ROTTEN KIDS AND CARBON EMISSIONS UNDER FEDERAL GOVERNANCE

by

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Introduction

During the 21st century, concern about the environment in general, and global climate change[1] in particular, has increased. Most of the concern has centred around greenhouse gas emissions, especially carbon emissions. While contemporary political debate suggests that there is considerable disagreement about the existence and cause of global climate change,[2] the overwhelming majority of scientists agree that human activity has appreciably affected the global climate in recent years.[3] In an attempt to reverse, or at least reduce, the effects of human activity on the environment, governments have introduced a multitude of new environmental regulations. Perhaps the most discussed and controversial of these is carbon emission regulation. A wide variety of regulations have been adopted, from conventional emission limits to more complicated emissions trading regimes. At the core of all carbon emission regulation is the desire to limit carbon emissions (Nordhaus 2007). While the differences among regulatory regimes have been extensively studied and modelled, the consequences of regulation in a federal context have not been as thoroughly investigated. In this paper, I will model carbon regulation under federalism from a game theory perspective. I will examine how a federal system of government impacts incentives and how this alters the

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[1] The term “global climate change” will be used in place of the more familiar “global warming” as a reminder that the recent changes to the global climate system have been broader than the latter term would indicate.

[2] For a discussion on the contemporary political debate on global climate change, see Giddens (2009)

[3] For a discussion on the difference in the scientific consensus and the coverage in the press, see Boykoff & Boykoff (2004).

behaviour of both subnational[1] and central[2] governments. In particular, I will use the "rotten kid theorem" to explain why self-interested subnational governments may choose the socially optimal level of carbon emissions when the federal government uses transfers to redistribute income between subnational jurisdictions.

The rotten kid theorem has previously been used to shed light on many economic phenomena, including in the area of environmental regulation. However, it has not been applied to the area of carbon regulation. More importantly, in the broad context of environmental regulation it has only been applied in a relatively narrow range of circumstances. Specifically, the application of the theorem in environmental regulation has only been minimally studied in a federal context. The present paper will examine the application of the rotten kid theorem to environmental regulation under federalism in a variety of scenarios.

The first section of this paper will review the previous literature; it will broadly outline fiscal federalism, introduce environmental regulation literature, and briefly review some of the basic scientific literature on carbon emissions. The first section will also introduce the "rotten kid theorem", review some conditions under which it applies, and its limitations. The second part of the paper will introduce a theoretical framework under which a model will be created that illustrates some of the implications of the rotten kid theorem in a more precise manner. The model will consist of two self-interested subnational governments and a benevolent central government which tries to maximize

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[1] For simplicity, "subnational" will refer to a region or government which is a member of a larger political entity. For example, provinces and states are subnational entities. Note that countries themselves can be considered subnational in some contexts. For example, the individual members of the EU would be considered subnational entities for the purpose of this article because they are subject to the governance of the EU.

[2] The term "central" will refer to governments which have the power to legislate with respect to multiple subnational areas. For example, this would be a federal government in the US or Canada or the EU government in Europe.

its social welfare function through transfers. The paper will show that, under certain conditions, the incentives of the subnational governments will be such that they will behave in a more cooperative manner than may be expected.

Literature Review

Before the introduction of any theoretical framework, it is important to review previous results. This allows us to increase our awareness of the limitations and shortcoming of the existing body of knowledge. In order to properly understand the economics of carbon regulation and to create a more relevant theoretical model, we should understand the science of global climate change and the effects of carbon emissions. To this end, before any economic literature is reviewed, the basic scientific principles will be discussed. Following a discussion of the science, the economics literature will be reviewed. Both the basics of fiscal federalism and recent literature regarding environmental regulation in a federal context will be reviewed, specifically as it it relates to carbon pricing. Finally, the rotten kid theorem will be addressed.

Overview of the Science of Carbon Emissions

While contemporary political debate would lead the casual observer to conclude that the existence of global climate change is controversial, the overwhelming majority of experts believe that the global climate system has unequivocally changed in the past century (Oreskes 2007). The most obvious of these changes has been the increase in average global temperature. The exact cause of this change is not fully understood, but it is generally agreed that this has been due to greenhouse gases. Additionally, there is much evidence to suggest that the pace of global climate change is accelerating and will continue to do so if current policies are maintained (Cox *et al.* 2000).

