aligned}\hat{\Pi}(t,\tilde{t},V^*) &\equiv -\beta t + \mu(1-\alpha)n[(1-\theta)v(t) + \theta\hat{v}_k(t,\tilde{t})] + \mu\alpha V^* \\ &\quad -\frac{1}{2}n\psi[(1-\theta)v(t)^2 + \theta[(1-k)\hat{v}_k(t,\tilde{t})^2] - ni(\tilde{t}) \\ &= -\beta t + (1-\alpha)\mu\left[(1-\theta)(t/\phi) + \theta\min\{\tilde{t}/\phi, t/((1-k)\phi)\}\right] + \alpha\mu V^* \\ &\quad -(1/2)\phi\left((1-\theta)(t/\phi)^2 + \theta[(1-k)\min\{\tilde{t}/\phi, t/((1-k)\phi)\}^2 + k(\tilde{t}/\phi)^2]\right). \end{aligned} \tag{22}$$

The last term represents a sunk cost, which is independent of the current (second-period) choice of tax.

Given (22), the interior solution for the optimal choice of tax is $t' = (1-\alpha)\mu - \beta\phi/[(1-\theta)+\theta/(1-k)]$. The choice of capital-intensive firms, however, is constrained to be less than or equal to $v = \tilde{t}/\psi$ by the installed capacity. Given this constraint, the lowest tax that can support an abatement level $v = \tilde{t}/\psi$ by the capital-intensive firms is identified by the equality $\tilde{t}/\psi = t/[(1-k)\psi]$, which gives $t'' = (1-k)\tilde{t}$. Raising the tax above this level has no effect on the abatement choice of capital-intensive firms, but has a positive effect on the abatement choice of the other firms. Thus, for $t > t''$, the relevant first-order condition for an ex-post policy optimum is $-\beta + (1-\theta)n[(1-\alpha)\mu - t]/\psi = 0$, which gives $t''' = (1-\alpha)\mu - \beta\phi/(1-\theta)$. Then, if $t''' > t''$ the government will select $t = t'''$. If, however, $t''' < t''$, the government will select $t = t'$ if this is less than t''; otherwise, the government will select $t = t'$: by doing so, it can still secure an abatement level of $\tilde{t}/\psi$ by the capital-intensive firms while minimizing the distributional costs associated with the tax. Notice that, as long as the government's objective is concave in t, when $(1-\alpha)\mu - \beta\phi/[(1-\theta)+\theta/(1-k)] > (1-k)\tilde{t}$ we know that welfare will be increasing in t at $t = (1-k)\tilde{t}$, implying that t'' will be a constrained optimum for the government. We can therefore express the optimal ex-post tax as

$$\hat{t}(\tilde{t}) = \min\left\{t', \max\{t'', t'''\}\right\}. \tag{23}$$

For $\tilde{t} = t^C = \mu - \beta\phi$, we have three possible optimal deviation regimes:

1. $t'' < t''' < t' \rightarrow \hat{t}(t^C) = t'''$, if and only if $\alpha < \alpha_1$;
2. $t''' < t'' < t' \rightarrow \hat{t}(t^C) = t''$, if and only if $\alpha_1 < \alpha < \alpha_2$;
3. $t''' < t' < t'' \rightarrow \hat{t}(t^C) = t'$, if and only if $\alpha > \alpha_2$;

where

$$\alpha_1 \equiv \frac{\theta\beta\phi + k(\theta-1)(\mu-\beta\phi)}{(\theta-1)\mu}, \quad \alpha_2 \equiv \frac{\mu k[1+(\theta-1)k] + \beta\phi(\theta-1)(1-k)}{\mu[1+(\theta-1)k]}. \tag{24}$$

Lemma 1 *Under binding horizontal coordination ($\alpha = 0$), the minimum discount factor, δ^{HC}, for which a globally optimum level of taxation can be supported under repeated interaction by Nash-reversion punishment strategies lies between zero and one.*

