How should standards be set and met?: An incomplete contracting approach to delegation in regulation

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Preliminary — Comments welcome

Abstract

Regulation often takes the form of a standard that can be met through the implementation of any of a number of different policies. This paper examines how the authority to set the standard and the authority to choose the combination of policies to meet the standard should be allocated between a central government and local governments, when neither setting nor meeting the standard is contractible. In the context of the United States, for example, should standards regarding such public goods as the environment or education be set and implemented by the federal government, by individual state governments, or by both? Is it ever second-best efficient to separately allocate the power to set the standard from the power to meet the standard? A central finding is that "conjoint federalism" (the central government sets the standard while the local governments meet the standard), which is the regulatory structure often used in federations such as the United States and the European Union, tends to be the *least* efficient form, while a reverse form of delegation, in which local governments choose their own individual standards which the central government then decides how to collectively meet, tends to be the *most* efficient.

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1 Introduction

The issue of how best to distribute power between different tiers of a hierarchical government has been of interest to economists at least since the time Tiebout (1956), Olson (1969) and Oates (1972) published their pioneering works on the topic. Under what circumstances would it be optimal to distribute regulatory responsibility to both central (or federal) and local (or state) tiers of government? In the context of the United States, for example, should standards regarding such public goods as the environment or education be set and implemented by the federal government, by individual state governments, or by both? Likewise, in the context of the European Union, which regulatory decisions should be made by the European Commission, and which by individual member countries? In a firm, is it better for the boss to decide the production target and how to achieve it, or should the power to make one or both of these decisions be delegated to her subordinates? More generally, in any hierarchical organization, who should have the power to set and meet standards: the central authority, or the constituent units? In this paper I use an incomplete contracting paradigm to examine the efficiency of delegating regulatory power, and make a case for why, under certain circumstances, the form of delegation often used in such federations as the United States and the European Union should be reversed.

Regulations that involve standards can be modeled as a two-stage decision-making process. In the first stage, a standard, or target output level, is set for each state (or unit). The output level can correspond to, for example, an air quality standard, a student test score standard, or a production target. The first-stage standard chosen stipulates the output level that each state must achieve.

In the second stage of regulation, policies, or inputs, are chosen for each state in order to meet the standard chosen in stage one. Because there are multiple combinations of policies that can meet a given standard, the input decision entails choosing a particular input policy mix. For example, to meet a given air quality standard, a decision must be made about the policy for reducing smokestack emissions from power plants and that for reducing tailpipe emissions from cars. Likewise, to meet educational standards, a policy mix of training teachers and buying new books needs to be chosen. Similarly, a manufacturing plant can choose to produce a target number of widgets by training workers to better operate new machines, or by hiring more workers to assemble the widgets manually.

Among the different types of input policy that might be chosen to meet the output standard, some may involve spillovers from one state to another. For example, a policy that abates emissions from power plants in one state is likely to benefit neighboring states because it would reduce the plume that is blown across state boundaries. In contrast, a policy that abates emissions from low-lying automobile tailpipes is less likely to have any effect on other states. Similarly, multiple states might benefit from one state's teacher training program, especially if teachers move from state to state, but no other state will be affected if, say, the state of Massachusetts were to simply buy newer books for its own schoolchildren. Likewise, educating workers to operate new machines may induce knowledge spillovers across plants that would not be generated by merely hiring more unskilled workers.

It is often the case that the policies with more positive spillovers are also the ones that are more expensive to implement. As a consequence, the policy that is more costly from the standpoint of an individual state is less costly from a social point of view, and the non-cooperative decisions of individual states, which do not account for interstate spillovers, will diverge from the optimal coordinated choice. Inefficiencies would therefore arise if individual states were allocated the power either to set the standard or to meet the standard, or both. In contrast, for both stages of regulatory decision-making, a federal government would be able to internalize any externalities that exist among local state governments and achieve a cooperative outcome.

Although the central government can internalize externalities, however, it suffers from an agency problem: its preferences about the output good are less well-aligned with local citizen welfare than those of state governments are. For example, because the electoral college system in the United States induces incumbent presidential candidates to care more about states with more electoral votes, the federal government might care little about educational quality and other public goods in states such as Montana that have few electoral college votes. Similarly, a concern for international affairs and military power abroad may induce the federal government to neglect domestic local public goods altogether. In contrast, local governments are better able to tailor their policy to the preferences of their particular local constituents, and therefore have preferences about the output good that are better aligned with local preferences. As a consequence, while state governments act in the interest of local citizen welfare, central governments do not.

The key trade-off between centralized and decentralized systems of regulation that I model is thus the following: while the central government can better internalize externalities, local governments have better aligned preferences.[2] Because of this trade-off, it is possible that the most efficient regulatory structure may involve delegation: the central government retains the power to either set or meet the standard, but not both, and delegates the power to make the remaining decision to the local governments.

The issue of how to distribute power between different tiers of government has been examined extensively by economists over the past few decades, and much of their work has focused on the same trade-off I have chosen between externalities and local preferences (see e.g. Alesina, Baqir & Hoxby, 2002, & references therein). The primary distinguishing feature of this paper is that, while most of the previous literature on federalism has been agnostic about the nature of the underlying contractual environment, I analyze the

[2] See Lin (2004b) for some other trade-offs between centralized and decentralized control and for reasons why I chose not to include them in this model.

issue using an incomplete contracting paradigm. The allocation of decision-making power matters precisely because neither setting nor meeting the standard is contractible, for the non-contractibility precludes individual states from coordinating with each other via contracts and side payments. If states could write contracts with each other, then they could internalize externalities and achieve the social optimum on their own, and there would be no need to allocate power to a central government. However, when contracts are incomplete, then the allocation of power matters because it determines which tier of government can make which decision.

In addition to exploiting novel synergies between the two erstwhile separate literatures on incomplete contracts and on federalism in order to examine the optimal distribution of regulatory power, a second main contribution of this paper is that in an extension to my model I allow for the possibility that including the federal government in the regulatory hierarchy renders decisions about output contractible. For example, if the federal government has regulatory power, it might be able to monitor and verify the output levels, and therefore enable states to contract on them. The dependence of contractibility on power distribution is an added complexity heretofore absent in models of organizational structure.

The research question I pursue is the following: *when is delegation the most efficient distribution of power and in what form should it take?*

One central finding of my paper regards the inefficiency of "conjoint federalism", the decentralization scenario in which the federal government sets the standard and the state governments meet the standard. According to my results, conjoint federalism is often less efficient than completely centralized control and sometimes also less efficient than completely decentralized control. Moreover, under certain values of the parameters, conjoint federalism is actually the *least* efficient allocation of power. For example, conjoint federalism is the worst choice if the federal government does not value the benefits of the output good to at least one of the states.