Greenhouse gases are the constituents of the atmosphere that absorb and emit thermal infrared radiation. Part of this radiation is emitted in the direction of the earth's surface which results in an elevation of the temperature of the earth; this is the greenhouse gas effect. The primary greenhouse gases are water vapour, carbon dioxide, nitrous oxide, methane, and ozone. While water vapour is the largest contributor to the greenhouse gas effect, the concentration of water vapour is largely determined by the atmospheric temperature. The concentration of water vapour is higher at higher temperatures. In other words, water vapour is not itself responsible for changes to the earth's temperature, but rather serves to magnify the effects of other factors that change global temperatures (Kiehl and Trenberth 1997). Among the "true" greenhouses gases, it is carbon dioxide that is the largest contributor to the greenhouse effect. It is estimated that between (approximately) 10% and 25% of the greenhouse gas effect is caused by carbon dioxide (Kiehl and Trenberth 1997). Methane, the next most important greenhouse gas contributes less than half this amount. Other greenhouses gases have a much greater effect on a per molecule basis, but the sheer amount of carbon dioxide in the atmosphere results in it having a much greater cumulative impact. It is also estimated that increases in the concentration of carbon dioxide is responsible for approximately two thirds of the increase in global temperature.

On a global basis, the most obvious effect of the increase in greenhouse gases has been the increase in the Earth's surface temperature. However, there have been other impacts as well. Increases in temperatures have led to rising global sea levels, reduced snow cover, increased hydrological runoff, and shifts in plant and animal ranges (Tol 2009). The effects of greenhouses gases have not been limited to increased global temperatures and its related consequences. It is also likely that heat waves, heavy precipitation events, droughts, and tropical storms have increased due to the increases in greenhouse gases.

The effects of greenhouses gases have not been uniform across the regions of the earth (Hansen *et al*. 2006) Even if only temperature increases are examined, it is clear that the changes in temperatures resulting from increases in greenhouse gases differ across regions. In general, temperatures are increasing most rapidly at the poles and less rapidly closer to the equator. In addition to the fact that temperatures are not increasing at a uniform rate across regions, some regions are much more sensitive to changes in temperature than others. For example, relatively dry areas are generally highly sensitive to temperature changes due to their fragile water systems. Also, many of the effects of increased greenhouse gas levels have much different impacts on different areas of the world. For example, low lying areas are more sensitive to rising sea levels.

Before moving onto the economic literature, we should note two important points: 1) the carbon emissions of one area affects other areas 2) different jurisdictions have different sensitivity to carbon emissions. These two properties should be kept in mind when constructing our model.

Fiscal Federalism and the Economics of Environmental Regulation

At the core of the study of fiscal federalism is the tension between what the roles of the central and subnational governments should be. It is not always easy to decide which functions central governments should perform and which functions subnational governments should perform. However there are certain factors that make it more advantageous for one level of government to perform certain functions. One of the central goals of fiscal federalism scholarship is to identify which factors should be used in determining the level of government that is best-suited to perform certain functions. General principles can be formulated which guide this determination. This section will briefly outline the major issues in fiscal federalism and some general principles that have crystallized in the literature. It will also discuss how the economics of environmental regulation fits into the general framework of fiscal federalism.

In recent decades, there have been movements to both centralize and decentralize certain functions of government. Perhaps the best examples of these conflicting forces are found in Europe. In recent decades, the central governments of the United Kingdom and Spain have increasingly shifted power to regional governments while the European Union has centralized (at a supranational level) many functions previously conducted at nationally. The movement to both centralize and decentralize has been reflected in the area of environmental regulation. One example of this is the European Environmental Agency which began its operations in 1994 and has centralized certain policy making functions while simultaneously decentralizing administrative functions. At the same time, the academic world has tried to conceptualize and model the interactions between different levels of government.

The origins of fiscal federalism are housed in earlier notions of public finance which held that the role of the government was to act when private markets failed.[1] Public economics literature has focused on finding the causes of market failures and how they could be corrected by government. Early public finance research generally assumed that governments would maximize social welfare (sometimes in order to

[1] This overview of fiscal federalism draws on two articles by Wallace Oates (1999 and 2005).

maximize their own likelihood of reelection). In the federal context, each level of government was assumed to maximize the social welfare function relevant to its own constituency. The primary advantage of federalism identified in the early literature, was the ability of federal systems to supply local public goods according to local conditions, rather than uniformly. When conditions or preferences vary by locale, federal systems can achieve better outcomes than unitary governments supplying a uniform level of public goods irrespective of local conditions.

While the conclusions of fiscal federalism dictate that subnational governments have control over local public goods, central governments should have jurisdiction of issues that are too large to be addressed by subnational governments. For example, central governments are better equipped to handle issues like prices and macroeconomic stability. Likewise, they are in a better position to address income redistribution because of the undesirable migration effects that any local redistribution will have. The supply of local public goods that have externalities on neighbouring areas is best done by a combination of local provision and federal subsidization or taxation as appropriate.