Proof: When $\alpha = 0$, the minimum discount factor for which a globally optimum level of taxation can be supported under repeated interaction is equal to

$$\delta^{HC} = \frac{\hat{\Pi}(\hat{t}(t^C), t^C, V(t^C)) - \Pi(t^C, V(t^C))}{\hat{\Pi}(\hat{t}(t^C), t^C, V(t^C)) - \Pi(t^{NC}, V(t^{NC}))}, \tag{25}$$

where $t^C = \mu - \beta\phi > t^{NC} = \mu - \beta\phi/(1-\theta)$. Since $\hat{\Pi}(\hat{t}(t^C), t^C, V(t^C)) > \Pi(t^C, V(t^C)) > \Pi(t^{NC}, V(t^{NC})) > 0$, the numerator in (25) is always smaller than the denominator, and both are positive, implying $0 < \delta^{HC} < 1$. □

Proof of Proposition 2

This proof is by example. Proposition 3 below describes conditions under which $\delta^{HC} > \delta^{NC}$. Consider instead the case where $1 - \beta\phi/\mu < \theta < kt^C/(kt^C + \beta\phi)$, implying $\hat{t}(t^C) = t'''$ and $t^{NC} = 0$. In this case, the derivative of δ^{NC} with respect to α, for α approaching zero, is

$$\left(\frac{\partial\delta^{NC}}{\partial\alpha}\right)_{\alpha\rightarrow 0} = \frac{2\theta\mu\beta\phi(\theta-1)^2(t^C)^2}{\left[\mu^2(\theta-1) - 2\mu\beta\phi(\theta-1) + \beta^2\phi^2(\theta-\theta^2-1)\right]^2} > 0, \tag{26}$$

implying $\delta^{HC} < \delta^{NC}$. □

Proof of Proposition 3

For α approaching zero, there are only two possible optimal deviation regimes: in the first regime, $\hat{t}(t^C) = t'''$ and

$$\theta < \frac{k(\mu-\beta\phi)}{k\mu + \beta\phi - \beta\phi k}; \tag{27}$$

in the second regime, $\hat{t}(t^C) = t''$ and

$$\theta > \frac{k(\mu-\beta\phi)}{k\mu + \beta\phi - \beta\phi k}. \tag{28}$$

In the first regime, the deviation payoff $\hat{\Pi}(\hat{t}(t^C), t^C, V(t^C))$ increases with α, the cooperation payoff $\Pi((t^C), V(t^C))$ is independent of α, and the Nash-reversion payoff $\Pi(t^{NC}, V(t^{NC}))$ decreases with α—if $t^{NC} > 0$—or is independent of α—if $t^{NC} = 0$. Therefore, (16) can be written as

$$\delta^{NC} = \frac{f(\alpha) - \Psi}{f(\alpha) - g(\alpha)}, \tag{29}$$

with $f'(\alpha) > 0$, $g'(\alpha) \leq 0$, and $f(\alpha) > \Psi > g(\alpha)$. This implies that the numerator in (29) always increases in α by more than the denominator does, and so $\partial\delta^{NC}/\partial\alpha > 0$. In the second regime, when $kt^C/(kt^C + \beta\phi) < \theta < 1 - \beta\phi/\mu$, we have $\hat{t}(t^C) = t''$ and $t^{NC} > 0$. In this case, the deviation payoff $\hat{\Pi}(\hat{t}(t^C), t^C, V(t^C))$ is independent of α, but the Nash-reversion payoff $\Pi(t^{NC}, V(t^{NC}))$ is decreasing in α, implying $\partial\delta^{NC}/\partial\alpha < 0$. □

Proof of Proposition 4

This proof is by example. When $\theta = 0$, we have $\Pi(\hat{t}(t^C), t^C, V(t^C)) - \Pi(t^C, V(t^C)) = \Pi(t^C, V(t^C)) - \Pi(t^{NC}, V(t^{NC})) = \alpha^2\mu^2/(2\phi)$, implying $\delta^{VC} = 1/2$. For θ approaching zero, δ^{NC} falls with θ:

$$\left(\frac{\partial\delta^{NC}}{\partial\theta}\right)_{\theta\to 0} = -\frac{\alpha\mu(\alpha\mu - 2\beta\phi)(t^C)^2}{\left[(1+\alpha^2)\mu^2 - 2\mu\beta\phi + \beta^2\phi^2\right]^2} < 0, \tag{30}$$

implying $\delta^{NC} < \delta^{VC} = 1/2$. For θ approaching unity, δ^{NC} increases with θ:

$$\left(\frac{\partial\delta^{NC}}{\partial\theta}\right)_{\theta\to 1} = \frac{(t^C)^2}{\beta^2\phi^2} > 0, \tag{31}$$

and, for a broad range of parameter values, we have $\delta^{NC} > \delta^{VC} = 1/2$; for example, under parameterizations for which $t^{NC} = 0$, as θ approaches unity, δ^{NC} also tends to unity. □

