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Environmental Policy in a Federation with Special Interest Politics and Inter-governmental Grants

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Abstract

The paper explores the potential effect of intergovernmental grants (IGG) on sub-national (local) environmental policy in a federal structure. In the model, a politically-inclined local government receives campaign contributions from the polluters' lobby in return for lower pollution taxes. A benevolent federal government uses IGG as an incentive to reduce the resulting distortion in the local pollution tax. IGG are formulaic transfers that are conditional on pollution levels - lower pollution in a sub-national jurisdiction relative to others translates into a higher share of the grant and vice versa. In equilibrium, the *grant effect* reduces the distortion created in the pollution tax by the *lobby effect*, and may even lead to a higher than Pigouvian tax when the local government assigns a large enough weight on social welfare and/or when the grant is large enough. Further, IGG result in the tax levels of jurisdictions becoming interdependent in an interesting way. Environmental policies in two jurisdictions may become strategic complements or substitutes depending on their relative pollution levels. The possibility of strategic substitution implies that federal welfare may not increase even when environmental policy becomes stricter in one state.

Journal of Economic Literature Classifications: D72, D78, H23, H77, Q58

Key Words: endogenous environmental policy, environmental federalism, inter-governmental grants, lobbying, pollution tax.

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1 Introduction

The optimal locus of environmental policy in federal systems remains an unresolved public policy issue. The principle of subsidiarity in fiscal federalism argues in favor of decentralized policy for a strictly local environmental problem. However, the literature on environmental federalism does not provide any clear direction as the debate on "race-to-the-bottom" remains largely inconclusive.[1] As things stand, national governments in several federal countries, both developed and developing, influence sub-national (local) environmental policy. In many countries, federal governments are making strategic use of intergovernmental grants (IGG) along with, or instead of, direct regulation of local environmental concerns. Such IGG are designed as formulaic transfers conditional on environmental performance of sub-national jurisdictions. For example, Brazil (Ecological ICMS introduced in early 1990s) and Portugal (Amended Local Finances Law, 2007) have introduced ecological indicators, such as protected areas and waste management, for the redistribution of fiscal transfers to the local level (Ring 2002, Ring *et al.* 2010). The Finance Commission of India, an independent body responsible for the design of formulaic IGG has earmarked an environmental grant to be distributed, inter-se, based on states' relative performance in managing forests and water resources and promoting renewable energy (Government of India 2009).[2] The Planning Commission of India, an executive body responsible for supplementing state budgets is also considering the use of an EPI (Environmental Performance Index) ranking as one of the criteria for devolving funds to

[1]The "race-to-the bottom" hypothesis argues that the principle of decentralization can be undermined if sub-national governments choose less stringent environmental policy, as compared to a centralized equilibrium, in order to attract new industry, capital or jobs. No consensus, however, has emerged in the empirical or theoretical literature on the hypothesis. For instance Oates and Schwab (1988) show that inter-jurisdictional competition can be efficiency-enhancing under certain assumptions. Other papers show that policy distortions depend on a number of other factors, such as the choice of the policy instrument and distribution of 'pollution rents' (Wellisch 1995), number of homogenous jurisdictions (Kunce and Shogren 2002), use of capital taxation for the provision of non-environmental public goods (Oates and Schwab 1988, Kunce and Shogren 2005), and presence of imperfect competition in the polluting industry (Markusen *et al.* 1995, Levinson 1997). See Oates (2001) for a discussion on the topic.

[2]The grant covers the period 2010-2015 and equals Rs. 150 billion (roughly 2.5 billion USD), constituting about 4.7 percent of total grants-in-aid to states. As an example of the allocation formula, the share of each state in the forest sub-grant depends on (1) its share in the country's total forest area; (2) percentage of forested area in its total geographical area relative to the national average; and (3) a weight reflecting the quality of forests. The formula used is:

$$G_i = \frac{\left(\frac{F_i}{\sum F_i} + R_i\right) * \left(1 + \frac{M_i + 2H_i}{A_i}\right)}{\sum_{i=i}^{n}\left[\left(\frac{F_i}{\sum F_i} + R_i\right) * \left(1 + \frac{M_i + 2H_i}{A_i}\right)\right]},$$

where, for the i^{th} state, Gi: Share in grant, Fi: Total forest area, Mi: Moderately dense forest area, Hi: Highly dense forest area, Ai: Geographical area, and Ri:$max[0, \left[\frac{F_i}{A_i} - \frac{\sum F_i}{\sum A_i}\right]/100]$.

states (Chandrasekharan *et al.* 2013).

This approach to federal environmental policy constitutes the motivation for this paper. Using a full information setting, we model a federal system with two (later extended to n) states, in each of which industrial production causes a strictly local environmental externality that reduces welfare. Each state government uses a tax to regulate local pollution. At the same time, the tax may be influenced by interest groups such as the industry lobby. A higher pollution tax lowers industry profits and the industry lobby makes campaign contributions to a politically inclined state government in exchange for a tax rate that is less than socially optimal. The state government maximizes a weighted sum of pure social welfare and campaign contributions. The weight it attaches to campaign contributions relative to social welfare can be interpreted as the extent of its corruptibility. In comparison, the federal government is benevolent and is concerned about the loss in welfare due to a distortion in the pollution tax. It uses IGG as a strategic environmental policy instrument - higher pollution relative to the other jurisdiction translates into a lower share of the earmarked grant and vise versa. Thus, environmental policy is a combined endogenous outcome of the interaction between agents at multiple levels of government. First, there is an interaction between the polluters' lobby and a self-interested state government which is modeled in the vein of Grossman and Helpman (1994). Second, an interaction takes place between the national and state governments in the form of inter-jurisdictional competition for performance-linked fiscal grants.

Our paper focuses on a common source of distortion in local environmental policy that owes to the power wielded by polluters.[3] For example, states in India have failed to enforce nationally-prescribed pollution standards, when in fact they can impose stricter levels, mainly due to the influence of the polluters' lobby on policy makers and the bureaucracy (Mandal and Rao 2005, OECD 2006). There are also several examples of politically-motivated policy distortions in the economy that bear heavily on the environment. A notable one is the perpetuation of highly subsidized electricity for agriculture by state governments mainly due to the clout of the rich farmers' lobby. These subsidies have continued despite having contributed to over-exploitation of groundwater in several parts of the country (Badiani *et al.* 2012, Birner *et al.* 2011, Dubash 2002, Kumar 2005). In the same vein, the formidable lobby of sugar mills and cane farmers has ensured that sugarcane, a highly water intensive crop, receives policy incentives even in arid and drought-prone provinces of the country with grave ecological consequences (CSE 2013, Lall 2013). Several studies suggest that rents from the sugarcane industry are an important source of campaign contributions for governments in these states (Sridharan 1999, Banerjee *et al.* 2001, and Sukhtankar 2012).

[3]The model can be extended to the use of IGG to correct other forms of local distortions such as those arising due to inter-jurisdictional pollution spill-overs. An extension of the model along these lines has been characterized and is available with the authors.

This paper makes two main contributions to the literature. First, it introduces IGG as a policy instrument in the environmental federalism literature, which to the best of our knowledge is new. Second, it connects themes in environmental federalism and endogenous environmental policy. The literature on environmental federalism has, broadly, dealt with two levels of policy interactions. One, 'horizontal' policy interactions amongst jurisdictions competing for (mobile) capital when the externality itself is local- the basis of the 'race-to-the-bottom' literature. Two, 'vertical' policy interactions between levels of government when the externality is inter-jurisdictional. Silva and Caplan (1997), Caplan and Silva (1999) and Caplan *et al.*(2000) deal with transboundary pollutants in federal economies. More recently, Williams (2012) models the case where both federal and state governments can regulate the same pollutant, with or without inter-jurisdictional spillovers, through a selection of instruments. Much of this literature assumes a benevolent government acting in public interest. On the other hand, the vast and growing literature on endogenous environmental policy in the presence of organized lobbies assumes a homogenous self-interested government, as in Fredrikkson (1997) and Aidt (1998). This contrasts with the reality of multiple tiers of government that interact, sometimes with conflicting objectives, in decision making.