On the surface, it would appear that a central government could (with perfect information) provide the optimal level of public goods according to local conditions and preferences. The early literature cites two reasons why this outcome is unlikely to occur: 1) it is more difficult for the central government to get perfect information on local preferences and conditions compared to a subnational government; 2) there are political constraints that make it difficult for a central government to have widely different policies in different subnational jurisdictions. Later models and empirical evidence challenged the second of these two rationales (Lockwood 2002).

In the environmental context, it follows that since most types of pollution (especially greenhouse gas emissions) have effects outside the area in which they are produced, the federal government is in the best position to regulate pollution. In fact, most attempts to model pollution regulation in a federal system have found that regulation by the central government is more efficient. For example, a recent paper which uses an empirically based simulation model to explore the trade-off between federal and state regulation of the environment, found that US states acting in their own best interests would lose 30% of the benefits of first-best regulation, while the federal government would lose only 0.2% (Banzhaf and Chupp 2010). This is primarily due to the fact that externalities are more important than any differences between the states.

While most theoretical models have found that federal regulation of pollution is preferred, some of the empirical evidence finds the opposite. A 2002 article, which compared environmental regulation in US before and after 1970 (when the federal government became more heavily involved), found that the states were more effective in the regulation of air pollution (Revesz 2001). Similarly, a study which looked at the behaviour of US states found that states which increase their environmental regulations influence their neighbours to do likewise (Fredriksson and Millimet 2002). This is the opposite of what might be predicted, because a reduction in your neighbouring state's pollution would presumably decrease the marginal cost of your pollution.

In other models, a combination of both central and subnational regulation is preferred. For example, a 1999 sequential game model (Caplan and Silva 1999) found that if subnational governments move first and set pollution taxes while the federal government subsequently set pollution abatement levels, the result would be socially efficient. In general, it is preferable for subnational governments to act first so that the federal government can correct for any inefficiencies that their self-interested behaviour causes.

While taxation is not explicitly dealt with in this paper, it is informative to have a brief overview of how different levels of government should use taxation to collect the revenue necessary to provide government services. One of the main findings of the early literature on taxation in public economics is that subnational governments should generally rely on benefit taxes, for example user fees and property taxes. This is due to the fact that the use of non-benefit taxes at the subnational level can result in distortions (Inman and Rubinfeld 1996), for example capital flight (Gordon 1983). Just as central governments are in a better position to redistribute income, they are also in a better position than subnational governments to use progressive income taxes.

The assumption that governments act in a strictly benevolent, social welfare maximizing manner was common in early fiscal federalism models. However, some models had more nuanced assumptions about the motivations of government and the role of federalism. "Leviathan" models were constructed under the assumption that the goal of government was to increase in size by maximizing its own revenues (Brennan and Buchanan 1980). In these models, the role of federalism is to create competition among subnational governments which serves to constrain their growth.[1] Later models have questioned whether competition between jurisdictions is beneficial or whether it creates its own distortions (Volden 2005).

More recent models have two additional features: an explicit role for political agents (rather than modelling the government as a coherent whole) and informational dynamics. Research which models political agents explicitly, pays more attention political processes and the individual actions of public officials. Newer models have

[1] This position has found empirical support (Rodden 2003).

shown that differences in the information that different levels of government have access to can substantially change federal economic outcomes. An important class of asymmetric information models take the form of principal-agent models. One group of principal agent models treats the federal government as the principle and the subnational governments as the agent. Under certain conditions, it is efficiency enhancing for the central government to attach conditions to the transfers it makes to subnational governments (Levaggi 2002). Another group of models treats the electorate as the principals and elected officials as the agents. In some of these models, the population is better off in a federal system even when the entire population is homogeneous.

Literature in the area of environmental federalism has generally assumed that both federal and subnational governments act in order to maximize their own social welfare functions. Each government is seen as a benevolent institution which does not have ulterior motives. The relative lack of literature in this area highlights the fact that more research can be conducted to study how political motivations and the political process might impact environmental regulation in a federal environment.

The Rotten Kid Theorem

The so called “rotten kid theorem” was introduced by Gary Becker in a much praised 1974 article. In this article, he argues that if the head of a household is benevolent and sufficiently wealthy, each member of the household, regardless of how selfish they are, will act in a way that maximizes the total income of the family rather than his own personal income. The reason for this behavior can be explained as follows: if the head of the household is benevolent and treats the consumption of each family member as a “normal good”, he will try to equalize the consumption of each member of the household. Therefore, a selfish family member will only be able to maximize his own consumption by maximizing the consumption of the family as a whole.