Proof of Proposition 5

For $\alpha > 0$ and θ arbitrarily close to zero, t' is arbitrarily close to t''', and both are arbitrarily close to $(1-\alpha)\mu - \beta\phi$; then, since t'' is only selected if it lies between t' and t''', we can conclude that $\hat{t}(t^C)$ will be arbitrarily close to $(1-\alpha)\mu - \beta\phi$. We have shown that with quadratic costs and linear damage the gain to deviating to $(1-\alpha)\mu - \beta\phi$ is the same as the loss from both countries reverting to that level, if no costs are sunk (proof of Proposition 4). If some of the costs are sunk, however, the deviation gain is less than the cost of Nash reversion; hence for θ approaching zero, we have $\delta^{NC} < 1/2$. □

Renegotiation-Proof Punishment Strategies

Van Damme (1989) has shown that the following strategy profile are renegotiation proof: each country plays cooperatively as long as the other country plays cooperatively. If country i defects in a given period (and country j does not), then player j will defect until country i plays cooperatively. As soon as country i has repented by playing cooperatively, country j forgives the initial defection and returns to playing cooperatively.

Van Damme's arguments are developed for the infinitely repeated prisoner dilemma with a discrete strategy space. In such case, the strategy that inflicts the maximum punishment on the defector while ensuring that the punisher is better off than under unbroken cooperation involves the punisher playing her one-shot best response against the defector during the punishment phase, and the defector adopting a tax t^C in excess of her own best response.

With a continuous and unrestricted strategy space, it may be possible to inflict more severe punishment through punishment strategies prescribing that the defector adopt a "repentance" tax, t^R, in excess of t^C—which would then replace t^C in conditions (18) and (19). In our model specification, however, linear damage implies that deviation gains are independent of the level of tax in the other country; furthermore, such gains are monotonically increasing in the tax level from which deviations take place. Hence, since the right-hand sides of (18) and (19) are the same, equality of the left-hand sides implies that the repentance tax must be equal to t^C.

As discussed in the text, a punishment strategy prescribing that the punishing country adopt a tax t^{NC} in the punishment phase is not renegotiation-proof, because all players would benefit from a coordinated move to an alternative punishment strategy featuring t^{VC} instead. Such alternative strategy would always be a subgame-perfect equilibrium strategy of the continuation game, as the following argument demonstrates. Suppose that deviations from t^{VC} to t^{NC} by the punishing country are punished by indefinite Nash reversion; then, if t^C can be supported by a renegotiation-proof punishment strategy, it can also be supported by a Nash-reversion punishment strategy (Lemma 2), and so can $t^{VC} < t^C$.

When δ is sufficiently small, then it may be feasible (in the renegotiation-proof sense) and optimal for punishment to last more than one period. In these cases, the expression we derive in (21) overestimates the minimum discount factor for which efficient policies can be supported by renegotiation-proof punishment strategies. Nevertheless, even in the case of multi-period punishment, vertical miscoordination will have an analogously ambiguous effect on the deviation incentives

Lemma 2 *The minimum discount factor δ^{NC} for which a globally optimum level of taxation can be supported by Nash-reversion punishment strategies under repeated interaction is always smaller than the corresponding discount factor when renegotiation-proof punishment strategies are used.*