The literature that comes closest to this paper in terms of examining endogenous environmental policy in a federal set-up includes Fredriksson (2001) and Fredriksson *et al.* (2006). The first paper models the case when a national government has the authority to levy a pollution tax on firms while a self-interested state government can provide abatement subsidies. It is shown that when the level of abatement subsidy can be influenced by local lobby groups, an increase in the federal pollution tax can lead to higher subsidy, resulting in higher pollution and lower welfare. In contrast, we model an interaction between the federal and state policy instruments without the federal government directly regulating local pollution. IGG thus serve as an incentive to move towards the optimal level of the first-best instrument- a locally determined pollution tax. Fredriksson *et al.*(2006) develop a political economy model of the race-to the-bottom hypothesis. It is shown that in the presence of inter-jurisdictional mobility of capital, decentralized environmental policy that is influenced by local interest groups is weaker as compared to that determined at the national level. This arises because returns to capital and labor are increasing in emissions, leading to more intensive lobbying by capital owners and workers for lax environmental policy. Thus, Fredriksson *et al.* (2006) compare decentralized versus centralized policy in the presence of lobbying and inter-jurisdictional competition for capital. Our paper is different in that we model the case where both tiers of government employ policy instruments and jurisdictions compete, not over capital, but over a share in IGG. As such, while existing literature examines policy interactions either between the federal and state governments or among state governments, this model captures elements of both.

This paper also contributes to the growing research that introduces political economy considerations in the normative theory of intergovernmental transfers (Sato 2007 provides a good survey). In particular, it is complementary to the literature on the soft budget constraint, wherein states choose their fiscal policy opportunistically in anticipation of fiscal bailout by a federal authority (Vigneault 2007 surveys research on the soft budget constraint). A parallel stream of literature examines strategic and partisan motives in allocation of grants among provinces. Boex and Martinez-Vazquez (2006) discuss political influences as a major determinant of grant allocation internationally. The role of partisan politics in the inter-state distribution of discretionary grants is well documented for India- see Rao and Singh (2001), Arulampalam *et al.* (2009) and Khemani (2007). Goodspeed (2002) and Sengupta (2011) bring these two strands of the literature together to study the soft budget constraint when grant allocation is itself motivated by political expediency. In Sengupta's model, a public good produced in each province of a federation is financed by locally procured taxes and transfers from the federal government. They show that partisan allocation of the grant alters the incentives of provincial governments to raise local revenues and may lead to an interaction in provincial taxes. Specifically, a higher political element in transfers leads to a lower tax in the favorite region but a higher tax in the other. The combined effect on federal production of the public good (the sum of provincial revenues) and federal welfare may go in either direction. Our paper finds that a similar interaction in provincial policy can arise even when grant allocation is objective but is linked to the relative provision of public good (environmental quality in this case) in a province.

The paper derives several interesting outcomes. As expected, the influence of a polluters' lobby in a state leads to a lower pollution tax in comparison to the first-best Pigouvian level. With the inclusion of IGG from the federal government aimed at reducing this distortion, the equilibrium tax can exceed the Pigouvian level when the weight on social welfare and/or the grant amount are high enough. An interesting result that emerges is that competition for performance-linked grants creates a strategic interdependence between environmental taxes of the two jurisdictions, even when there are no environmental spillovers. Specifically, environmental policy of the larger polluter is a strategic substitute of that of the small polluter, while environmental policy of the smaller polluter is a strategic complement of that of the larger polluter. This happens because a difference in relative pollution levels asymmetrically affects the stakes of the two states in the grant, in turn leading to asymmetric policy responses. The possibility of strategic substitution implies that federal emissions may not fall and federal welfare may not increase when environmental policy becomes stricter in one state. On the other hand, strategic complementarity introduces the possibility of a race-to-the bottom in environmental policies among jurisdictions. This becomes more likely as the number of environmentally homogenous jurisdictions in the federation increases.[4]

The paper is structured as follows. Section 2 describes the basic model and derives the equilibrium level of pollution tax in the presence of a polluters' lobby and a self-interested state government. Section 3 introduces IGG and discusses the resulting change in the equilibrium tax level. It then analyzes the policy interactions that emerge between jurisdictions due to IGG. Section 4 discusses implications for pollution and welfare at both federal and state levels of a change in the grant amount and the extent of corruption in any state. Section 5 generalizes the analysis to n jurisdictions. Section 6 concludes.

2 The model

Consider a federal nation consisting of two jurisdictions or states, two state governments, and one federal government. The state government is assumed to be corruptible while the federal government is benevolent. The population of each state comprises consumers and industrialists. The latter produce two goods in each state. Production of one of the goods generates local pollution, confined to that state. The state government uses an environmental tax to regulate pollution. Industrialists form a lobby to influence the level of the tax by operating bribes to the state government. Finally, the federal government intervenes to correct this distortion by providing IGG that are linked to relative levels of pollution in the two states.

In what follows, we describe state 1. A similar set of conditions will hold for state 2, which will have variables represented by superscript $*$ throughout the analysis. To begin with, we assume away the role of the federal government- that is, absent federal government constitutes our baseline case.

2.1 Firms

Firms in each state produce two goods - z and x. The numeraire non-polluting good, z, is produced by means of constant returns to scale (CRS) production technology using only labor as input. Profit maximization and mobility of labor across sectors imply that the wage rate is normalized to one.

[4] In another context, Curtis Eaton (2004) analyzes the taxonomy of social dilemmas defined in terms of plain and strategic complementarity or substitution in the pay-off functions of firms in the provision of both private and public goods, when firms behave as Cournot or Bertrand duopolists. Plain complementarity (substitution) refers to the cross-effects in the pay-off functions being positive (negative), while strategic complementarity (substitution) implies that cross-effects in marginal pay-off functions are positive (negative). In comparison, our paper derives the possibility of joint strategic substitution and complementarity in policy responses (here, pollution taxes) of the state governments. The best-response functions in Curtis Eaton (2004) are assumed to be linear (through a specific choice of pay-off functions), while they turn out to be non-linear in general in our paper.

The non-numeraire and polluting good, x, is produced by $k \geq 1$ identical firms with CRS technology that uses labor and a sector-specific input which is immobile and non-tradable. Good x is sold in a competitive market at a given price, p. The state government controls pollution by levying an emissions tax, t, per unit of x produced by firms. In response, each firm, i, undertakes abatement expenditure, a_i, which determines the pollution intensity, θ_i per unit of x produced. We assume $\theta_a < 0$ and $\theta_{aa} > 0$. For each firm, the cost of producing x is given by the identical cost function $C(x, a)$, such that $C_x > 0$, $C_a > 0$, $C_{xx} > 0$, $C_{aa} > 0$, $C_{ax} > 0$ and $C_{xa} > 0$. The profit function of each of the k firms is given by:

$$\Pi_i(t) = px_i - C(x_i, a_i) - t\theta_i(a_i)x_i, \tag{1}$$

which yields the following first-order conditions for profit maximization (ignoring firm-specific notations):

$$\frac{\partial \Pi(t)}{dx} = p - C_x - t\theta(a) = 0, \tag{2}$$

$$\frac{\partial \Pi(t)}{da} = -C_a - tx\theta_a = 0. \tag{3}$$

Equation (2) implies that each firm will produce up to the point where price is equal to net-of-tax marginal cost. Equation (3) balances the marginal cost of reducing pollution by increasing abatement expenditure with the marginal gain in terms of lower pollution taxes. Equations (2) and (3) implicitly define the equilibrium values of x and a as functions of t. Using the implicit function rule, it can be shown that $\frac{\partial x(t)}{\partial t} < 0$ and $\frac{\partial a(t)}{\partial t} > 0$, provided the production function is sufficiently concave in the costs of abatement and production (see Appendix 1 for detailed proof). In other words, an increase in the pollution tax reduces output and increases pollution abatement expenditure. Conditions (2) and (3) also imply that x_i's and a_i's are equalized across firms. Aggregate pollution, $\sum_i \theta_i x_i$, can therefore be expressed as $\theta k x_i = \theta X$. It follows that

$$\frac{\partial(\theta X)}{\partial t} = \theta_a a_t X + \theta X_t < 0, \tag{4}$$

For notational brevity, we express aggregate pollution, $\theta(a(t))X(t),$ as $e(t)$ henceforth.