Ironically, conjoint federalism is the particular regulatory structure that is often used for many regulations in such federations as the United States and the European Union, where in many cases the central government sets a standard that individual states must then implement. For example, air quality regulation in both the U.S. and the EU stipulates that standards be chosen by the central authority and implemented by individual states (Farrell & Keating 1998; Europa, 2004a).[3] Similarly, the U.S. Elementary and Secondary Education Act (also known as the "No Child Left Behind Act") stipulates that a test-based accountability system be set by the federal government and met by each state (Elmore, 2002; U.S. Department of Education, 2004). Likewise, under the Planning and Compulsory Purchase Act in the United Kingdom, the British

[3] Indeed, the term "conjoint federalism" was used by Farrell and Keating (1998) to describe the U.S. ozone regulatory structure. I borrow this term from their paper.

government determines the number of new houses that are needed in each part of the country, while local planning authorities must prepare and implement the actual development schemes (Her Majesty's Stationery Office, 2004; "Building in Britain", 2004).[4] Beginning in 1969, conjoint federalism supplanted state control for many environmental regulations in the United States as a result of federal research in pollution, mounting public concern with environmental issues and the ineffectiveness of state pollution control efforts. Because conjoint federalism is inflexible and constrains state autonomy, however, states backlashed against it in the early 1990s (Keleman, 2004).

A second central finding is that under certain values of the parameters, a case can be made for a reverse form of delegation, in which the federal government retains the power to meet the standard but delegates the power to set individual standards to the states. For example, reverse conjoint federalism is second-best efficient if the federal government does not value the benefits of the output good to at least one of the states. Moreover, if output becomes contractible when the federal government has power, then reverse conjoint federalism can achieve the first-best outcome. Thus, contrary to common practice, it may be best to allow individual units to each set their own standard and then to have the central authority decide how each unit should meet its standard. For example, states should each decide their own air quality standard or test score standard, but the federal government should be the tier that decides how to regulate emissions sources and how to improve schools in order to meet these standards. The federal role should be that of a facilitator.

Although reverse conjoint federalism is uncommon, some regulatory structures do resemble this form. For the regulation of crime in the United States, the federal government aids the states in meeting the criminal laws they each set on their own by providing the Federal Bureau of Investigation's fingerprint service (Zimmerman, 1992). Similarly, while states set individual child support laws, the U.S. federal government implements policies to address, enforce and collect interstate child support payments when parents live in different states (Zimmerman, 1996). Reverse conjoint federalism also appears to describe the underlying philosophy of the World Trade Organization (WTO). For example, Article 20 of the General Agreement on Tariffs and Trade (GATT) allows member countries to each set their own health and safety standards, but the WTO sets the code of practice for preparing, adopting and applying these standards (WTO, 2004a). Similarly, member countries can each decide their own trade policies and practices (output), while the WTO reviews and meets these policies (WTO, 2004b).

The intuition behind my results is the following. Because the socially cost-effective choice of input policies diverges from the privately cost-effective choice, local governments fail to internalize externalities both when setting standards and when meeting standards. On the other hand, because the central government has

[4] I thank Oliver Hart for this latest example of how the construction of houses can help elucidate theoretical models of incomplete contracting. His first example, detailed in Hart (1995), was alluded to by Dekel, Lipman and Rustichini (1998).

preferences over the output good that diverge from those of local citizens, it suffers from an agency problem when setting the standards. The optimal allocation of the power to set the standard should therefore depend on the relative magnitude of the externality that arises from local governments' non-coordinated decision about setting the standards and the agency problem that arises when the central government sets the standards, and should therefore vary from case to case depending on the values of the parameters. As for the power to meet the standard, however, the optimal allocation is unambiguous: the central government is weakly preferred to local governments who, for any given level of the standard, will choose to overallocate their policy mix towards the privately cheaper but socially more expensive policy.

My two central findings then follow directly. Standards set by a central government are better met by the central government rather than by local governments, since the federal government is the weakly preferred tier to meet the standards: it is for this reason that conjoint federalism is often dominated by complete centralization. Moreover, if the agency problem is sufficiently severe that it outweighs the externality that would arise if local governments set the standards, then it may be best to let local governments each decide their own standard, rather than let the central government, whose preferences differ, decide for them; as a consequence, reverse conjoint federalism may be the most efficient.

My results therefore suggest that social welfare may be increased by reversing the form of delegation often used in regulatory decision making. Although I apply my model to regulation in particular, the implications of my model are generalizable to any problem of organizational choice in the presence of interjurisdictional externalities.

The balance of this paper proceeds as follows. I begin with a brief review of the relevant literature in Section 2. I present my model of delegation in regulation in Section 3. I solve a basic version of the model in Section 4 and analyze its main results in Section 5. In Section 6, I extend my basic model to allow contractibility to depend on power allocation. In Section 7, I generalize my model to allow for two-sided spillovers from both types of input policy. Section 8 concludes.

2 Previous Literature

2.1 Organizational structure and incomplete contracts

My research draws upon two main strands of existing literature. First, the contractual framework of my model draws upon the burgeoning literature on organizational structure and incomplete contracts which evolved from the transactions cost theories of Coase (1937), Williamson (1975), and Klein, Crawford and

Alchian (1978), and which was later formalized by Hart and co-authors (see e.g. Hart, 1995, & references therein). Two sub-branches of the literature on contractual incompleteness impinge upon my work. The first is that on firm boundaries. In particular, my model of the optimal governmental structure is an extension of Hart and Holmstrom's (2002) model of market structure and firm scope to a political context. The key contribution of Hart and Holmstrom's model is that it provides a foundation for firm boundaries that is a more plausible description of large companies and organizational structure than were earlier theories that focused on asset ownership. According to their model, firm boundaries matter because (1) there are benefits to coordinated decision-making, (2) decisions are non-contractible but transferable through ownership, (3) managers of individual units enjoy non-transferable private benefits, and (4) owners can divert profit. In an analogous fashion, spillovers, non-contractible but transferable decisions, and non-transferable local private benefits are elements of my model that deem governmental structure important.

My model builds upon the Hart and Holmstrom (2002) framework in several ways. My first innovation is that, unlike Hart and Holmstrom, who assume that the decision is binary, my choice variables are continuous. A second contribution of my model is that it examines not only the extremes of complete decentralization and complete centralization, extremes analogous to Hart and Holmstrom's two organizational forms of nonintegration and integration, respectively, but also considers intermediate cases of partial decentralization, or delegation, as well.[5] Delegation is possible in my model because I distinguish between two types of non-contractible decisions: decisions about input policies and decisions about output standards. Because two separate decisions need to be made, the federal government is able to delegate one of the decisions to the state governments. Indeed, the result that delegation is often second-best efficient is one of the central findings of this paper. A third innovation is that my primary application is not firm boundaries but rather federalism. The regulation of public goods such as environmental quality is well-suited to Hart and Holmstrom's framework because externalities are rampant, preferences over these public goods can differ, and because both input and output can be difficult to observe and verify. A final innovation is that in an extension to my model I allow for the possibility that decisions about output become contractible if and only if the federal government has power. The dependence of contractibility on power distribution is an added complexity heretofore absent in models of organizational structure.