The argument supporting the rotten kid theorem can be made more rigorous if we introduce assumptions about technology and tastes, as demonstrated by Bergstrom (1989). He introduces the model with n kids and one consumption good x. Each kid’s utility is determined solely by his consumption, so that the utility of kid i is $u_i(x_i) = x_i$. The utility of the head of the household (u_o) is given by his own consumption (x_o) and the consumption of each of his children $u_o(x_o, \ldots\ldots\ldots\ldots, x_n)$. This function is strictly increasing in all x_i’s. Each member of the household earns a personal income m_i, which depends on his own actions a_i and the actions of other members of the household. The vector of actions is $\boldsymbol{a}$. The head of the household is assumed to be so wealthy that he chooses to give all of his income to other members of the household. If these conditions are met, Bergstrom shows that in the two-stage game, where households first choose their actions and then the head choose how to allocate his income, the self-interest of each family member coincides with the collective interests of the family.

One major issue with the rotten kid theorem is that it is not robust. When small changes are made to the assumptions, its results do not hold. Bergstrom (1989) showed that the theorem generally fails if the kids care about their activities. This occurs, for example when leisure is a complement to consumption. When this is the case, it is in the kids’ best interests to use more leisure than would be required to maximize total utility. Similarly, the theorem does not hold when time is introduced. Lindbeck and Weibull (1988) showed that when individuals can choose between present and future consumption, the outcome will be inefficient and the rotten kid theorem will not apply. The “kids” will have an incentive to free ride, knowing they can take advantage of the altruism of the donor. They undersave in the first period to get a larger transfer in the second period. It is the lack of the ability for the donor to commit to a second period decision that creates the inefficiency. This result is known as the “smart kid theorem”.

A two period model similar to that of Lindbeck and Weibull (Bruce and Waldman 1990), also finds that the kids will undersave because of the parent’s inability to commit. It also shows that the parents will have to choose one of two courses of action in the second period, both of which involve inefficiencies. On the one hand, if the parent chooses to transfer in the second period, the result will be the same as found in Lindbeck and Weibull: the kid will have an incentive to undersave. On the other hand, if the parent chooses not to transfer to the kids in the second period, the kids will behave selfishly. In either case the family will not be on the pareto efficient frontier.

The rotten kid theorem may also not apply in situations when the set of choices to be made is discrete rather than continuous. For example, Lundberg and Pollak (2003) showed that when when families choose between discrete options like whether to move or have a child, they will generally not reach an efficient decision in a two period game. Again, this inefficiency comes from an inability to commit. When discrete decisions are made in a one period game, the efficiency returns.

The Model

Introduction and Framework

Before introducing the model, it is important to remember what it will be trying to achieve. The principal goal of this model is to show how self-interested subnational governments can be induced to act in a seemingly altruistic manner by a central government which uses transfers to maximize its social welfare function. The mechanism by which this occurs will serve as an illustration of the rotten kid theorem discussed above. In this model, the central government plays the part of the benevolent parent and the subnational governments play the part of the "rotten children".

There are three actors in the model: two subnational governments and the central government. The model abstracts from the more realistic scenario of multiple subnational governments for the sake of simplicity. The subnational governments can be thought of as provinces or states of a single federal country or as sovereign countries interacting under the umbrella of a supranational union, such as the European Union. In the model, the subnational governments are able only to choose their level of pollution. This may seem like an unrealistic assumption. However, we can consider a situation where the amount of pollution is determined only by the production or income of an economy. In this case, allowing a subnational government only the choice of a level of pollution is equivalent to allowing it to choose its level of production. Rather than consider an explicit production or income function, focusing solely on pollution allows for us to concentrate on greenhouse gas emissions.

The utility functions for states A and B are as follows:

$$U_a = T_a + (P_a - P_a^2) - aP_b$$

$$U_b = T_b + (P_b - P_b^2) - bP_a$$

The subscripts "a" and "b" refer to subnational jurisdictions "A" and "B" respectively. The term "P_a" refers to the amount of pollution emitted by A while "P_b" refers to the pollution emitted by B. The term "T_a" refers to the amount transferred to state A by the central government. Similarly, "T_b" refers to the amount transferred to state B by the central government. The symbols "*a*" and "b" are constants between 0 and 1 which reflect the fact that each state is adversely affected by some, but not all, of the pollution from the neighbouring state. We will assume that $a>b$. This reflects the fact that state A is assumed to be more sensitive to the pollution of state B than vice versa. This could be due to one of several reasons. For example, A could be more sensitive to changes in the local climate because of its relatively dry climate.