It may be noted that while x_i's and a_i's are equalized across firms within each state, these may differ between states. This could arise due to differences in production and emissions control technologies, input and output prices and technological factors specific to the corresponding industrial sectors in each state.

2.2 Consumers

Each of the n homogenous consumers derives utility from the consumption of z and x. A fraction, α, of the population is adversely affected by aggregate emissions, e, irrespective of the distribution of emissions across firms. Utility is assumed to be quasi linear and additively separable as follows:

$$U = c^z + u(c^x) - \lambda D(e),$$

where c^z and c^x are consumption of z and x, and $u(c^x)$ is a strictly concave and differentiable sub-utility function, i.e $u' > 0$, $u'' < 0$. Disutility from pollution, D, is increasing in aggregate emissions, $D' > 0$ and $D'' > 0$, with $\lambda = 1$ for α proportion of the population and 0 otherwise. Each individual supplies a fixed amount of labor, equal to l, and has two sources of income (Y): a fixed wage income, wl, and an equal share of total pollution tax revenue, $te(t)$. Consumption of x by each individual, c^x, can be expressed in terms of demand, $d(p)$, where demand is given by the inverse of u_{c^x}. The consumption of z then equals $Y - pd(p)$. Utility maximization, subject to the budget constraint, yields the following indirect utility function:

$$V(Y, p, t) = wl + \frac{1}{n}te + \beta(p) - \lambda D(e), \tag{5}$$

where $\beta(p)$ is the consumer surplus from x, equal to $u(d(p)) - pd(p)$. Given the choice of a quasi-linear utility function, the demand for x is a function of p alone with no income effects [5].

2.3 State government and the political process

The state government uses a pollution tax to control local pollution. Since profits are declining in the tax (from (1)), the k firms overcome the problem of free-riding and organize themselves into a lobby that makes a prospective monetary offer to the incumbent government in exchange for a favorable tax policy. This takes the form of a schedule that maps offers of campaign contributions to different levels of pollution taxes chosen by the government. It is assumed that high transaction costs prevent the consumers from forming an organized lobby. Being politically-inclined, the state government is assumed to maximize a weighted sum of pure social welfare (welfare of the citizen voter) and campaign contributions. Thus, implicit here is a democratically elected government that collects contributions during its term in office to support future campaign expenditures in an un-modeled election. This political process follows the common-agency model of politics, developed by Grossman and Helpman (1994) using the menu-auction framework of Bernheim and Whinston (1986). The model has been used extensively in the endogenous environmental policy literature and we use its equilibrium characteristics modified for the case of a single lobby.[6]

[5] Demand for x is independent of t. A change in t affects the local production of x and there is a proportional change in imports to meet the final demand for x. In order to avoid any inter-jurisdictional interactions due to import/export, we assume that imports are sourced from a third jurisdiction or another nation.

[6] See, for instance, Aidt (1998, 2010), Damania *et al.* (2004), Fredriksson (1997), Mehra (2010), and Persson (2012) for applications of the Grossman and Helpman (1994) model in the context of single or multiple lobby groups.

Let the campaign contribution schedule offered by the industry lobby, I, be denoted by $\Lambda^I(t)$ and the indirect utility (gross of bribe) of the lobby be given by:[7]

$$\Omega^I = \Sigma_{i=1}^k \Pi_i(t).$$

Using the first-order conditions of the firms, (2) and (3), and the envelope property, it is straightforward to show that:

$$\Omega_t^I = -e(t). \tag{6}$$

The equilibrium properties of Grossman and Helpman (1994) require that:[8]

$$\frac{\partial \Lambda^I(t)}{\partial t} = \frac{\partial \Omega^I(t)}{\partial t}. \tag{7}$$

The intuition underlying (7) is that the lobby sets its contribution schedule such that the change in contributions due to a marginal change in tax rate is equal to the corresponding change in its welfare. The shape of the schedule thus reveals the lobby's true preference in the neighborhood of the equilibrium. Turning to the state government, let its objective function be given by:

$$\Omega^{SG} = \Lambda^I + \delta W^{SG}, \tag{8}$$

where $\delta \geq 0$ is the exogenously given weight on welfare relative to campaign contributions, and W^{SG} is pure social welfare.[9] The weight on welfare may be thought of as a measure of corruption in the state such that a higher δ implies lower corruption. W^{SG} can be expressed as the sum of firms' profits, consumer surplus and pollution tax revenue, less disutility from pollution:

$$W^{SG} = \Sigma_{i=1}^k \Pi_i(t) + n\beta(p) + te(t) - \alpha n D(e(t)). \tag{9}$$

From (8) and using (7), it follows that the equilibrium tax $\hat{t}$ is the solution to the necessary condition in (10):

$$\Omega_t^{SG}(\hat{t}) = \Omega_t^I(\hat{t}) + \delta W_t^{SG}(\hat{t}) = 0. \tag{10}$$

[7] It is assumed here that the share of industrialists in the total population is insignificant and hence their share in the pollution tax revenue is negligible.

[8] A detailed discussion of the equilibrium characteristics is provided in Grossman and Helpman (1994) and Fredriksson (1997).

[9] As explained by Grossman and Helpman 1994, δ can also be understood as $\frac{\delta_2}{\delta_1 - \delta_2}$ with δ_1 and δ_2 representing weights that the government attaches to campaign contributions and net (of campaign contributions) welfare, where it is assumed that $\delta_1 > \delta_2$, i.e. *politicians value a dollar in their campaign coffers higher than in the hands of the public.* This assumption implies no restrictions on the size of the parameter δ.

Substituting from (6) and (9) and solving, we get the implicitly defined equilibrium level of the pollution tax as:

$$\hat{t} = \alpha n D'(e(\hat{t})) + \frac{e(\hat{t})}{\delta \frac{\partial e(\hat{t})}{\partial t}}. \tag{11}$$

From (4) we know that $\frac{\partial e}{\partial t} < 0$. Thus, the tax in (11) will be lower than the socially optimal tax rate which is equivalent to $\alpha n D'$. The latter can be derived by maximizing pure social welfare, in (9), with respect to t. This gives the expected result that:

Proposition I *The equilibrium tax of a self-interested state government is lower as compared to the socially optimal Pigouvian level.*

3 Federal government and inter-governmental grants

We now introduce a benevolent federal government, which uses IGG to minimize the distortion in local environmental policy. IGG constitute a distinctive policy instrument in fiscal federalism and have been used for multiple objectives in addition to their traditional role in equalizing fiscal capacity and ensuring a minimum service standard across jurisdictions.[10] IGG can be of several types: formulaic or discretionary; conditional or unconditional in use by the recipient; contingent or not on matching contribution by the recipient. Motivated by recent international experience, we focus on formulaic IGG used by federal governments to deal with local environmental issues. By focusing on formulaic as against discretionary grants, we are also able to assume away strategic/ partisan influence on the grant allocation itself.