In addition to that on firm boundaries, a second sub-branch of the incomplete contracting literature that relates to my work is that on the allocation of authority. Most of the papers in the literature examine the optimal allocation of decision-making authority within organizations in the presence of both agency and information problems (see e.g. Aghion & Tirole, 1997; Harris & Raviv, 2002; Marino & Matsusaka, 2002).

[5] Incidentally, delegation was modeled in an earlier (March 2002) version of Hart and Holmstrom's paper, entitled "Vision and Firm Scope", but was omitted in subsequent drafts.

My paper differs from the majority of this literature in three ways. First, my model allows for delegation to be justified on the grounds of agency problems alone, instead of requiring that information problems be present as well. Second, my model applies the question of authority allocation to governments as well as to firms. Commitment to delegate authority is arguably more credible in the context of a hierarchical government, where such commitment can occur through legislation, than in the context of multi-tier corporations, where such commitment must take place through contracts or asset allocation. Third, I distinguish between two types of input in my model. My paper thus revisits the issues of multitasking principal-agent models raised by Holmstrom and Milgrom (1991) in light of recent advances in incomplete contracts.

2.2 Federalism

The second main strand of literature relevant to this paper is that on federalism. According to Webster's dictionary (1991, p. 454), federalism is defined as "the distribution of power in an organization (as a government) between a central authority and the constituent units." In the context of the United States, and in the terminology used in this paper, the central authority is the federal government and the constituent units are the states. In the context of the European Union, the issue of federalism is sometimes termed "subsidiarity", which is "the principle whereby the Union does not take action (except in the areas which fall within its exclusive competence) unless it is more effective than action taken at national, regional or local level" (Europa, 2004b).

My work contributes to the federalism literature in several ways. First, it examines federalism in light of the new literature on incomplete contracts. While a second generation economic theory of federalism has recently arisen that uses advances in the theory of the firm to investigate taxation, public goods provision, the preservation of market incentives, and other questions of fiscal federalism (see e.g. Seabright, 1996; Qian & Weingast, 1997), this second generation economic theory of federalism has yet to be applied to regulation. For example, although there is a thriving literature on multi-jurisdictional environmental regulation (see e.g. Bui, 1998; Oates 2001; Sarnoff, 1997; Sigman, 2004), little work has been done to date examining environmental federalism in the context of contractual incompleteness. An incomplete contracting paradigm is essential for any sensible examination of federalism, as it is precisely because contracts are incomplete that the allocation of power matters. Moreover, regulation is well-suited to an incomplete contracting paradigm because it is often difficult, if not impossible, for individual states to contract on either input policies or output levels.

A second contribution that this paper makes to the federalism literature is that it enables a comparison of some of the main competing arguments for local control. Most previous models of federalism focus exclusively on one of the disadvantages of centralization, whether it be inferior information about local conditions (Crémer, Estache & Seabright, 1996); diminished accountability to the wishes of any particular region or locality (Seabright, 1996); incentives that are not perfectly aligned with citizen welfare (see e.g. Qian & Weingast, 1997); or imperfections in the decision making institutions at the federal level such as an inability to treat local districts non-uniformly (see e.g. Oates, 1972), restrictions on voting and/or cost-sharing rules (see e.g. Besley & Coate, 2003) or the need to use the same rules for different projects (Rubinchik-Pessach, 2002). Although the mechanisms underpinning these disadvantages are different, their reduced-form implications are the same: the federal government does not maximize social welfare because its objective function and constraints differ from those that would be used by a benevolent social planner. By positing that the federal government uses benefit functions in its optimization problem that are potentially different from the ones a benevolent social planner would use, while remaining agnostic about the actual source of the dichotomy, I am able to at least partially capture these erstwhile separate arguments for decentralization in a single meta-model.

A third contribution this paper makes to the federalism literature is that it develops a theory for delegation. The majority of models in the federalism literature consider only the extremes of complete centralization and complete decentralization; in contrast, my model allows for intermediate forms of decentralization as well.

By exploiting novel synergies between the literatures on incomplete contracting and on federalism, my paper makes valuable contributions to both.

3 A Model of Delegation in Regulation

3.1 The Two Stages of Regulation

A common form of regulation involves the setting and meeting of standards for a particular good in question. This good, which I term "output", is the good regulators care about and can represent, for example, ambient air quality, student achievement, the number of widgets produced, or, more abstractly, performance. Let q_i denote the output in state i.

In order to produce the output good, policies must be implemented. I call these policies "inputs". There are two different types of input policy that can be implemented to produce output: type-a and type-b. These two types may represent, for example, two different types of technology, emissions reductions from two different types of sources, two different policy instruments, or investment in human versus physical capital. In the case of ozone smog regulation, since ozone is formed in ambient air by two different types of precursors, each input type may correspond to a policy for reducing emissions of a different type of precursor.[6] The input policy choice of each state i is given by the vector (a_i, b_i) of two types of input.

I model regulation as a two-stage process. In the first stage, a standard is set: that is, the output q_i is chosen for each state i. In the second stage, the standard is met: that is, the input policy mix (a_i, b_i) is chosen for each state i in order to implement the set of output standards $\{q_i\}_i$ chosen in the first stage.[7] I assume that, irrespective of who makes the choice, policies are always chosen to comply with the standard dictated in stage 1.

There are generically many combinations of the two types of input policy that can be implemented in order to meet any given output standard. However, the particular choice of type-a and type-b input policy levels will be governed by the following trade-off: while the type-b input policy is privately less costly to implement, the type-a input policy induces positive spillovers and thus is the socially less costly input type. As a consequence, a non-cooperative Nash equilibrium[8] input policy choice would allocate more input toward type-b than a coordinated choice would. My distinction between these two types of input is needed to allow for the possibility that, even after the output standard is chosen, it matters whether or not the input policy choice is made in a coordinated fashion.

There are many reasons why the effects of a policy may spill over from one state to another. For example, if the policy generated and disseminated knowledge and other forms of human capital, then such human capital could easily spill over to other states. Similarly, if the input policy abated emissions of a transboundary pollutant, then any policy that abated the pollutant in one state would result in lower quantities of that pollutant in another state.[9]

For concreteness, consider air quality regulation. Once set, a given standard for ambient air quality can be met through a combination of two types of policy: a policy that reduces smokestack emissions from power plants (type-a), and a policy that reduces tailpipe emissions from cars (type-b). Power plants are more expensive to regulate but, because smokestack emissions can be blown from one state to another, the benefits from smokestack regulation in one state can spill over to the other state. In contrast, cars are cheaper to regulate, but, because low-lying tailpipe emissions are unlikely to get blown across state boundaries, the tailpipe regulatory policy in one state does not affect any other state.[10] Thus, while it may be privately less costly to abate emissions from cars than it is to abate emissions from power plants, it may be socially

[6] Even more abstractly, one input type may correspond to emissions reduction while the other corresponds to emissions relocation.

[7] Regulations that specify standards that can be achieved in a variety of ways are sometimes termed "performance-based regulations" (Coglianese, Nash & Olmstead, 2002).