The first part of the first equation T_a does not exhibit diminishing marginal returns. It may be more realistic to assume diminishing marginal utility of income, but our simplifying assumption does not change the point being illustrated. The pollution of each subnational government has a positive marginal utility at low levels of pollution and increasingly high levels of pollution at higher levels. While we are not explicitly modelling a production function, we are implicitly assuming one. At sufficiently high levels of pollution, the marginal effect of pollution becomes increasingly negative as the negative effects of pollution overwhelms any positive effect. This reflects the fact that increasing levels of greenhouse gases and other pollutants have an increasingly greater effect on the environment as they increase above their natural level. The third term reflects the fact that pollution emitted by the neighbouring province only has a negative effect. We assume that the marginal effect is constant partially for the sake of simplicity and partially to reflect the fact that only some of the effects of pollution are absorbed by neighbouring countries. Some effects of greenhouse gas emissions, for example smog, have a greater effect locally. Also, some forms of pollution that are coincident with the release of greenhouse gas emissions, for example soil pollution, have little or no effect on a neighbouring state. For these two reasons, the marginal effect of the pollution of the neighbouring state is not increasing and also discounted by a constant between zero and one.

Social Optimum

Before we look at how each subnational government and the central government behaves in a variety of scenarios, it will be informative to see what the socially optimum level of pollution is. We will define the social optimum as the maximum of the joint utilities of both subnational governments. Because transfers to each subnational government have the same marginal utility they will not affect the sum of utilities and therefore the social optimum. We can find the social optimum by summing the total utilities and taking first order conditions with respect to P_a and P_b.

$$U_t = U_a + U_b$$

$$U_t = [T_a + (P_a - P_a^2) - aP_b] + [T_b + (P_b - P_b^2) - bP_a]$$

After taking the first order conditions of $\partial U_t/\partial P_a = 0$ and $\partial U_t/\partial P_a = 0$, we find that the optimum level of pollution are as follows:

$$P_a^o = (1-b)/2$$

$$P_b^o = (1-a)/2$$

Recalling our earlier condition that $a>b$, we see that $P_b^o<P_a^o$. This is explained by the fact that since state A is more sensitive to the pollution of B than vice versa, it is optimal for state B to produce a lower level of pollution than state A. As a and b increase we see that the optimal level of pollution decreases. In other words, as a higher percentage of

the pollution of one state is absorbed by its neighbouring, the optimal level of pollution of that state decreases. In this model, as *a* and *b* approach their maximum level of 1, the optimal level of pollution falls to zero.

We will also compute the level of utility attained by each state so that we can compare this to that which they attain under different scenarios. If we substitute the optimum levels of pollution of $P_a^o = (1-b)/2$ and $P_b^o = (1-a)/2$ into the utility functions of $U_a^o = T_a + (P_a^o - P_a^{o2}) - aP_b^o$ and $U_b^o = T_b + (P_b^o - P_b^{o2}) - bP_a^o$ we find that $U_a^o = ¼ - ¼b^2 - ½a + ½ a^2$. Similarly, we find that $U_b^o = ¼ - ¼a^2 - ½b + ½ b^2$. Now that we have found our socially optimal level of pollution and the corresponding levels of utility, we can investigate how these levels compare to those attained under a variety of scenarios.

Although we defined the social optimum as the maximum of the joint utilities, given the nature of our utility functions, the specific form of the social welfare function will not affect the socially optimal level of pollution.[1] Since the marginal utility from transfers is always constant for both jurisdictions, we can achieve any distribution of utilities we want, while keeping the total utility constant through transfers. As such, the nature of the social welfare function will only affect the optimal level of transfers, rather than the optimal level of pollution. Since we will later use a maximin utility function, we should note that the optimal transfers with a maximin utility function satisfy the following:

$$U_a^o = U_b^o$$

$$T_a^o + (P_a^o - P_a^{o2}) - aP_b^o = T_b^o + (P_b^o - P_b^{o2}) - bP_a^o$$

$$\Rightarrow T_a^o - T_b^o = (b^2-b) - (a^2-a)$$

[1] This is true as long as the marginal social utility of at least one of the jurisdiction's utility is positive. In other words, it will be true if it is always possible to increase the social welfare function by increasing the utility of at least one of the jurisdictions.

Without an Active Central Government

We will first consider the situation when the central government does not play an active part in the model. In this scenario, the central government will transfer a given amount to each state unrelated to the amount of pollution that each state produces. In other words, the central government does not try to maximize social welfare and does not respond to the action of the states. The subnational government consequently behave in a manner which is equivalent to how they would behave in the absence of a central government. We will first consider the case where each state acts simultaneously, then consider sequential moves.

Simultaneous Moves

Since each state is strictly self-interested, each subnational government will only consider its own utility when deciding how much pollution to emit. State A will choose its level of pollution in order to maximize its individual utility. In other words it will choose P_a in order to maximize:

$$U_a = T_a + (P_a - P_a^2) - aP_b$$

Taking the first order condition of $\partial U_a/\partial P_a = 0$, we find that $P_a = ½$. Similarly we find that $P_b = ½$. Substituting P_a and P_b, we find that $U_a = T_a + ¼ - ½a$ and $U_b = T_b + ¼ - ½b$.