Specifically, the national government offers each state government a share in an earmarked environmental grant, T, based on the latter's relative pollution level.[11] To keep matters simple, we assume that state 1's share is equal to $s = (1 - \frac{e}{e+e^*}) = \frac{e^*}{e+e^*}$. Similarly, state 2's share, $s^* = \frac{e}{e+e^*}$ with $s + s^* = 1$. Thus, the share of each state in T is decreasing in own pollution level but increasing in the pollution level of the other state. It is assumed that T is exogenously given, being implicitly financed from lumpsum taxes on activities which are not modeled here. Further, we assume that in each state, the grant money is distributed equally to all consumers through a lumpsum transfer per capita. This implies an additional term, $\frac{1}{n} sT$, in equation (5). The welfare function of the state government is now given by:

$$W^{SG} = \Sigma_{i=1}^{k} \Pi_i(t) + n\beta(p) + te(t) + \frac{e^*(t^*)}{e(t) + e^*(t^*)} T - \alpha n D(e(t)). \tag{12}$$

[10] IGG have been used by governments to compensate for inter-jurisdictional benefit spillovers, influence local priorities, and create macroeconomic stability in depressed regions etc (Shah, 2003).

[11] Implicit here is that environmental quality corresponds directly with emissions in each state.

Using (12) instead of (9) in the state government's equilibrium condition, (10), and solving as before, we get the implicitly derived equilibrium tax rate in state 1, when it takes the tax rate in state 2 as given:

$$\hat{t} = \alpha n D'(e(\hat{t})) + \frac{e^*(t^*)}{(e(\hat{t}) + e^*(t^*))^2} T + \frac{e(\hat{t})}{\delta \frac{\partial e(\hat{t})}{\partial t}}. \tag{13}$$

Similarly, the equilibrium tax in state 2, $\hat{t}^*$, is given by:

$$\hat{t^*} = \alpha^* n^* D^{*'}(e(\hat{t^*})) + \frac{e(t)}{(e(t) + e^*(\hat{t^*}))^2} T + \frac{e^*(\hat{t^*})}{\delta^* \frac{\partial e^*(\hat{t^*})}{\partial t^*}}. \tag{14}$$

The expressions in (13) and (14) constitute the best-response functions of the environmental tax of state 1 and 2, respectively, given any tax level chosen by the other. The simultaneous solution to these functions yields the optimal environmental tax pair (t, t^*) as the Nash equilibrium outcome of the game. It may be noted here that the equilibrium tax rates in the two states could differ following a difference in any of the model parametres: p, α, n and δ as well as inherent differences in technologies, input prices and other factors specific to industries in the two states.

We assume that the second-order conditions for the state governments' maximization problem hold, that is, $\Omega_{tt}^{SG} < 0$ and $\Omega_{t*t*}^{SG*} < 0$.[12]

Examining the optimal tax, it is seen that its equilibrium level in each state has three components, given by the three terms in the r.h.s of (13) and (14) respectively. The first r.h.s term in (13) represents the Pigouvian component which is equal to the pure marginal disutility from pollution. The second term is the positive *grant effect* or the incentive created by IGG due to a marginal change in the level of pollution, which is a function of the relative level of pollution in the state. The third term is the negative *lobby effect* which is captured by (negative of) the marginal change in lobby surplus (-e) relative to the marginal change in pollution weighted by welfare ($\delta \frac{\partial e}{\partial t}$). We can compare the equilibrium tax in the presence of IGG (13) with the equilibrium tax in absence of IGG (11) through comparative statics of (13) with respect to T. It can be shown that $\frac{dt}{dT}$, $\frac{dt^*}{dT}$ > 0 though the incentive effect of the grant is smaller for the larger polluter (see Appendix 2.1 for proof). Thus we get:

Proposition II: *In comparison with the baseline case (of a self-interested state government and no IGG), the introduction of pollution-linked IGG leads to an increase in the pollution tax determined by a self-interested government in each state.*

[12]This requires that in each state, the damage due to pollution is very steeply rising (D'' is large enough) or that damage due to pollution is steeply rising and the relative weight on welfare is high (D'' and δ are large). Specifically, the second condition requires that $\delta, \delta^* > 1$, i.e. the weight on pure social welfare net of campaign contributions is greater than half the weight on campaign contributions.

Given that the *grant effect* and the *lobby effect* in (13) are opposite in sign, it is their relative magnitudes that will ascertain how the politically-determined equilibrium tax in the presence of IGG compares with the first-best Pigouvian tax.[13] From (13) we find that the *grant effect* will dominate the *lobby effect* due to a marginal increase in the pollution tax if the marginal increase in social benefit due to a higher grant share (captured by $\delta\frac{\partial e}{\partial t}\frac{e^*T}{(e+e^*)^2}$) exceeds the marginal loss in lobby surplus (given by $-e$). This condition, in turn, implies that:

Proposition III: *The introduction of pollution-linked IGG can lead to a larger-than Pigouvian tax when the local government assigns a high enough weight on pure social welfare and/or when the IGG are large enough.*

Given that the second-order conditions for the optimum require that δ (and δ^*) be large enough, equation (13) suggests the possibility of the grant-effect dominating the lobby effect.

3.1 Strategic policy interaction between states

Taking the best-response functions, (13) and (14), that express $t = f(t, t^*)$ and $t^* = g(t, t^*)$ respectively, and suppressing arguments, it can be shown that:

$$\frac{dt}{dt^*} = \frac{\delta T}{(e+e^*)^3\Delta}\frac{\partial e}{\partial t}\frac{\partial e^*}{\partial t^*}(e^* - e) \ \text{, and}$$

$$\frac{dt*}{dt} = \frac{\delta^* T}{(e+e^*)^3\Delta^*}\frac{\partial e}{\partial t}\frac{\partial e^*}{\partial t^*}(e - e^*),$$

where $\Delta = \Omega_{tt}^{SG} < 0$, $\Delta^* = \Omega_{t*t*}^{SG*} < 0$, $\frac{\partial e}{\partial t} < 0$, and $\frac{\partial e^*}{\partial t^*} < 0$. Thus, we have the following set of conditions:

$$\frac{dt}{dt^*}\begin{cases} > 0, \text{ if } e < e^*, \\ = 0, \text{ if } e = e^* \\ < 0, \text{ if } e > e^* \end{cases} \quad \text{and} \quad \frac{dt^*}{dt}\begin{cases} > 0, \text{ if } e^* < e, \\ = 0, \text{ if } e^* = e \\ < 0, \text{ if } e^* > e \end{cases} \tag{15}$$

[13] If we view the grant as compensation to the state economy for the pollution tax, this result can be related to the literature that examines how the use of pollution tax revenue can itself be an instrument for creating political support for the tax. For example, Cremer *et al* (2004) demonstrate the possibility of lower (higher) than Piguouvian taxes depending on who determines the refunding rule (constitutional planner or majority voters) and who benefits more from it (owners of capital or labour). Marsiliani and Renstrom (2000) find that earmarking of pollution tax revenue for abatement serves as a partial solution to the time-inconsistency problem in environmental policy. More recent work examines the influence of refunding rules on the response of the polluters' lobby to the imposition of the tax (see for instance Aidt 2010, Fredriksson and Sterner 2005). In this paper, we assume that the grant money is redistributed to the citizens but as an extension it will be interesting to study the effect of different uses of the grant on the equilibrium level of the pollution tax.