[8] Throughout this paper, I will use the terms "non-cooperative" and "Nash equilibrium" interchangeably.

[9] For a spatial econometric estimation of the spillovers induced by transboundary pollutants, see Lin (2005).

[10] In this stylized example, I assume that cars themselves do not travel across state borders and that car manufacturers tailor their cars to meet the regulations set by each state. I also assume that it makes no difference to the profits of car manufacturers how the state-by-state tailpipe regulations are set.

more costly to do so.[11]

As another example, consider education. Once a standard is set for student achievement, it can be met by either the privately less costly policy of teaching to the test (type-b) or by the socially more cost-effective policy of teacher training (type-a). Unlike a policy of teaching to the test, a teacher training program, while more expensive for a state to implement, is likely to have positive spillovers onto other states, which may benefit from, for example, better trained teachers who move to their states, or from ideas for how to develop a training program of their own.

There are thus two types of regulatory decisions that can be made for each state i: the stage-one decision about setting the output standard q_i and the stage-two decision about the input policy mix (a_i, b_i) that should be implemented to meet the standard. I now outline the various ways in which the power to make these decisions can be allocated.

3.2 Decentralization Scenarios

In my model, governmental power encompasses the right to make decisions and the ability to enforce them. There are two types of power: one for each of the two stages of regulation. **Output power** is the right and ability to set, measure, monitor, and enforce the standard for output q_i in stage one. **Input power** is the right and ability to choose, measure, monitor, and enforce the (conditional) input policies (a_i, b_i) to meet the standard in stage two.[12] For each state i, the **output boss** OB_i is the tier of government with output power while the **input boss** IB_i is the tier with input power.[13]

The two types of power can be separately allocated to different tiers of government. As shown in Figure 1, each decentralization scenario that I consider corresponds to a different allocation of power between the federal tier of government and the state tier of government.[14]

[11] The application to environmental federalism is described in more detail in Lin (forthcoming). Lin (2004a) examines delegation in the presence of agency and information problems, and applies the theory and simulations to the Clean Air Act.

[12] I sometimes refer to the stage-two input policy choice as a "conditional" input policy choice, since the choice is conditional on the stage-one output standard.

[13] My notion of power is analogous to the notion of ownership propounded by Hart and Holmstrom (2002); the "boss" terminology is borrowed from their work as well.

[14] A possible extension to my model would distinguish between the power to make decisions about type-a input and the power to make decisions about type-b input, and would then evaluate a decentralization scenario in which these two types of input power are allocated to different tiers of government.

The Allocation of Power

Decentralization Scenario	Output Boss (sets the standard)	Input Boss (meets the standard)
Social Optimum	$\mathbb{P}$	$\mathbb{P}$
State Control	$\mathbb{S}$	$\mathbb{S}$
Federal Control	$\mathbb{F}$	$\mathbb{F}$
Conjoint Federalism	$\mathbb{F}$	$\mathbb{S}$
Reverse Conjoint Federalism	$\mathbb{S}$	$\mathbb{F}$

Figure 1: The distribution of the two types of power under the different decentralization scenarios. $\mathbb{P}$ denotes the social planner, $\mathbb{F}$ denotes the federal government and $\mathbb{S}$ denotes the state governments.

To achieve the social optimum, a social planner would have the power to choose both the output standard and the conditional input policy levels for each state. In other words, the planner would have both output power and input power over both states. The solution to her problem yields the socially efficient choice of output and input levels, since it accounts for both local preferences as well as cross-state externalities. It is against this first-best benchmark that I will compare various scenarios of decentralization.

Complete decentralization corresponds to **state (S) control**, in which each state has the power to choose both its own output standard and its own conditional input policy levels. Thus, each state retains its own output power and input power. In the noncooperative Nash equilibrium that ensues, each state's choice is a best response to the other state's choice. Using the terminology of the firm boundary literature, if the states were individual plants or units, then state control would be the market structure in which the individual firms were non-integrated.

In the opposite extreme, complete centralization corresponds to **federal (F) control**, in which the federal government has the power to choose both the output standard and the conditional input levels for all states. The federal government thus has both output power and input power over both states. Federal control is similar to planner control because both scenarios involve allocating all power to one centralized authority; federal control differs from planner control, however, because the objective function used by the federal government diverges from social welfare. Using the terminology of the firm boundary literature, if the states were individual plants or units, then federal control would be the market structure in which the individual firms were integrated.

When externalities exist and when the federal government's preferences diverge from social welfare, neither state control nor federal control achieves the social optimum. As a consequence, it is possible that the most efficient regulatory structure may involve delegation: the central government retains the power to either set or meet the standard, but not both, and delegates the power to make the remaining decision to the local governments.

In this paper I examine two forms of delegation. The first form of delegation is **conjoint federalism (C)**, in which the federal government retains the power to set the output standards for both states but delegates to each state the power to decide its own conditional input policies to meet the standard. Thus, the federal government has output power but each state has its own input power. This form of delegation is the one currently used in both the United States and the European Union for air quality regulation: the federal government sets ambient air quality standards that each state must implement policies to meet. It is also the form of regulatory structure used for education in the United States, where the federal government sets a test-based accountability system that each state must then meet. Beginning in 1969, conjoint federalism supplanted state control for many environmental regulations in the United States as a result of federal research in pollution, mounting public concern with environmental issues and the ineffectiveness of state pollution control efforts. Because conjoint federalism is inflexible and constrains state autonomy, however, states backlashed against it in the early 1990s (Keleman, 2004).

The second form of delegation is **reverse conjoint federalism (R)**, in which the federal government commits to delegating to each state the power to choose its own output level while retaining for itself the power to choose both states' conditional input levels. Thus, the federal government has input power while the states each have their own output power.

Although reverse conjoint federalism is uncommon, some regulatory structures do resemble this form. For the regulation of crime in the United States, the federal government aids the states in meeting the criminal laws (or "output standards") they each set on their own by providing (as an "input policy") the Federal Bureau of Investigation's fingerprint service. Similarly, while states set individual child support laws (output), the U.S. federal government implements (input) policies to address, enforce and collect interstate child support payments when parents live in different states. Reverse conjoint federalism also appears to describe the underlying philosophy of the World Trade Organization (WTO). For example, Article 20 of the GATT allows member countries to each set their own health and safety standards, but the WTO sets the code of practice (the "input policies") for preparing, adopting and applying these standards. Similarly, member countries can each decide their own trade policies and practices (output), while the WTO is responsible for reviewing and meeting these policies (input).

The purpose of my paper is to examine how power should be distributed among tiers of government and, in particular, to determine conditions under which delegation – either via the commonly used conjoint federalism or the rarely used reverse conjoint federalism – may be optimal. The allocation of power matters because contracts are incomplete; I now explain the incomplete contracting framework in more detail.