We can recall that the optimal levels of pollution were found to be $P_a^o = (1-b)/2$ and $P_b^o = (1-a)/2$. Remembering that both a and b are between 0 and 1, we see that both state A and state B produce pollution that is greater than the optimal amount. This is due to the fact that each country is not taking into account the effect that its pollution has on the neighbouring state. In other words, the negative externality associated with pollution results in an amount being produced that is higher than the social optimum.

We can now examine how this higher level of pollution impacts the utility of each state. In the case of state A, the answer is clear: state A is unambiguously better off in the social optimum than in the equilibrium without an active central government. We recall that we found the social optimum level of utility to be $U_a^o = T_a + \frac{1}{4} - \frac{1}{4}b^2 - \frac{1}{2}a + \frac{1}{2}a^2$. We immediately see that $U_a^o > U_a$ since $\frac{1}{2}a^2 > \frac{1}{4}b^2$ (recall that $a > b$).

The utility attained by state B is more ambiguous. If we compare U_b to U_b^o we see that $U_b^o > U_b$ if and only $\sqrt{2}b > a$. In other words if and only if b is sufficiently large compared to a (greater than about 71% of the size of a), state B will be better off in the optimum than it would be in this equilibrium.

We can explain the fact that both states will not necessarily be better off in the social optimum if we understand that there are two competing effects at play. In the social optimum, each state is made worse off because they are producing at a level of pollution below their self-interested ideal. However, each state is also better off because the neighbouring state is producing a lower level of pollution. In state A, which is affected more by the pollution of its neighbour, the latter effect will always overwhelm the first. By contrast, in state B, the second effect will overwhelm the first if and only if $\sqrt{2}b > a$.

Sequential Moves

In this model (when there is not an active central government), the sequential move equilibrium will be identical to the simultaneous move equilibrium, regardless of which country acts first if each subnational government simply chooses its own level of pollution. The reason for this is that there is no interaction between the marginal effects of the pollution produced by state *A* and *B.* In other words, each state will choose a level of pollution that is not influenced by the level of pollution chosen by the neighbouring state. This can be seen from the fact that in the simultaneous move equilibrium, each state's choice of pollution levels was not influenced by the amount chosen by its neighbour. As such, all the results from the simultaneous move equilibrium apply to the sequential move equilibrium.

The sequential move outcome is more interesting if the first mover is given the ability to not only set its own level of pollution but to also announce how it will react to the actions of the second mover. We will consider the scenario where the first mover announces what its own actions will be, contingent on the actions of the second mover, and credibly commits to these announced actions. The second mover then decides on its actions with full information about the future reactions of the first mover. In this scenario, the social optimum will be reached.

To simplify this scenario, we will assume that A, the first mover, gives B, the second mover, two options. Government A will choose one course of actions if B pollutes at (or below) a prespecified amount and also transfers a certain amount (or more) to A (this course of actions will be referred to as "cooperative action"). If B pollutes more than or transfers less than these amounts, A will choose another course of actions (this course of action will be referred to as "threat action"). For the sake of consistency, we will consider A's threat action to be identical to the simultaneous move equilibrium; that is, the threat action will be: $P_a^T = ½$.

In order for A in induce B to take cooperative action it must set the pollution and transfers such that B's utility is higher when it takes cooperative action than it is when it takes the threat action. In the threat action, B knows that $P_a^T = ½$. We earlier found that B's best response will be to act in a symmetrical manner and set $P_b^T = ½$. Since neither

A nor B will use any transfers, this will result in $U_b^T = ¼ - ½b$. In order for the cooperative action to be attractive to B, it must result in a higher level of utility than this.

For A to maximize it first mover advantage, it must in effect grow the size of the total pie as large as possible and then extract the maximum amount of transfer from B, while ensuring that B's utility remains equal or greater than $U_b^T = ¼ - ½b$. For the sake of simplicity, we will assume that B will choose to cooperate if both actions give the same utility. In other words, A needs to choose its cooperative action such that $U_b^C = U_b^T = ¼ - ½b$. In order for A to maximize the total utility available, it will have to ensure that the pollution emitted by itself and B is equal to the socially optimal amount. Any other level of pollution will reduce the amount of utility it can extract from B through transfers. This implies that $P_a^C = P_a^o = (1-b)/2$ and similarly $P_b^C = P_b^o = (1-a)/2$.