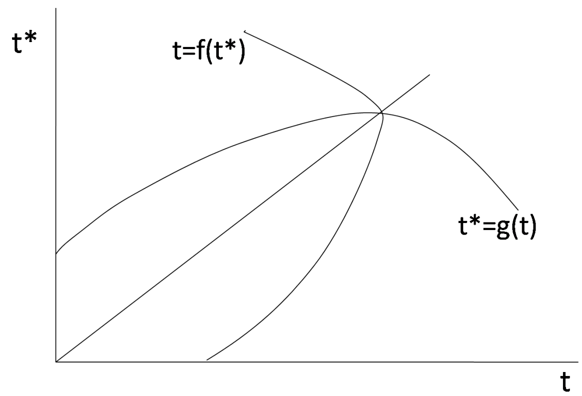

Figure 1: Strategic interactions in environmental policy: the case of symmetric states

Assuming that the states are symmetric, the conditions implied in (15) are plotted in Figure 1. Along the 45° line from the origin, $t = t^*$, hence $e(t) = e^*(t^*)$. To the right of the 45° line, $t > t^*$, such that *ceteris paribus*, $e(t) < e^*(t^*)$ (since pollution is declining in the tax). It follows from (15) that in this region $\frac{dt}{dt*} > 0$ but $\frac{dt*}{dt} < 0$. By the same logic, to the left of the 45° line $t < t^*$, implying that $\frac{dt}{dt*} < 0$ but $\frac{dt*}{dt} > 0$. If the two states are symmetric in all parametres, their best-response functions would intersect along the 45° line, leading to equal tax rates, identical pollution levels and equal grant shares in both (Figure 1). Let us consider a more realistic case of states being asymmetric. Figure 2 illustrates the case in which the government in state 2 is more corrupt than in state 1 (captured by $\delta > \delta^*$). This would result in a higher t for a given t^*.[14] The best-response functions would then intersect to the right of (or below) the 45° line, leading to an equilibrium with $t > t^*$ and $e < e^*$.

In either case, the best reaction functions have different slopes in the vicinity of the Nash equilibrium (the point where the best-response functions intersect) such that the pollution tax of the smaller polluter is a strategic complement of the tax of the larger polluter, whereas the latter is a strategic substitute of the former. Thus,

Proposition IV: *Competition for IGG leads to an asymmetric strategic interaction in the environmental policies of the two states depending on their relative pollution levels. When $\delta > \delta^*$, implying ceteris paribus that $t > t^*$ and $e < e^*$, t is a strategic complement of t^* while t^* is a strategic substitute of t. The opposite is true when $\delta < \delta^*$.*

Intuitively, when the more corrupt state, and hence the larger polluter, increases (decreases) its tax, the less corrupt state and hence the smaller polluter, faces greater (less) competition for its

[14]Mathematically, it is straightforward to show that $\frac{\partial t}{\partial \delta} > 0$, $\frac{\partial t^*}{\partial \delta^*} > 0$

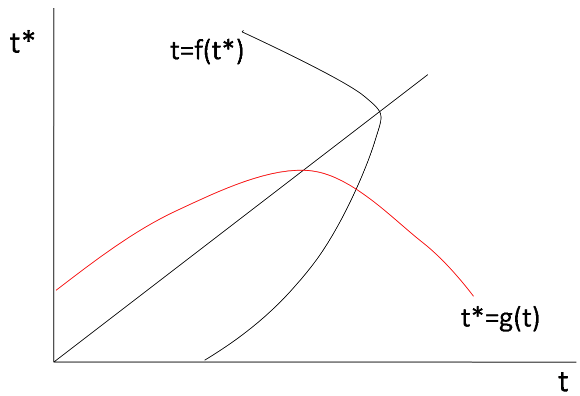

Figure 2: Strategic interactions in environmental policy: the case when state 2 is more corrupt

hitherto higher share of the grant, leading it to increase (lower) its tax level. Any change in environmental policy of the less corrupt state (smaller polluter) has the opposite effect on the other state (larger polluter). A higher tax in the smaller polluter further reduces the stakes of the larger polluter (already receiving the smaller share of the grant) in the grant, leading it to lower its tax. A reduction in the tax level of the smaller polluter, on the other hand, by freeing-up grant monies, creates an incentive for the larger polluter to tighten its environmental policy.

The uniqueness and stability of the equilibria in Figures 1 and 2 would be ensured if the best-response functions are concave. Concavity requires that damage from pollution is steeply rising (D'' and $D^{*''}$ are large), the objective functions of the state governments are concave enough (Δ and Δ^* are large enough) and that emission levels in the two states are not too far apart.[15] Intuitively, if emission levels are very different, states cannot effectively compete for a larger pie of the grant by changing their pollution levels, thus undermining the principle behind the grant. Thus, an important underlying assumption in the model necessary for the stability of the Nash equilibrium is:

Assumption 1 (A1): States in the federation are not too heterogenous in their environmental outcomes.

Interestingly, Sauquet *et al.* (2014) offer recent empirical evidence of strategic inter-jurisdictional interaction in environmental policies due to performance-based IGG in Brazil. Several states of Brazil have been implementing the ICMS-E- a fiscal transfer out of a fixed pool of money to municipalities on the basis of their relative performance in the creation and management of conservation units (CUs). In the state of Parana, which has implemented the scheme since 1992, they find

[15]Specifically, given our stylized model, the specific condition is that emissions in one state should not be more than twice the other - see Appendix 3 for detailed proof.

that the ICMS-E directly influences the land allocation decisions of counties, though the benefits appear to taper off after an initial surge in the creation of CUs. They also find evidence that higher the initial performance of the neighbors, smaller the propensity for a county to increase the number and quality of its own CUs, as predicted by our model. More interestingly, they find statistically significant evidence of strategic substitutability between conservation decisions, post 2000, implying that the utility gained from the creation of a protected area decreased if a neighbor created more protected areas. It is argued that these negative interactions could contribute to forest fragmentation in the region, thus undermining the ultimate success of the ICMS-E.[16]

4 State vs. federal emissions and welfare

We now study the environment and welfare implications of changes in two key parameters of the model - the grant itself and the weight assigned to pure social welfare by a state government. We do this by working through changes in and interactions between tax policies in the states.

First, we examine the implication of increasing (or introducing) T. The net effect on federal emissions can be expressed as:

$$\frac{dE}{dT} = \frac{de}{dT} + \frac{de^*}{dT} = \frac{\partial e}{\partial t}\frac{dt}{dT} + \frac{\partial e^*}{\partial t^*}\frac{dt^*}{dT}$$

We know from (4) that $\frac{\partial e}{\partial t}, \frac{\partial e^*}{\partial t^*} < 0$ and from Proposition II that $\frac{dt}{dT}, \frac{dt^*}{dT} > 0$. Thus, aggregate emissions will fall with the introduction of IGG.

Turning to the welfare implications, let aggregate welfare of the federation be written as $W^F = W^{SG} + W^{SG*}$. Using equation (12) and the corresponding expression for state 2, and substituting for the equilibrium tax rates from equations (13) and (14) respectively (given that taxes are set optimally in each state), we get the following:

$$\begin{aligned} \frac{dW^F}{dT} &= \frac{\partial W^F}{\partial T} + \frac{\partial W^F}{\partial t}\frac{dt}{dT} + \frac{\partial W^F}{\partial t^*}\frac{dt^*}{dT} \\ &= 1 + \underbrace{\left(\frac{e}{\delta} + \frac{e^*}{(e+e^*)^2} T \frac{\partial e}{\partial t}\right)\frac{dt}{dT}}_{\text{indirect effect on federal welfare via t}} + \underbrace{\left(\frac{e^*}{\delta^*} + \frac{e}{(e+e^*)^2} T \frac{\partial e^*}{\partial t^*}\right)\frac{dt^*}{dT}}_{\text{indirect effect on federal welfare via } t^*} \end{aligned} \quad (16)$$

The r.h.s has three terms. The first term represents the direct marginal welfare effect of the higher grant in states 1 and 2 combined. In the absence of any cost of raising the grant, this is equal

[16] Their paper does not specifically go into whether a county's strategic response (complementarity vs substitutability) to its neighbor's policy is also shaped by its relative level of CUs, as suggested by our model.