Proof: In the case of Nash-reversion punishment strategies, δ^{NC} is defined by (16), whereas in the case of renegotiation-proof punishment strategies, δ^{NC} is defined by (21). The two expressions have the same denominator. Notice that $\hat{\Pi}(\hat{t}(t^C), t^C, V(t^C)) - \Pi(t^{NC}, V(t^{NC})) = \Upsilon + \alpha\mu(V(t^C) - V(t^{NC}))$—with Υ being the difference between the deviation and Nash-reversion payoffs, excluding the foreign term—while $\Pi(t^C, V(t^C)) - \Pi(t^C, V(t^{VC})) = \alpha\mu(V(t^C) - V(t^{VC}))$. Since $\Upsilon > 0$ and $V(t^{NC}) < V(t^{VC})$, it follows that the denominator in (16) is larger than the denominator in (21). □

Proof of Proposition 6

As shown in the Proof of Proposition 3, when α tends to zero, the optimal deviation tax is either t'' or t''', depending on where θ lies. As in the Nash-reversion case, when t'' and $t^{NC} > 0$, the deviation payoff $\hat{\Pi}(\hat{t}(t^C), t^C, V(t^C))$ is independent of α, but the Nash-reversion payoff

$\Pi(t^{NC}, V(t^{NC}))$ is decreasing in α, implying $\partial\delta^{NC}/\partial\alpha < 0$. However, unlike in the Nash-reversion case, an increase in the international spillover also helps when the deviation tax is $\hat{t}(t^C) = t''$, since in this regime the critical discount factor always falls with α:

$$\frac{\partial\delta^{NC}}{\partial\alpha} = -\frac{\beta\theta\phi[\alpha\mu(1-\theta) + \beta\theta\phi]}{\alpha^3\mu^2(1-\theta)} < 0. \tag{32}$$

□

Proposition 8 *When $\alpha > 0$, the minimum discount factor for which a globally optimum level of taxation, t^C, can be supported by renegotiation-proof punishment for $\theta > 0$ can be greater than or smaller than the corresponding value for $\theta = 0$.*

Proof: In the renegotiation-proof case, the only difference between δ^{NC} and δ^{VC} comes from the deviation incentives. In the case of vertical coordination (i.e. $\theta = 0$), the deviation payoff is

$$\Pi(t^{VC}, V(t^C)) = \frac{(1-\alpha^2)\mu^2 - 2\mu\beta\phi + \beta^2\phi^2}{2\phi}. \tag{33}$$

Sufficient conditions the deviation gain to be larger with no commitment ($\theta > 0$) are:

1. for the regime where $\hat{t}(t^C) = t'''$,

$$\alpha < \alpha_1, \qquad \theta > \theta_1 \equiv \alpha\mu(\alpha\mu - 2\beta\phi)/(\alpha^2\mu^2 - 2\alpha\mu\beta\phi + \beta^2\phi^2); \tag{34}$$

2. for the regime where $\hat{t}(t^C) = t''$,

$$\alpha_1 < \alpha < \alpha_2, \qquad \theta > \theta_2 \equiv \frac{(\alpha\mu - k\mu + k\beta\phi)^2}{k(\mu-\beta\phi)(-2\alpha\mu + k\mu + 2\beta\phi - k\beta\phi)}; \tag{35}$$

3. for the regime where $\hat{t}(t^C) = t'$,

$$\alpha > \alpha_2, \qquad \theta > \theta_3 \equiv \frac{(k-1)\Big[-2\alpha\mu^2 + \alpha^2\mu^2 + (\mu-\beta\phi)\big(2\beta\phi + k(\mu-\beta\phi)\big)\Big]}{k\Big[-2\alpha\mu^2 + \alpha^2\mu^2 + k(\mu-\beta\phi)^2 + \beta\phi(2\mu-\beta\phi)\Big]}. \tag{36}$$

□

Non-stationary Subgame-Perfect Punishment Strategies

Abreu (1988) has shown that indefinite Nash reversion is not necessarily the most effective subgame-perfect punishment strategy. If punishment is concentrated in the periods that immediately follow defection, the prospect of increased future cooperation may be used to induce the non-defector to punish the defector more harshly.