3.3 The Incomplete Contracting Framework

The primary feature that distinguishes my model from previous work on regulatory federalism is that I operate in a paradigm of contractual incompleteness. In particular, I assume that neither the input policies (a_i, b_i) nor the output good q_i is contractible among individual states either ex ante or ex post. Under these assumptions, the distribution of the two types of power is important because it determines which tier of government can decide the levels of input and output that will be implemented.[15]

I choose the incomplete contracting framework for two main reasons. A first reason why I assume contracts are incomplete is to provide a possible justification for the existence of a federal government. If contracts were complete, then individual state governments could coordinate by contracting on input and output levels and then dividing the surplus through transfers or side payments; as a consequence, there would be no need to allocate any power to a central government and therefore no need for a federal government at all. It is precisely because contracts are incomplete and coordination is no longer possible that one might consider creating a central government and allocating power to it.

A second reason for contractual incompleteness is that my assumptions on the non-contractibility of input and output seem reasonable in the context of public goods regulation. There are several possible reasons why input and output may be non-contractible by individual states. First, because both the effectiveness of the input policies and the level of the output good may be affected by exogenous and often unpredictable stochastic factors and other unforeseen contingencies, the transactions costs of writing complete Arrow-Debreu state-contingent contracts that specify the appropriate input and output choices for every possible state of the world may be prohibitively high. These stochastic factors would include weather for the case of air quality and cohort effects or parental involvement for the case of education.

A second reason why states cannot contract on input and output is that, even if they were written, contracts between individual local governments may not be enforceable. For example, if the "states" in my model were individual countries, then no contracts between these sovereign states could be enforced.

A third reason why contracts might be incomplete is that, especially for public goods, input and output are subject to what Williamson (1971) termed "strategic misrepresentation risk" and therefore might not be verifiable. In the context of air quality regulation, for example, one possible argument for the non-verifiability of the input policy is as follows. Input policies, such as those stipulating reductions in power plant emissions, need to be enforced. Because the input boss is endowed with enforcement authority, he

[15] Later on in this paper I will allow for the case in which the input level (a_i, b_i) is not contractible either ex ante or ex post, and that output q_i is only contractible when the federal government has at least one form of power. In other words, (a_i, b_i) is never verifiable; q_i is not verifiable unless the federal government is included in the regulatory hierarchy. Under these assumptions, the distribution of power is important both because it determines which tier of government can make decisions about input, decisions that are not contractible, and because it determines whether or not output is contractible.

can essentially enforce whatever emissions reductions he wishes, and can neglect to enforce any reductions imposed upon him from outside. Indeed, owing to spillovers in input policies, if state governments had input power, then each state government would likely have an incentive to mislead the other state governments about the extent and success of its policies. Even if Ohio and Maine wrote a contract that specified the amount of smokestack emissions reductions that would take place in each state, Ohio might claim to have complied without Maine ever being able to verify that it did, for Ohio could easily mislead Maine about how much abatement it achieved. Similar arguments could be made for why the quality of an educational input policy to train teachers may not be verifiable.

The argument for the non-verifiability of output is similar. Output must be monitored or measured. Since the quality of the environment or of schools is difficult to measure or monitor with certainty, its level can be obscured by the government with output power from all other governments. Thus, at least for my basic model, output is not contractible.[16]

High transactions costs, the lack of enforcement, and non-verifiability are all possible reasons why input policies, and, to a lesser extent, output goods, are non-contractible among states. It is precisely because contracts are incomplete that the allocation of power matters.

3.4 Welfare

In my simple model, there is one federal government and two state governments.[17] The aggregate benefit to residents of state i of output q_i is $V_i(q_i)$.[18] Benefits are measured in terms of money equivalents. Because I use the sum over all states of the aggregate benefits to each state i as my welfare criterion, I call $V_i(q_i)$ the "true" benefit function for state i.

While each state government uses its correct respective aggregate benefit function in assessing the benefits of output, the federal government does not. Thus, there is an agency problem: the preferences of the federal government over the output good differ from those of the local constituents.

There are many possible reasons why the federal government's preferences may not reflect social welfare.[19] First, voting rules might create a divergence between federal and local preferences. For example, if preferences of governments reflect those of the median voter among their constituents, and if states were heterogeneous, then the median voter in the entire nation would not be the same as the median voter in

[16] Later I assume that output becomes contractible when the federal government has power because the federal government can standardize the measurement technology. This assumption actually strengthens my case for the optimality of reverse conjoint federalism.

[17] My model can of course be generalized to any organization consisting of a central authority and constituent units.

[18] I remain agnostic about how the benefit functions from individual citizens are aggregated to the state level.

[19] I assume in this paper that the preferences of the state governments are perfectly aligned with local welfare. The same arguments still apply even if this assumption were relaxed, as long as the preferences of the state governments are better aligned with local preferences than those of the federal government are.

each state. Since their median voters would differ, state and federal governments would have different preferences. Voting institutions such as the electoral college system may also create incentives for the federal government to care about some states more than others. A second reason why the federal government may fail to maximize social welfare is that, for equity reasons, it may prefer to use the same benefit function for all states. For example, it may be constrained, perhaps by legislation, to value education or the environment in both states equally. A third source of an agency problem is the need for the federal government to balance domestic with foreign policy objectives. Owing to possible trade-offs between national and international interests, the federal government may not be able to fully attend to domestic concerns. Thus, voting rules, equity concerns and international objectives are all potential sources of an agency problem.[20]

One strength of my model is that it is agnostic about the actual mechanism underlying the agency problem; my results therefore do not hinge on the verity of any particular agency story, but rest only on the assumption that *some* story exists that makes the state government's preferences better aligned with local welfare than the federal government's preferences are.

Although my model is general enough to capture the reduced-form implications of any of a number of agency stories, I focus on two special cases of the agency problem. In one case, for reasons about which I remain agnostic, the federal government does not value the benefits to one of the states. For example, because the electoral college system in the United States induces incumbent presidential candidates to care more about states with more electoral votes, the federal government might care little about educational quality and other public goods in states such as Montana that have few electoral college votes. In the other case, the federal government does not care much for local benefits from the output at all. For example, a concern for international affairs and military power abroad may induce the federal government to neglect domestic local public goods altogether.[21]

To model the agency problem in its most general form, I allow the benefit function used by the federal government to differ from the true benefit function. For each state i, the federal government uses the "federal" benefit function $V_{F,i}(q_i)$ as the aggregate state benefit instead of the "true" benefit function $V_i(q_i)$. I assume that the federal benefit function is simply a non-negative scalar multiple of the true benefit function:

$$V_{F,i}(q_i) = \eta_i V_i(q_i) \tag{1}$$

where $\eta_i \geq 0$. One can interpret the parameters $\eta = (\eta_1, \eta_2)$ as the vector of weights that the federal

[20] In addition to an agency problem, an information problem may be another possible reason why the federal government does not use the true benefit functions. In this case, the federal government is unable to correctly measure what these preferences are and therefore uses an incorrect estimate of them. See Lin (2004a) for an examination of both agency and information problems in the context of air quality regulation.

[21] A third case in which the federal government is constrained to treat states uniformly will be the subject of future work.

government puts on the states' benefit functions in its own objective function. Different mechanisms underlying the agency problem would be manifested in different values of this weight vector. Moreover, if $\eta = (1, 1)$, then there is no agency problem; the federal benefit functions reflect the true benefit functions.