to one.[17] The second and third terms represent indirect effects on welfare of a change in t and t^* respectively, following an increase in T. Substituting from (13) and (14) for these effects respectively and suppressing arguments, (16) can be expressed as:

$$\frac{dW^F}{dT} = 1 + (\hat{t} - \alpha n D')\frac{\partial e}{\partial t}\frac{dt}{dT} + (\hat{t^*} - \alpha^* n^* D^{'*})\frac{\partial e^*}{\partial t^*}\frac{dt*}{dT} \tag{17}$$

Given $\frac{\partial e}{\partial t}$, $\frac{\partial e^*}{\partial t^*} < 0$ from (4) and $\frac{dt}{dT}$, $\frac{dt^*}{dT} > 0$ from Proposition II, the sign of $\frac{dW^F}{dT}$ will depend on whether the equilibrium tax level in each state is higher or lower then the Pigouvian optimal. From Proposition III, we know that *ceteris paribus* a state will over-correct its tax if it receives a high enough grant and/or has a low enough level of corruption. Thus, from (17) we can infer that a large enough grant may undermine welfare, especially in low-corruption regimes, and any further increase in the grant will only exacerbate this distortion.[18] The welfare loss will be larger once the cost of raising the grant is included in the model. Thus, we have

Proposition V: *Compared to the baseline case of a politically-inclined state government and no IGGs, the introduction of performance-linked IGG will reduce federal emissions but may lead to lower federal welfare when the grant amount is large enough.*

We next consider the pollution and welfare implications of a change in the extent of corruption in a state as captured by the weight assigned to pure social welfare relative to campaign contribution. It can be shown that following an exogenous increase in δ:

Lemma I:

$$\begin{aligned} &\frac{dt}{d\delta} > 0 \ , \\ &\frac{dt^*}{d\delta} \gtreqless 0 \text{ if } e \gtreqless e^*. \end{aligned} \tag{18}$$

See Appendix (2.2) for a formal proof of this result. Given that *ceteris paribus*, a higher δ would lead to lower emissions, *Lemma I* implies that $\frac{dt^*}{d\delta} \gtreqless 0$ if $\delta \lesseqgtr \delta^*$. Thus, as a state government

[17] It is easy to see using (12) and the corresponding expression for state 2 that the sum of direct welfare effects of a change in T in the two states will be given by $\frac{\partial W^F}{\partial T} = \frac{e^*}{e+e^*} + \frac{e}{e+e^*} = 1$

[18] This result can also be inferred directly from (16). Given that $\frac{dt}{dT}$ and $\frac{dt^*}{dT} > 0$, there is higher tax in both states following an increase in T. In turn, this has two effects on welfare. One, it leads to higher welfare in each state due to a diversion of bribes into welfare. This is captured by a decline in lobby surplus in each state ($\frac{e}{\delta}$, $\frac{e^*}{\delta^*}$), which we know from (7), leads to a proportional reduction in bribes. Two, lower emissions in a state lead to a reduction in the grant share of the *other* state, reducing the latter's welfare (captured by the second expression within each bracket). For a large enough T, the direct positive welfare effect within a jurisdiction can be outweighed by the negative cross-effect in the other jurisdiction, especially when corruption levels are low.

becomes more concerned about social welfare, as expected, it will increase its equilibrium pollution tax-rate. The response of the other state is, however, contingent on its relative corruption level. Following the reasoning in Proposition IV, the more (less) corrupt state will respond with a lower (higher) tax.

Writing the net effect on federal emissions as

$$\frac{dE}{d\delta} = \frac{de}{d\delta} + \frac{de^*}{d\delta} = \frac{\partial e}{\partial t}\frac{dt}{d\delta} + \frac{\partial e^*}{\partial t^*}\frac{dt^*}{d\delta},$$

and using Lemma I, it is straightforward to see that when $\delta < \delta^*$, an increase in δ will cause both t and t^* to rise, and consequently $E = (e + e^*)$ will fall given $\frac{\partial e}{\partial t}$, $\frac{\partial e^*}{\partial t^*} < 0$. However, when $\delta > \delta^*$, an increase in δ will result in higher t but lower t^*. In turn, e will fall and e^* will rise and the net effect on federal emissions will be ambiguous. If we assume that the direct effect on e (via t) is stronger than the second-order substitution effect on e^* (through the effect of a change in e on t^*), there will be a fall in federal emissions. However, a large-enough grant can create a strong substitution effect to the extent that federal emissions increase. Mathematically, this can be seen from the functional forms of $\frac{dt}{d\delta}$ and $\frac{dt^*}{d\delta}$ in Appendix 2.2. With a large enough grant, $\frac{dt^*}{d\delta}$ can be higher than $\frac{dt}{d\delta}$, which can lead to an overall increase in emissions when $\delta > \delta^*$.

Turning to welfare implications, the net effect in federal welfare following a marginal change in δ can be expressed as:

$$\frac{dW^F}{d\delta} = \frac{\partial W^F}{\partial t}\frac{dt}{d\delta} + \frac{\partial W^F}{\partial t^*}\frac{dt^*}{d\delta} = \underbrace{\left(\frac{e}{\delta} + \frac{e^*}{(e+e^*)^2}T\frac{\partial e}{\partial t}\right)\frac{dt}{d\delta}}_{\text{effect on federal welfare via t}} + \underbrace{\left(\frac{e^*}{\delta^*} + \frac{e}{(e+e^*)^2}T\frac{\partial e^*}{\partial t^*}\right)\frac{dt^*}{d\delta}}_{\text{effect on federal welfare via } t^*} \quad (19)$$

An increase in δ will affect federal welfare via changes in t and t^*, which are captured in the two terms on r.h.s respectively. Substituting from (13) and (14) respectively for these effects, (19) can be written as:

$$\frac{dW^F}{d\delta} = (\hat{t} - \alpha n D')\frac{\partial e}{\partial t}\frac{dt}{d\delta} + (\hat{t^*} - \alpha^* n^* D^{'*})\frac{\partial e^*}{\partial t^*}\frac{dt*}{d\delta} \quad (20)$$

The signs of the two terms on r.h.s will depend on (i) the equilibrium tax in each state as compared to the Pigouvian level, which from Proposition III is a function of the size of T and δ in each state, and (ii) relative corruption levels in the two states which will determine the signs of $\frac{dt}{d\delta}$ and $\frac{dt^*}{d\delta}$ following *Lemma 1.* The four possibilities that arise are summarized in Table 1.

Intuitively, when the grant size is large enough, we start with a welfare-distorting over-correction of pollution taxes in both states. An increase in δ when $\delta > \delta^*$ will further increase t but reduce t^*. This exacerbates the welfare loss in state 1 but reduces it in state 2, the net effect being ambiguous. However, an increase in δ when $\delta < \delta^*$ will lead to an increase in both t and t^*,

Table 1: Possible effects of a marginal increase in δ on federal welfare

	$Tlarge$	$Tsmall$
$\delta > \delta^*$	ambiguous	ambiguous
$\delta < \delta^*$	-	+

reducing welfare further in both states and undermining federal welfare. When T is low enough we start with pollution taxes in both states being short of the welfare-optimizing Pigouvian levels. Now an increase in δ when $\delta > \delta^*$ will increase t but reduce t^*, leading to a welfare gain in state 1 but a further welfare loss in state 2, the net federal effect being ambiguous. On the other hand, an increase in δ when $\delta < \delta^*$ will lead to an increase in both t and t^* increasing welfare in both states. This leads us to:

Proposition VI *The effect on federal welfare following an increase in δ will depend on (i) relative corruption levels in the two states and (ii) size of IGG. Only when the more corrupt state reduces its level of corruption and IGG are small enough is a gain in federal welfare assured.*

The result that corruption reform in a state may reduce federal welfare may prima facie appear to support the "grease the wheels" hypothesis of corruption. The hypothesis implies that corruption, which in general is welfare-reducing, may be beneficial in situations where other aspects of governance are ineffective. However, on closer reflection, our result suggests that in the presence of an existing distortion (here, corruption), an additional distortion (created by large IGG) leads to lower, not higher, welfare. This in fact is the explanation behind "sand the wheels" explanation of the welfare-reducing effects of corruption even where governance is already weak (Méon and Sekkat 2005).