Consider the following punishment strategy. Each country plays t^C as long as the other country does the same. If country i defects in period z (and country j does not), then in period $z+1$ country i plays t^C and country j plays $t^P < t^{NC}$. If they both do this in period $z+1$, they both revert to t^C from period $z+2$ onwards; if country i (the defector) does not play t^C

in period $z+1$, reversion to t^C by both countries is postponed; if country j (the punisher) does not play t^P in period $z+1$, both countries revert to playing t^{NC} indefinitely from $z+2$ onward. The difference between this strategy and the renegotiation-proof strategy described in Section 4 is that it involves the punisher using a tax that is below the unilaterally optimal tax, t^{NC} (and hence below t^{VC}), which in turn implies a more severe punishment for the defector.

In order for the above punishment strategy to be a subgame-perfect equilibrium strategy of the continuation game, the defector must have no incentive to deviate at $z+1$:

$$\hat{\Pi}(\hat{t}(t^C), t^C, V(t^P)) - \Pi(t^C, V(t^P)) \leq \delta \left[\Pi(t^C, V(t^C)) - \Pi(t^C, V(t^P))\right]. \tag{37}$$

Moreover, the punisher must have no incentive to deviate from t^P at $z+1$; thus the lowest tax that the punisher can be persuaded to adopt is a tax $t^P < t^{NC}$ for which the gain from deviating at $z+1$ is less than the loss from reverting to t^{NC} rather than t^C in future periods, i.e.

$$\hat{\Pi}(\hat{t}(t^P), t^P, V(t^C)) - \Pi(t^P, V(t^C)) \leq \frac{\delta}{1-\delta} \left[\Pi(t^C, V(t^C)) - \Pi(t^{NC}, V(t^{NC}))\right]. \tag{38}$$

The above, when binding, identifies the lowest sustainable t^P. Given this, players would not defect in period z if

$$\hat{\Pi}(\hat{t}(t^C), t^C, V(t^C)) - \Pi(t^C, V(t^C)) \leq \delta \left[\Pi(t^C, V(t^C)) - \Pi(t^C, V(t^P))\right]. \tag{39}$$

In our model conditions (37) and (39) coincide. The minimum discount factor for which t^C can be supported by the above punishment strategy is then identified by a combination of values δ and t^P which satisfy (37) and (39) with equality.

It can easily be shown that the above punishment strategy can outperform Nash reversion. Consider, for example, the case $\theta = 0$. Then, we have $\hat{\Pi}(\hat{t}(t^C), t^C, V(t^C)) - \Pi(t^C, V(t^C)) = (1/2)\left[\Pi(t^C, V(t^C)) - \Pi(t^C, V(t^C))\right] < (1/2)\left[\Pi(t^C, V(t^C)) - \Pi(t^C, V(t^P))\right]$, for $t^P < t^{NC}$, implying that the minimum discount factor for which t^C can be supported will be less than 1/2. Notice that, for $0 < \delta < 1$, the right-hand side of (38) is positive and independent of t^P, while the a left-hand side is increasing in t^P for $t^P < t^{NC}$ and is zero at $t^P = t^{NC}$; hence, we can always find a value $t^P < t^{NC}$ that satisfies (38).

With this type of strategies, "cooperation" between the defector and the punisher is required during the punishment phase. Vertical miscoordination (a larger θ) can then help to support t^C not just by making deviations from t^C less attractive at z, but also by making deviations from t^P less attractive for the punisher at $z+1$ and thus by making it possible to support a lower t^P. Horizontal miscoordination (a larger α) allows the effect of vertical miscoordination on t^P to translate into a more severe horizontal punishment, since the effect of a lower t^P on the defector increases in α.

To illustrate, consider the case $\theta = 1$. Then a choice $t^P = 0$ can be supported. Since all firms use capital, if $t^P = 0$ is expected, no investment will take place; then any ex-post increase in the tax will have no effect on abatement and produce an adverse distributional effect, and so the punisher cannot gainfully deviate from $t^P = 0$ in period $z+1$. In turn, the ability to apply $t^P = 0$ during punishment will produce a larger effect on the right-hand side of (39) the larger is α.