Since we know the level of utility that needs to be achieved by B and the level of pollution emitted by both A and B, we can find the amount of transfer. The condition on B's utility is:

$U_b^C = U_b^T = ¼ - ½b$

$\Rightarrow T_b^C + P_b^C - [P_b^C]^2 - bP_a^C = ¼ - ½b$ by definition of the utility function

$\Rightarrow T_b + (1-a)/2 - [(1-a)/2]^2 - b(1-b)/2 = ¼ - ½b$ since $P_a^o = (1-b)/2$ and $P_b^o = (1-a)/2$

When we solve this in terms of T_b, we find: $T_b = a^2/4 - b^2/2$. This implies that the T_b will be negative (B will have to transfer money to A) if $\sqrt{2}b > a$. If this condition does not hold, T_b will be positive and A will have to agree to transfer money to B. Even if *A* is compelled to transfer money to B in order to make cooperation attractive, A will always be better off in the cooperative outcome. The total utility available in the cooperative outcome is at a maximum since both A and B pollute at the socially efficient level. Since, A sets the transfer such that B's utility is the same in the cooperative outcome as the noncooperative outcome, A's utility must be higher in the cooperative outcome.

With a Central Government

We will now consider the situation where the central government plays a more active role. We have seen that when the central government is not active, each self-interested subnational state pollutes at a level above which they would pollute in the social optimum. We will now see how the behavior of the subnational governments can be altered by an active central government. We will look at two scenarios. The first is where the central government first decides on the amount to transfer to the subnational states and then they decide on their level of pollution. In the second scenario, the subnational states decide their level of pollution first and the central government then decides how much to transfer to each state. We will see that the central government can induce the subnational government to reduce their level of pollution to the socially optimum level when it moves second. However, when the central government acts first, the lack of a credible commitment from the subnational governments causes the pollution level to be at the same level they were in the equilibrium without an active central government.

Before we consider the two scenarios we will briefly make a few comments about the central government. The first thing we should note is that the central government is purely altruistic. Its only role is to maximize the social utility function. Because of the nature of the utility functions of the states, the marginal utility of transfers will also be constant. Since the total amount transferred to both subnational governments combined is always constant, the central government cannot use transfers to affect the total utility.

As such, the most appropriate social utility function is a maximin function. Rather than try to maximize total utility, the central government will try to maximize the utility of the state with the lowest utility.

Central Government Acts First

Since this is a sequential game, we will solve it by backwards induction. When the central government acts first, it take into account how the subnational governments will react to its actions when it decides on how much money to transfer to each subnational government. The subnational governments take the actions of the central government as a given and subsequently optimize their own behavior. We saw above that this will result in each subnational government producing the same level of pollution, $P_a = P_a = ½$.

The central government acts knowing at what level the two subnational governments will choose to pollute. Because the marginal utility of transfers is always constant for each subnational government and equal between governments, the central government achieves its maximin objective by equating the utilities of the two subnational governments:

$$U_a = U_b$$

$$T_a + (P_a - P_a^2) - aP_b = T_b + (P_b - P_b^2) - bP_a$$

When we substitute $P_a = P_a = ½$, we find that the maximin condition becomes:

$$\mathrm{T}_a = \mathrm{T}_b + (a\text{-}b)/2$$

Since $a > b$, we see that $T_a > T_b$. In other words, the central government will transfer more money to the state which is more greatly affected by the pollution of its neighbour. The greater transfer will exactly offset the negative utility caused by the increased sensitivity of state A to the pollution of state B.

Central Government Acts Second

The more interesting results occur when the central government acts after the subnational governments. When this happens, the subnational governments can take the future actions of the central government into account when deciding on their own actions. They both know that the central government will try to equalize the utilities of both subnational governments. This means that if a subnational government increases its level of pollution it knows that the transfers it receives will be reduced. This is due to the fact that increasing its own pollution will result in the utility of its neighbour being reduced, which will in turn cause the central government to divert transfers away from the state which increased its pollution and towards its neighbour.

The maximin condition for the central government is as follows:

$$U_a = U_b$$

$$T_a + (P_a - P_a^2) - aP_b = T_b + (P_b - P_b^2) - bP_a$$

If we place the further condition that total amount to be transferred to both state A and state B is a constant (i.e $T_a + T_b = K$), we find that the central government's maximin conditions become:

$$T_a = [K - P_a + P_a^2 + aP_b + P_b - P_b^2 - bP_a]/2$$

$$T_b = [K - P_b + P_b^2 + bP_a + P_a - P_a^2 - aP_b]/2$$

Each state will take its respective transfer function into account when deciding on its level of pollution. When these expressions are substituted into the respective utility functions, the expressions become:

$$U_a = T_a + (P_a - P_a^2) - aP_b$$

$$U_a = [K - P_a + P_a^2 + aP_b + P_b - P_b^2 - bP_a]/2 + (P_a - P_a^2) - aP_b$$

$$U_b = T_b + (P_b - P_b^2) - bP_a$$

$$U_b = [K - P_b + P_b^2 + bP_a + P_a - P_a^2 - aP_b]/2 + (P_b - P_b^2) - bP_a$$

Maximizing these two respective equations for state A and B using the appropriate first order conditions, we find:

$$P_a = (1-b)/2$$

$$P_b = (1-a)/2$$

We recall that these are identical to the pollution levels we found at the social optimum. This means that in this model the central government was able to induce the socially optimal level of pollution using transfers.