5 Generalizing to n jurisdictions

We now extend the analysis to the case of n jurisdictions. We find that when there are more than two states, there is a change in the condition that determines the direction of the strategic interaction in tax policies. Now the pollution tax in a state is a strategic substitute (complement) of the other's if its pollution level is higher (lower) than the aggregate of remaining states. Mathematically, let the share of state j in the grant now be given by the expression $s_j = \frac{1}{N-1}\left(1 - \frac{e_j}{\sum_i e_i}\right)$, where N is the number of jurisdictions in the federation.[19] Suppressing arguments, the equilibrium

[19]The normalization of grant shares by $\frac{1}{N-1}$ is necessary to ensure that the shares add up to one

level of the tax in the *jth* jurisdiction is now given by:

$$\hat{t_j} = \alpha_j n_j D'_j + \frac{T}{N-1} \frac{\sum_{i \neq j} e_i}{(\sum_i e_i)^2} + \frac{e_j}{\delta_j \frac{\partial e_j}{\partial t_j}}.$$

The corresponding slope of the best response function of t_j with respect to t_k, $j \neq k$, is given by:

$$\frac{dt_j}{dt_k} = \frac{\delta_j T}{(N-1)(\sum e_i)^3 \Delta_j} \frac{\partial e_j}{\partial t_j} \frac{\partial e_k}{\partial t_k} (e_j - \sum_{i \neq j} e_i). \tag{21}$$

From equation (21), it follows that:

Proposition VII *In general, when n jurisdictions compete for pollution-based-shares in a fixed federal grant, the pollution tax policy of a jurisdiction is a strategic complement (substitute) of any other jurisdiction's pollution tax, if the former's pollution level is smaller (larger) than the aggregate of the rest of the federation.*

To the extent that the likelihood of emissions of one state exceeding the combined emissions of the rest in a federation (even if it is the most corrupt state in the federation) becomes smaller as n rises, the possibility of strategic substitutability in inter-jurisdictional tax policies is lower compared to the 2-jurisdiction model. This is especially so since the stability of the model requires that the jurisdictions are not too heterogenous in their environmental outcomes (from A1). However, the increased possibility of strategic complementarity implies that a reduction in the pollution tax in one state can trigger the rest to follow suit, thus causing a race-to-the-bottom in pollution taxes while competing for federal grants.

6 Conclusions and some policy lessons

Motivated by the recent use of federal grants linked to environmental/ecological indicators, we study how sub-national (state-level) environmental policy may respond to such grants. We start with a sub-optimal environmental policy in a state due to the influence of an industry lobby on a rent-seeking state government. We then introduce IGG from the federal government that are aimed at reducing this distortion. The interesting result that emerges from the model is that competition for IGG leads to an asymmetric interaction in state environmental policies. Environmental taxes in two states may become strategic complements or substitutes of each other depending on their relative levels of pollution. As the number of jurisdictions in the federation increases, the possibility of strategic complementarity rises, and a race-to-the bottom in environmental taxes cannot be ruled out.

The analysis offers some useful insights on the use of IGG as a federal policy instrument. One, we find that such a system of grants can effectively regulate environmental outcomes only when states are not too heterogenous in their environmental performance. Two, while the grant provides an incentive to each state to strengthen its environmental policy, this incentive is greater for the state which is already a better environmental performer. To that extent, the grant is more a reward for performers than an incentive for laggards. Three, a high enough grant can undermine welfare by leading to a higher-than Pigouvian level of pollution tax. This may not be undesirable in itself given that marginal damages from environmental degradation are not fully understood and most likely under-estimated. Four, the bigger concern about the grant arises from the interaction it creates amongst sub-national environmental policies. The possibility of strategic substitution implies that in response to higher pollution tax in a state (say, due to lower corruption), its neighbor may respond with a lower pollution tax, which can actually increase federal emissions and reduce welfare if the grant is large enough. Interestingly, there is recent empirical evidence of strategic substitution in conservation decisions of counties in Brazil due to a system of grants linked to their conservation efforts.

As a possible extension of this research, it will be interesting to empirically study the relevance of our results in countries like India after a few years of experience with such IGG. At a theoretical level, it is possible to enhance the model with extensions. In particular, it will be useful to introduce the cost of provisioning the grant as a deadweight loss or an additional tax. Different uses of the grant allocation can also be examined e.g. earmarking for an environmental public good, compensating polluters, or reducing other taxes in the economy to study how the use of the grant affects the equilibrium tax and also where the grant can be most efficiently used for a double-dividend. The federal government's objective function can also be explicitly introduced either in a Stackelberg or a simultaneous-move game. Finally, we could study the effect of grants on alternative policy instruments, such as pollution standards, and in addressing other sources of distortion in environmental policy, such as inadequate fiscal or enforcement capacity in states.

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Appendix 1: Firm-level production decisions

From section 2.1, equations (2) and (3) implicitly define the equilibrium values of x and a as functions of the pollution tax, t. Using the implicit function rule for a simultaneous 2 equation case ($F^1(x,a,t)=0$ and $F^2(x,a,t)=0$), for the system of equations represented by equations (2) and (3), respectively, we get the following:

$\frac{\partial x}{\partial t} = \frac{J_1}{J}$, where J is

$$J = \begin{vmatrix} \frac{\partial^2 \Pi(t)}{\partial x^2} & \frac{\partial^2 \Pi(t)}{\partial x \partial a} \\ \frac{\partial^2 \Pi(t)}{\partial a \partial x} & \frac{\partial^2 \Pi(t)}{\partial a^2} \end{vmatrix} = \begin{vmatrix} -C_{xx} & -C_{xa} - t\theta_a \\ -C_{ax} - t\theta_a & -C_{aa} - tx\theta_{aa} \end{vmatrix} \tag{A1}$$

and J_1=

$$J_1 = \begin{vmatrix} -\frac{\partial^2 \Pi(t)}{\partial x \partial t} & \frac{\partial^2 \Pi(t)}{\partial x \partial a} \\ -\frac{\partial^2 \Pi(t)}{\partial a \partial t} & \frac{\partial^2 \Pi(t)}{\partial a^2} \end{vmatrix} = \begin{vmatrix} \theta & -C_{xa} - t\theta_a \\ x\theta_a & -C_{aa} - tx\theta_{aa} \end{vmatrix} \tag{A2}$$

Here, J is unambiguously > 0 from the second-order conditions for profit maximization. If the production function is sufficiently concave in abatements costs, J_1 can be assumed to be < 0, implying $\partial x / \partial t < 0$.

Likewise, $\frac{\partial a}{\partial t} = \frac{J_2}{J}$, where J_2, is given by:

$$J_2 = \begin{vmatrix} \frac{\partial^2 \Pi(t)}{\partial x^2} & -\frac{\partial^2 \Pi(t)}{\partial x \partial t} \\ \frac{\partial^2 \Pi(t)}{\partial a \partial x} & -\frac{\partial^2 \Pi(t)}{\partial a \partial t} \end{vmatrix} = \begin{vmatrix} -C_{xx} & \theta \\ -C_{ax} - t\theta_a & x\theta_a \end{vmatrix} \tag{A3}$$

Once again, $J_2 > 0$ and $\frac{\partial a}{\partial t} > 0$ if the production function is sufficiently concave in production costs.