CESifo Working Paper Series

(for full list see www.cesifo.de)

---

923 Bernard M.S. van Praag and Adam S. Booij, Risk Aversion and the Subjective Time Discount Rate: A Joint Approach, April 2003

924 Yin-Wong Cheung, Kon S. Lai, and Michael Bergman, Dissecting the PPP Puzzle: The Unconventional Roles of Nominal Exchange Rate and Price Adjustment, April 2003

925 Ugo Trivellato and Anna Giraldo, Assessing the 'Choosiness' of Job Seekers. An Exploratory Approach and Evidence for Italy, April 2003

926 Rudi Dornbusch and Stanley Fischer, International Financial Crises, April 2003

927 David-Jan Jansen and Jakob de Haan, Statements of ECB Officials and their Effect on the Level and Volatility of the Euro-Dollar Exchange Rate, April 2003

928 Mario Jametti and Thomas von Ungern-Sternberg, Assessing the Efficiency of an Insurance Provider – A Measurement Error Approach, April 2003

929 Paolo M. Panteghini and Guttorm Schjelderup, Competing for Foreign Direct Investments: A Real Options Approach, April 2003

930 Ansgar Belke, Rainer Fehn, and Neil Foster, Does Venture Capital Investment Spur Employment Growth?, April 2003

931 Assar Lindbeck, Sten Nyberg, and Jörgen W. Weibull, Social Norms and Welfare State Dynamics, April 2003

932 Myrna Wooders and Ben Zissimos, Hotelling Tax Competition, April 2003

933 Torben M. Andersen, From Excess to Shortage – Recent Developments in the Danish Labour Market, April 2003

934 Paolo M. Panteghini and Carlo Scarpa, Irreversible Investments and Regulatory Risk, April 2003

935 Henrik Jacobsen Kleven and Claus Thustrup Kreiner, The Marginal Cost of Public Funds in OECD Countries. Hours of Work Versus Labor Force Participation, April 2003

936 Klaus Adam, George W. Evans, and Seppo Honkapohja, Are Stationary Hyperinflation Paths Learnable?, April 2003

937 Ulrich Hange, Education Policy and Mobility: Some Basic Results, May 2003

938 Sören Blomquist and Vidar Christiansen, Is there a Case for Public Provision of Private Goods if Preferences are Heterogeneous? An Example with Day Care, May 2003

939 Hendrik Jürges, Kerstin Schneider, and Felix Büchel, The Effect of Central Exit Examinations on Student Achievement: Quasi-experimental Evidence from TIMSS Germany, May 2003

940 Samuel Bentolila and Juan F. Jimeno, Spanish Unemployment: The End of the Wild Ride?, May 2003

941 Thorsten Bayindir-Upmann and Anke Gerber, The Kalai-Smorodinsky Solution in Labor-Market Negotiations, May 2003

942 Ronnie Schöb, Workfare and Trade Unions: Labor Market Repercussions of Welfare Reform, May 2003

943 Marko Köthenbürger, Tax Competition in a Fiscal Union with Decentralized Leadership, May 2003

944 Albert Banal-Estañol, Inés Macho-Stadler, and Jo Seldeslachts, Mergers, Investment Decisions and Internal Organisation, May 2003

945 Kaniska Dam and David Pérez-Castrillo, The Principal-Agent Matching Market, May 2003

946 Ronnie Schöb, The Double Dividend Hypothesis of Environmental Taxes: A Survey, May 2003

947 Erkki Koskela and Mikko Puhakka, Stabilizing Competitive Cycles with Distortionary Taxation, May 2003

948 Steffen Huck and Kai A. Konrad, Strategic Trade Policy and Merger Profitability, May 2003

949 Frederick van der Ploeg, Beyond the Dogma of the Fixed Book Price Agreement, May 2003

950 Thomas Eichner and Rüdiger Pethig, A Microfoundation of Predator-Prey Dynamics, May 2003

951 Burkhard Heer and Bernd Süssmuth, Cold Progression and its Effects on Income Distribution, May 2003

952 Yu-Fu Chen and Michael Funke, Labour Demand in Germany: An Assessment of Non-Wage Labour Costs, May 2003

953 Hans Gersbach and Hans Haller, Competitive Markets, Collective Decisions and Group Formation, May 2003

954 Armin Falk, Urs Fischbacher, and Simon Gächter, Living in Two Neighborhoods – Social Interactions in the LAB, May 2003