Limitations, Omissions and Extensions

In any model there will be omissions, unsupported or unrealistic assumptions, and directions in which the model could be extended. It is important to be cognizant of these limitations and weaknesses so that the model is used responsibly and that future work can address its problems. In this section I will discuss the major limitations of this model and how they could be addressed in the future.

The first glaring weakness of the model is that it assumes perfect information for both the subnational and central governments. There are two distinct reasons why this is unlikely to occur. Firstly, we do not know how the climate will change for a given level of greenhouse gas emissions. Secondly, even if such information were available, it would be very unrealistic to assume that a given jurisdiction would have precise information on how climate change would affect its well-being. There would certainly be unforeseen consequences that would result from any level of climate change. It is even more unrealistic to assume that the central government would know exactly how climate change would affect each of its jurisdictions or that each jurisdiction would have this information for neighbouring jurisdictions. Current estimates on the costs of greenhouse gas emissions vary widely and themselves rest on the accuracy of assumptions which may not be accurate (Tol 1999).

A more complete model would try to take account of the existence of uncertainty and asymmetric and incomplete information. For example, each jurisdiction might have better information about its own preferences than the federal government or other jurisdictions do. Its own actions might also reveal information about its true preferences.

Each jurisdiction would have to weigh its actions taking into account the fact that it might be disadvantageous to reveal too much information about its own preferences. This might give each subnational jurisdiction less incentive to overpollute. Polluting less would signal to the central government that it was more sensitive to pollution and thus signal that it had a lower utility level than it actually had, resulting in the central government giving it more resources than it otherwise should.

Possibly a more glaring weakness in the model is that time does not play any role in the analysis. The effects of greenhouse gas emissions are expected to increase over time which should be taken into account by a more realistic model. There is no discounting of future time periods or changes in the cost structure over time as there might be in a more robust model. It is difficult to say what would happen if time were introduced into the model. The outcome would heavily depend on exactly what role time played. One way to introduce time into the model would be to have the cost of pollution be based on the cumulative total of pollution rather than on the current level of emissions. This would mean that the marginal cost of pollution would increase over time. Depending on the details of the model, this might result in the amount of pollution decreasing over time as the marginal cost of pollution rises. This type of model might be a better way of viewing how pollution affects the world because the global climate change has less to do with how much pollution is occurring in the present and more to do with how much pollution has occurred in the past. A more realistic model would account for this.

Aside from the informational weaknesses in the model, there are also major assumptions made about the structure of the governments themselves. Both levels of government are assumed to be social utility maximizing actors; in the model, each government tries to maximize the social utility of its constituents. This neglects the fact that governments generally do not simply try to maximize social utility, but also have other motivations. By glossing over this fact, the model completely ignores the political process and political institutions. One way we could overcome this weakness is to have a model where the government has goals other than maximizing the social welfare function. For example, the central government may be biased towards having equal transfers. This could be because the central government finds it politically untenable to greatly favour one jurisdiction over the other. We could also explicitly model the behavior the actions of individual political actors, rather than treating each government as a coherent whole.

A similar issue that the model overlooks is any variation within each subnational jurisdiction. Just as the conditions in a single country are unlikely to be the same, conditions within a state or province are also not likely to be the same. Additionally, there are likely to be heterogeneous preferences within each jurisdiction. The existence of heterogeneous preferences would likely alter the outcome of the model.

Conclusion

Greenhouse gas emissions are a serious and increasingly important issue. Their effects are already changing the climate in which we all live and will continue to do so for the foreseeable future. In recent decades, awareness of their effects has increased and new solutions have been advanced. Different approaches are needed to addressing greenhouse gas emissions depending on local conditions and political institutions. Importantly, the way in which greenhouse gas emissions can be addressed will depend on the system of government. The purpose of this paper has been to shed light on how the rotten kid theorem can shed light on how to address the problem greenhouse gas emissions in a federal framework. Specifically, it has shown how, under certain conditions, a federal government can use transfers to induce subnational governments to produce the optimal amount of pollution.

Of course, it would be difficult to directly apply this paper to political reality. For a variety of reasons previously mentioned, the rotten kid theorem may not apply if some of the conditions imposed in the model developed in the article are relaxed. Additionally, many of the assumptions of the model will certainly not hold in the real world. We do not live in a certain one period world with perfect information and a perfectly coherent social utility maximizing governments. Nonetheless, the basic idea behind the rotten kid theorem can be useful in understanding how a federal government can influence subnational governments into emitting the optimal amount of greenhouse gas emissions.

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