While each state reaps benefits from its own output, it also incurs the costs of the input policy that is chosen to meet the standard for this output. For each state i, the input policy mix (a_i, b_i) imposes a cost $C_i(a_i, b_i)$.[22]

Owing to spillovers in the type-a input policies, each state i's output q_i is a function of not only the two types of input policies in state i but also the type-a input policy in state j:

$$q_i = f_i(a_i, b_i; a_j) \tag{2}$$

Because there are two different types of policy, there are possibly many different policy vectors (a_i, b_i) that can achieve any standard for output q_i. When there is a multiplicity of policy choices that can meet a given standard, it is possible that the conditional input levels chosen in a non-coordinated Nash equilibrium would differ from those that would be chosen cooperatively. In particular, since I assume that type-b input is privately less costly but socially more costly than type-a input is, a non-coordinated Nash equilibrium input choice would allocate more input to type-b than a social planner would.

The utility U^i for each state i is simply the benefits it accrues from its output minus the input costs it incurs to achieve it:

$$U^i = V_i(q_i) - C_i(a_i, b_i). \tag{3}$$

Thus, while each state only incurs the cost of its own input, its benefits depends on the input levels of both states through their effect on that state's own output. I assume that each state i will always act so as to maximize its own utility U^i.

Since each state government's utility function correctly reflects the aggregate utility of its citizens, total welfare W is given by the sum of the utilities of all the states:

$$W = \sum_i U^i = \sum_i \left[V_i(q_i) - C_i(a_i, b_i)\right] \ . \tag{4}$$

A social planner would use total welfare W as her objective function. In contrast, because the federal government uses its own benefit function for the output good in place of the true benefit function, the federal government's objective function U^F is given by:

[22] I assume that states always incur the costs of their own policies regardless of who makes the policy choice.

$$U^F = \sum_i [V_{F,i}(q_i) - C_i(a_i, b_i)]. \tag{5}$$

I assume that the federal government will always act so as to maximize U^F, even though the benefits of output and the costs of input accrue to the citizens of the individual states.[23]

I denote the welfare difference between decentralization scenario X and decentralization scenario Y as Δ^{XY}, and call it the *relative welfare of X over Y*. Thus, the relative welfare of X over Y is given by:

$$\Delta^{XY} \equiv W^X - W^Y. \tag{6}$$

4 Solving the Basic Model

4.1 Functional Form and Parameter Assumptions of Basic Model

In this section, I describe the base case assumptions I impose for the various functions and parameters. For the most part, particular function forms were chosen to facilitate the derivation of closed-form solutions. However, as will be explained in a later section, the main intuition behind my results are robust to the particular functional forms chosen. I assume that all functions and parameters are known to all governments.[24]

For the benefit functions, I assume that the true benefit function from output is logarithmic for each state i:

$$V_i(q_i) = v_i \ln(q_i) \tag{7}$$

where $v_i > 0 \; \forall i$. I choose a logarithmic form both because it simplifies the analytic solution and because it results in nonnegative benefit functions for all output levels.

Since I assume that the federal benefit function for each state i is simply a non-negative scalar multiple of state i's true benefit function, the federal benefit function is given by:

$$V_{F,i}(q_i) = \eta_i v_i \ln(q_i) \tag{8}$$

[23] I assume that the federal government uses the correct cost function. There are several reasons why I choose to make the assumption that the agency problem manifests itself in the benefit function but not the cost function. First, unlike the benefits from a public good such as environmental quality – which depend on individual preferences, are intangible, and can be difficult to measure and monetize – costs are tangible and already denominated in money. Thus, while governments may differ in their preferences and therefore in the benefits the accrue, they are more likely to agree on the costs, assuming perfect information about the abatement technology. A second reason for this assumption is analytic simplicity. Third, the assumption that the federal government uses the correct cost function is needed so that the federal government makes a cost-effective conditional input policy choice when it has input power.

[24] Lin (2004a) examines the case in which there is incomplete information about these functions.

where $\eta_i \geq 0$. One can interpret the parameters $\eta = (\eta_1, \eta_2)$ as the vector of weights that the federal government puts on the states' benefit functions in its own objective function. Different mechanisms underlying the agency problem would be manifested in different values of this weight vector. If $\eta = (1,1)$, then there is no agency problem; the federal benefit functions reflect the true benefit functions. If $\eta = (1,0)$, then the federal government does not care about the benefits to state 2, while if $\eta = (0,1)$, then the federal government does not care about the benefits to state 1. If $\eta = (0,0)$, then the federal government does not care for output benefits at all. If $\eta = (\frac{\overline{v}}{\nu_1}, \frac{\overline{v}}{\nu_2})$, where $\overline{v} > 0$ is a constant, then the federal government uses the same benefit function $\overline{v}\ln(q_i)$ for both states i; such a case may occur if the federal government were constrained, perhaps by legislation, to value both states equally.[25]

For the cost functions, I assume that the cost $C_i(a_i, b_i)$ of exerting input (a_i, b_i) is linear and identical for the two states i:

$$C_i(a_i, b_i) = c_a a_i + c_b b_i \qquad \forall i, \tag{9}$$

where $c_a > 0$ and $c_b > 0$. While perhaps unrealistic, the assumption of linear and identical cost functions enables me to most easily and cleanly present the intuition behind my results.[26]

For the production functions, I assume that the output in each state i is a constant elasticity of substitution (CES) function of input:

$$q_i = f_i(a_i, b_i; a_j) = (f_A(a_i + \alpha_i a_j)^\rho + f_B b_i^\rho)^{\frac{1}{\rho}},$$

where $f_A > 0$, $f_B > 0$ and $\rho \leq 1$, and where the *type-a effective input spillover* α_i is a measure of the extent of the spillover to state i from state j's choice of type-a input. The production function can be rewritten as:

$$q_i = (f_A A_i^\rho + f_B B_i^\rho)^{\frac{1}{\rho}}, \tag{10}$$

where the type-a "effective" input A_i in state i is a weighted sum of the type-a "individual" inputs (a_i, a_j) exerted in both states:

$$A_i \equiv a_i + \alpha_i a_j \tag{11}$$

[25] Because I assume that the cost functions are identical for both states, then if the spillover were symmetric (i.e., $\alpha_i = \alpha_j$) and the federal government had output power, the federal government would act as if it were contrained to choose a uniform standard: identical federal benefit functions would lead the federal government to choose identical, or uniform, output levels for both states.

[26] A possible extension to my model would allow for the possibility of heterogeneous cost functions. For instance, cost functions may vary by state depending on the distribution of firms in each state.

and where the type-b "effective" input B_i in state i is simply the type-b "individual" input b_i exerted in state i:

$$B_i \equiv b_i. \tag{12}$$

When written as a function of the effective input levels (A_i, B_i), the production function is identical for the two states.