955 Margarita Katsimi, Training, Job Security and Incentive Wages, May 2003

956 Clemens Fuest, Bernd Huber, and Jack Mintz, Capital Mobility and Tax Competition: A Survey, May 2003

957 Edward Castronova, The Price of 'Man' and 'Woman': A Hedonic Pricing Model of Avatar Attributes in a Synthetic World, June 2003

958 Laura Bottazzi and Marco Da Rin, Financing Entrepreneurial Firms in Europe: Facts, Issues, and Research Agenda, June 2003

959 Bruno S. Frey and Matthias Benz, Being Independent is a Great Thing: Subjective Evaluations of Self-Employment and Hierarchy, June 2003

960 Aaron Tornell and Frank Westermann, Credit Market Imperfections in Middle Income Countries, June 2003

961 Hans-Werner Sinn and Wolfgang Ochel, Social Union, Convergence and Migration, June 2003

962 Michael P. Devereux, Measuring Taxes on Income from Capital, June 2003

963 Jakob de Haan, Jan-Egbert Sturm and Bjørn Volkerink, How to Measure the Tax Burden on Labour at the Macro-Level?, June 2003

964 Harry Grubert, The Tax Burden on Cross-Border Investment: Company Strategies and Country Responses, June 2003

965 Kirk A. Collins and James B. Davies, Measuring Effective Tax Rates on Human Capital: Methodology and an Application to Canada, June 2003

966 W. Steven Clark, Using Micro-Data to Assess Average Tax Rates, June 2003

967 Christopher Heady, The 'Taxing Wages' Approach to Measuring the Tax Burden on Labour, June 2003

968 Michael P. Devereux and Alexander Klemm, Measuring Taxes on Income from Capital: Evidence from the UK, June 2003

969 Bernhard Eckwert and Itzhak Zilcha, The Effect of Better Information on Income Inequality, June 2003

970 Hartmut Egger and Josef Falkinger, The Role of Public Infrastructure for Firm Location and International Outsourcing, June 2003

971 Dag Morten Dalen and Trond E. Olsen, Regulatory Competition and Multi-national Banking, June 2003

972 Matthias Wrede, Tax Deductibility of Commuting Expenses and Residential Land Use with more than one Center, June 2003

973 Alessandro Cigno and Annalisa Luporini, Scholarships or Student Loans? Subsidizing Higher Education in the Presence of Moral Hazard, June 2003

974 Chang Woon Nam, Andrea Gebauer and Rüdiger Parsche, Is the Completion of EU Single Market Hindered by VAT Evasion?, June 2003

975 Michael Braulke and Giacomo Corneo, Capital Taxation May Survive in Open Economies, July 2003

976 Assar Lindbeck, An Essay on Welfare State Dynamics, July 2003

977 Henrik Jordahl and Luca Micheletto, Optimal Utilitarian Taxation and Horizontal Equity, July 2003

978 Martin D. D. Evans and Richard K. Lyons, Are Different-Currency Assets Imperfect Substitutes?, July 2003

979 Thorsten Bayindir-Upmann and Frank Stähler, Market Entry Regulation and International Competition, July 2003

980 Vivek Ghosal, Firm and Establishment Volatility: The Role of Sunk Costs, Profit Uncertainty and Technological Change, July 2003

981 Christopher A. Pissarides, Unemployment in Britain: A European Success Story, July 2003

982 Wolfgang Buchholz, Richard Cornes, and Wolfgang Peters, On the Frequency of Interior Cournot-Nash Equilibria in a Public Good Economy, July 2003

983 Syed M. Ahsan and Panagiotis Tsigaris, Choice of Tax Base Revisited: Cash Flow vs. Prepayment Approaches to Consumption Taxation, July 2003

984 Campbell Leith and Jim Malley, A Sectoral Analysis of Price-Setting Behavior in US Manufacturing Industries, July 2003

985 Hyun Park and Apostolis Philippopoulos, Choosing Club Membership under Tax Competition and Free Riding, July 2003

986 Federico Etro, Globalization and Political Geography, July 2003

987 Dan Ariely, Axel Ockenfels and Alvin E. Roth, An Experimental Analysis of Ending Rules in Internet Auctions, July 2003

988 Paola Conconi and Carlo Perroni, Self-Enforcing International Agreements and Domestic Policy Credibility, July 2003