Appendix 2.1: Comparative statics with respect to T

By totally differentiating equation (13), and rearranging terms, we get:

$$\underbrace{\left(1 - \alpha n D'' \frac{\partial e}{\partial t} + \frac{2e^* T}{(e+e^*)^3} \frac{\partial e}{\partial t} - \frac{1}{\delta} + \frac{e \frac{\partial^2 e}{\partial t^2}}{\delta (\frac{\partial e}{\partial t})^2}\right)}_{\text{r}} \frac{dt}{dT}$$

$$= \underbrace{\frac{T}{(e+e^*)^3}(e-e^*)\frac{\partial e^*}{\partial t^*}}_{\text{f}} \frac{dt^*}{dT} + \frac{e^*}{(e+e^*)^2} \tag{A4}$$

Similarly totally differentiating equation (14) and rearranging terms:

$$\underbrace{\left(1-\alpha^* n^* D^{*\prime\prime}\frac{\partial e^*}{\partial t^*}+\frac{2eT}{(e+e^*)^3}\frac{\partial e^*}{\partial t^*}-\frac{1}{\delta^*}+\frac{e^*\frac{\partial^2 e^*}{\partial t^{*2}}}{\delta^*(\frac{\partial e^*}{\partial t^*})^2}\right)}_{\text{g}}\frac{dt^*}{dT}$$

$$=\underbrace{\frac{T}{(e+e^*)^3}(e^*-e)\frac{\partial e}{\partial t}}_{\text{h}}\frac{dt}{dT}+\frac{e}{(e+e^*)^2} \quad \text{(A5)}$$

Writing the resulting system of equations in matrix notation, we get:

$$\begin{vmatrix} r & -f \\ -h & g \end{vmatrix} = \begin{vmatrix} \frac{dt}{dT} \\ \frac{dt^*}{dT} \end{vmatrix} = \begin{vmatrix} \frac{e^*}{(e+e^*)^2} \\ \frac{e}{(e+e^*)^2} \end{vmatrix} \quad \text{(A6)}$$

where the value of the l.h.s determinant $rg - hf$, is given by:

$$\frac{\Delta}{\delta\frac{\partial e}{\partial t}} * \frac{\Delta^*}{\delta^*\frac{\partial e^*}{\partial t^*}} - \frac{T}{(e+e^*)^3}(e-e^*)\frac{\partial e^*}{\partial t^*} * \frac{T}{(e+e^*)^3}(e^*-e)\frac{\partial e}{\partial t} \quad \text{(A7)}$$

This uses the fact that the term (r) in expression (A4) can also be written as $\frac{\Delta}{\delta\frac{\partial e}{\partial t}}$ and the term (g) in expression (A5) can be written as $\frac{\Delta^*}{\delta^*\frac{\partial e^*}{\partial t^*}}$, where Δ and Δ^* are the SOC's of the objective functions of states 1 and 2 respectively.

In (A7), Δ, Δ^*,$\frac{\partial e}{\partial t}$, $\frac{\partial e^*}{\partial t^*} < 0$. Further given that $(e - e^*)$ and $(e^* - e)$ necessarily have the opposite signs, it follows that $rg - hf > 0$.

Using Cramer's Rule, we have

$$\frac{dt}{dT} = \frac{\frac{e^*}{(e+e^*)^2} * \frac{\Delta^*}{\delta^*\frac{\partial e^*}{\partial t^*}} + \frac{e}{(e+e^*)^2}\frac{T}{(e+e^*)^3}(e-e^*)\frac{\partial e^*}{\partial t^*}}{rg - fh}$$

$$\frac{dt^*}{dT} = \frac{\frac{e}{(e+e^*)^2} * \frac{\Delta}{\delta\frac{\partial e}{\partial t}} + \frac{e^*}{(e+e^*)^2} * \frac{T}{(e+e^*)^3}(e^*-e)\frac{\partial e}{\partial t}}{rg - fh} \quad \text{(A8)}$$

Thus we have, for the case when $e \lesseqgtr e^*$:

- $\frac{dt}{dT} > 0$
- $\frac{dt^*}{dT}$ is ambivalent in sign

The r.h.s in (A8) has two terms. The first term represents a (positive) direct effect of a change in T. The second represents a second-order effect of T via a change in t. Assuming that first-order effect dominates, we can infer that $\frac{dt^*}{dT} > 0$, though the incentive effect of the higher grant is somewhat muted for $t*$ due to the expected increase in t.

Appendix 2.2: Comparative statics with respect to δ

Totally differentiating equations (13) and (14), and writing in matrix notation, we have:

$$\begin{vmatrix} r & -f \\ -h & g \end{vmatrix} = \begin{vmatrix} \frac{dt}{d\delta} \\ \frac{dt^*}{d\delta} \end{vmatrix} = \begin{vmatrix} -\frac{e}{\delta^2 \frac{\partial e}{\partial t}} \\ 0 \end{vmatrix} \tag{A9}$$

Using Cramers's rule, we can get the comparative static results with respect to δ from (A9) as follows:

$$\frac{dt}{d\delta} = \frac{-\frac{e}{\delta^2 \frac{\partial e}{\partial t}} * \frac{\Delta^*}{\delta^* \frac{\partial e^*}{\partial t^*}}}{rg - fh}$$

$$\frac{dt^*}{d\delta} = \frac{-\frac{e}{\delta^2 \frac{\partial e}{\partial t}} * \frac{T}{(e+e^*)^3}(e^* - e)\frac{\partial e}{\partial t}}{rg - fh}$$

Given that $rg - fh > 0$, it is easily seen that $\frac{dt}{d\delta} > 0$. However, $\frac{dt^*}{d\delta} \gtrless 0$ according as $e^* \lesseqgtr e$

Appendix 3: Conditions for concavity of the best response functions

From equation (13), we can derive the slope of the best response function $t = f(t, t^*)$ as follows: $\frac{d^2 f(t^*)}{dt^{*2}} = A * (K + L + M + N)$, where

$$A = \frac{\delta^2 (\frac{\partial e}{\partial t})^2}{\Delta^2} > 0;$$

$$K = \frac{4(T)^2}{(e+e^*)^7} \frac{\partial e)}{\partial t} \left(\frac{\partial e^*}{\partial t^*}\right)^2 (e - e^*)(2e^* - e)$$

$$L = \frac{\Delta T}{\delta (e+e^*)^3} \frac{\partial e}{\partial t} \left[\frac{\partial^2 e^*}{\partial t^{*2}}(e - e^*) - \frac{2}{(e+e^*)} \left(\frac{\partial e^*}{\partial t^*}\right)^2 (2e - e^*)\right]$$

$$M = \frac{\delta (T)^2}{\Delta (e+e^*)^7} \frac{\partial e}{\partial t} \left(\frac{\partial e^*}{\partial t^*}\right)^2 \frac{\partial^2 e}{\partial t^2}(e - e^*)^2 \left[\alpha n D'' - \frac{2Te^*}{(e+e^*)^3} + \frac{2e}{\delta \left(\frac{\partial e}{\partial t}\right)^3} \frac{\partial^2 e}{\partial t^2} - \frac{1}{\delta \frac{\partial e}{\partial t}}\right]$$

$$N = \frac{6\delta (T)^3}{\Delta (e+e^*)^{10}} \left(\frac{\partial e^*}{\partial t^*}\right)^2 \left(\frac{\partial e}{\partial t}\right)^3 (e - e^*)^2$$

For concavity, we need $(K + L + M + N) < 0$. By inspecting the above expressions closely, we can infer that for both cases, $e < e^*$ and $e > e^*$, concavity will require that D'' be large, Δ be large enough and $e^* \not> 2e$. Similarly, from $\frac{d^2t^*}{dt^2}$, we get the necessary condition for concavity as $D^{*''}$ large, Δ^* large enough and $e \not> 2e^*$. Together, the necessary conditions for the concavity of the best-response functions may be written as: $e \not> 2e^*$; $e^* \not> 2e$; D'', $D^{*''}$ be large and Δ, Δ^* be large enough.