I choose to use a CES production function so that I can vary the elasticity of substitution between the two types of input.[27] The production function is linear when $\rho = 1$, Cobb-Douglas when $\rho = 0$, and Leontief when $\rho = -\infty$. So that the production function exhibits constant returns to scale and reduces to Cobb-Douglas when $\rho = 0$, I assume that the coefficients (f_A, f_B) sum to one: $f_A + f_B = 1$.

Given the linear cost function and the CES production function, the *marginal private cost of producing output via type-a input* for each state i is given by $MPC^A \equiv \frac{c_a}{\frac{\partial f_i}{\partial A_i}}$, while the *marginal private cost of producing output via type-b input* is given by $MPC^B \equiv \frac{c_b}{\frac{\partial f_i}{\partial B_i}}$.

Because type-a input spills over from one state to another, the marginal private cost of producing output via type-a input differs from its marginal social cost. I define the *marginal social cost of producing output via type-a input* in state i as $MSC_i^A \equiv \frac{1-\alpha_j}{1-\alpha_i\alpha_j} \frac{c_a}{\frac{\partial f_i}{\partial A_i}}$. Unlike the marginal private costs, the marginal social costs are not symmetric across the two states. Because type-b input does not spill over, its marginal social cost is equal to its marginal private cost for both states i: $MSC_i^B = MPC^B$.

I define the *relative marginal cost parameter* γ as the ratio of the marginal private costs when the production function is linear:

$$\gamma \equiv \lim_{\rho \to 1} \frac{MPC^A}{MPC^B} = \frac{c_a}{c_b} \frac{f_B}{f_A}. \tag{13}$$

Similarly, I define the *relative social cost parameter* κ_i as the parameter such that $\kappa_i \gamma$ equals the ratio of the marginal social costs for state i when the production function is linear:

$$\kappa_i \equiv \frac{1}{\gamma} \lim_{\rho \to 1} \frac{MSC_i^A}{MSC_i^B} = \frac{1-\alpha_j}{1-\alpha_i\alpha_j}. \tag{14}$$

In my model, it is privately (weakly) more costly to implement the type-a policy, but socially (weakly) more costly to implement the type-b policy. The higher relative private cost of type-a input is operationalized by the following assumption:

Assumption A1. In the limit as the two input types become perfectly substitutable (i.e., when $\rho = 1$), the marginal private cost of producing output via type-a input is *weakly greater* than the marginal

[27] For a CES production function, the elasticity of substitution is given by $\sigma = \frac{1}{1-\rho}$.

private cost of producing output via type-b input. In other words, $\gamma \geq 1$.

Similarly, the lower relative social cost of type-a input is operationalized by the following assumption:

Assumption A2. In the limit as the two input types become perfectly substitutable (i.e., when $\rho = 1$), for each state i, the marginal social cost of producing output via type-a input is *weakly less* than the marginal social cost of producing output via type-b input. In other words, $\kappa_i \gamma \leq 1 \; \forall i$.

Combining A1 and A2, one gets $\kappa_i \leq 1 \; \forall i$.

Because output is a CES function of the two different types of effective input, there are many different effective input vectors (A_i, B_i) that can achieve any given level of output q_i. Under assumptions A1 and A2, the conditional input policy mix chosen in a non-coordinated Nash equilibrium would allocate more of the input towards type-b than would a conditional input mix that was chosen cooperatively.

In order to best establish the intuition behind my results, I begin with the simplest case of a unique one-sided spillover. In particular, I assume not only that type-a input is the only type of input that spills over (i.e., the spillover is "unique"), but also that the input only spills over from state 2 to state 1, but not vice versa (i.e., the spillover is "one-sided").[28] Formally, I assume:

Assumption B1. Type-a input spills over from state 2 to state 1, but not from state 1 to state 2: $\alpha_1 \in (0, 1]$ and $\alpha_2 = 0$.

From assumption B1, $\kappa_1 = 1$ and $\kappa_2 = 1 - \alpha_1$. In order to satisfy assumptions A1 and A2 in the case of a unique one-sided spillover it must be the case that $\gamma = 1$.[29]

Thus, for each state i, there are two types of input that can be exerted to achieve output: the socially less costly type-a that spills over from state 2 to state 1, but not vice versa; and the privately less costly type-b, which does not spill over at all.

In order to better grasp this abstract theoretical framework, it may be helpful to refer back to the example of air quality regulation. In this example, each state can achieve clean air (output) either by regulating smokestack emissions from power plants located in that state (type-a input) or by regulating tailpipe emissions from cars owned by its residents (type-b input). Neither the level of clean air nor the amount of regulatory input exerted is observable or verifiable. Cars are cheaper to regulate but smokestack emissions travel across state borders. In particular, the wind blows smokestack emission from the upwind state 2 to the downwind state 1, but not the other way around.

[28] I generalize my model to two-sided spillovers from both input types in Section 7.

[29] See Lemma 1 in Lin (2004b).

The questions I hope to answer are the following. First, which tier of government should have the power to choose the ambient air quality standard (output power)? Second, which tier of government should have to power to choose how to regulate cars and power plants to meet the standard (input power)? Third, is it ever the case that these two types of power should be allocated to different tiers (delegation)?[30]

Having fully specified my base case model of regulation, I will now turn to solving it.

4.2 The Social Optimum

The social optimum would arise if a social planner had both input power and output power. In order to establish the first-best benchmark against which I will compare the various decentralization scenarios, I first derive the solution to the social planner's problem.

The social planner's two-stage regulatory problem is solved backwards. In the second stage of regulation, the social planner chooses the input policy levels (a_i, b_i) for each state i in order to meet the output levels $q = (q_1, q_2)$ chosen in stage one. Because the social planner has input power over all states, the conditional input levels will be chosen cooperatively. In particular, given any vector of outputs, she would choose input so as to minimize the sum of the costs to the two states. I will call conditional input levels *cost-effective* if, among all input levels that achieve a given target of output vectors, they implement the given output vector at minimum total cost. The cost-effective input choice is given by:

$$\begin{array}{rcl} \min_{\{a_i,b_i\}_i} \sum_i C_i(a_i,b_i) & = & c_a a_i + c_b b_i \\ \text{s.t.} \quad q_i & = & (f_A A_i^\rho + f_B B_i^\rho)^{\frac{1}{\rho}} \quad \forall i \\ A_i & \equiv & a_i + \alpha_i a_j \quad \forall i, j \neq i \\ B_i & \equiv & b_i \quad \forall i. \end{array} \tag{15}$$

The first-order condition for each state i is to set the marginal social cost MSC_i^A of producing output via type-a input equal to the marginal social cost MSC_i^B of producing output via type-b input:

$$(1-\alpha_j)\frac{c_a}{\frac{\partial f_i}{\partial A_i}} = \frac{c_b}{\frac{\partial f_i}{\partial B_i}} \quad . \tag{16}$$

This cooperative first-order condition can also be interpreted as requiring each state i to set the slope $-(1-\alpha_j)\frac{c_a}{c_b}$ of its "social budget constraint" equal to the slope $-\frac{\frac{\partial f_i}{\partial A_i}}{\frac{\partial f_i}{\partial B_i}}$ of its $q_i = \overline{q_i}$ isoquant, where $\overline{q_i}$ is the output level chosen for state i in stage one. The solution to problem (15) yields the following equations for conditional effective input $\forall i, j \neq i$:

[30] This is a highly stylized example, of course, but it is sufficient to convey the basic intuition behind my model, and more realistic features will be added in a later section.

$$\widetilde{A_i}(q_i) = \left(f_A + (\kappa_i\gamma)^{\frac{\rho}{1-\rho}} f_B\right)^{-\frac{1}{\rho}} q_i \quad (17)$$
$$\widetilde{B_i}(A_i) = (\kappa_i\gamma)^{\frac{1}{1-\rho}} A_i \quad . \quad (18)$$

If the production function were linear ($\rho = 1$), the cooperative first-order condition (16) would either always hold with equality or never hold with equality, since both sides of the equation would be constant. In particular, when $\kappa_i\gamma = 1$, as is the case for state 1, the first-order condition would always hold for state i. Thus, there would be infinitely many solutions for state i when $\kappa_i\gamma = 1$: namely, any combination of the two types of input along the given isoquant. In contrast, when $\kappa_i\gamma < 1$, as is the case for state 2, the cooperative first-order condition would never hold with equality and the following corner solution would arise for state i:

$$\widetilde{A_i}(q_i) = \frac{1}{f_A} q_i \quad (19)$$
$$\widetilde{B_i}(A_i) = 0 \quad (20)$$

Equations (19) and (20) are simply equal to the limits of equations (17) and (18) as $\rho \to 1$. In this corner solution, all the conditional input would be allocated toward the less socially costly type-a input. For analytical simplicity, I make the following assumption about the particular solution that arises in the knife-edge case of $\kappa_i\gamma = 1$ when there are infinitely many solutions to the cooperative first-order condition :

Assumption A3. When the production function is linear and $\kappa_i\gamma = 1$, then the corner solution corresponding to $\kappa_i\gamma < 1$ is the particular solution to the cooperative conditional input choice problem that is chosen.

Assumptions A2 and A3 imply that if the production function were linear and the conditional input levels were chosen cooperatively, then only the socially less costly type-a input would be exerted.

In the first stage of regulation, the social planner chooses the output standard q_i is chosen for each state i, anticipating the stage-two conditional input choices. Because the social planner has output power over all states, the standards would be set for both states simultaneously to maximize total welfare. Her problem is thus given by:

$$
\begin{aligned}
\max_{\{q_i\}_i} W &= \sum_i \left[v_i \ln(q_i) - c_a a_i - c_b b_i \right] \\
\text{s.t.} \quad a_i &= A_i - \alpha_i a_j \quad \forall i, j \neq i \\
b_i &= B_i \quad \forall i \\
A_i &= \widetilde{A_i}(q_i) \quad \forall i \\
B_i &= \widetilde{B_i}(A_i) \quad \forall i \quad ,
\end{aligned}
\tag{21}
$$

where $\widetilde{A_i}(q_i)$ and $\widetilde{B_i}(A_i)$ are the cost-effective conditional effective input levels given by equations (17) and (18), respectively, when $\rho < 1$ and equations (19) and (20) when $\rho = 1$. The first-order conditions are:

$$
q_i = \frac{v_i}{\left((1 - \alpha_j)\, c_a + c_b \widetilde{B_i'}(A_i) \right) \widetilde{A_i'}(q_i)} \quad \forall i \quad . \tag{22}
$$

The socially optimal choices of inputs and outputs account for both local preferences and interstate externalities. Having established the social optimum, I now analyze each of the decentralization scenarios in turn.

4.3 State Control

Under state control, each state retains its own input power and output power, and both inputs and outputs are chosen non-cooperatively. In the second stage of regulation, a Nash equilibrium in inputs would arise in which, for any given vector of outputs, each state would choose the conditional input levels that minimize its own costs of implementing its target output subject to the input levels chosen by the other state. In order to minimize its own cost, each state i would solve:

$$
\begin{aligned}
\min_{a_i, b_i} C_i(a_i, b_i) &= c_a a_i + c_b b_i \\
\text{s.t.} \quad q_i &= \left(f_A A_i^\rho + f_B B_i^\rho \right)^{\frac{1}{\rho}} \\
A_i &\equiv a_i + \alpha_i a_j \\
B_i &\equiv b_i \ ,
\end{aligned}
\tag{23}
$$

where the input choices (a_j, b_j) of the other state are taken as given. The first-order condition for state i would be to set its marginal private cost MPC^A of producing output via type-a input equal to the marginal private cost MPC^B of producing output via type-b input:

$$
\frac{c_a}{\frac{\partial f_i}{\partial A_i}} = \frac{c_b}{\frac{\partial f_i}{\partial B_i}}. \tag{24}
$$

This non-cooperative Nash equilibrium first-order condition can also be interpreted as requiring each state i to set the slope $-\frac{c_a}{c_b}$ of its private budget constraint equal to the slope $-\frac{\frac{\partial f_i}{\partial A_i}}{\frac{\partial f_i}{\partial B_i}}$ of its $q_i = \overline{q_i}$ isoquant, where $\overline{q_i}$ is the output level chosen for state i in stage one. The solution to state i's individual cost-minimization problem (23) yields the following equations for Nash equilibrium conditional effective input when $\rho < 1$:

$$\widetilde{\widetilde{A_i}}(q_i) = \left(f_A + \gamma^{\frac{\rho}{1-\rho}} f_B\right)^{-\frac{1}{\rho}} q_i \tag{25}$$

$$\widetilde{\widetilde{B_i}}(A_i) = \gamma^{\frac{1}{1-\rho}} A_i \ . \tag{26}$$

If the production function were linear ($\rho = 1$), then the Nash equilibrium first-order condition (24) would either always hold with equality or never hold with equality, since both sides of the equation would be constant. In particular, when $\gamma = 1$, as is the case in my simple model of a one-sided externality, the first-order condition would always hold. Thus, there would be infinitely many solutions for each state i when $\gamma = 1$: namely, any combination of the two types of input along the given isoquant. In contrast, when $\gamma > 1$, the Nash equilibrium first-order condition would never hold with equality and the following corner solution would arise for each state i:

$$\widetilde{\widetilde{A_i}}(B_i) = 0 \tag{27}$$

$$\widetilde{\widetilde{B_i}}(q_i) = \frac{1}{f_B} q_i \tag{28}$$

In this corner solution, all the conditional input is allocated toward the privately less costly type-b input. For analytical simplicity, I make the following assumption about the particular solution that arises in the knife-edge case of $\gamma = 1$ when there are infinitely many solutions to the Nash equilibrium first-order condition:

Assumption A4. When the production function is linear and $\gamma = 1$, then the corner solution corresponding to $\gamma > 1$ is the particular solution to the Nash equilibrium conditional input choice problem that is chosen.

Assumptions A1 and A4 imply that if the production function were linear and the conditional input levels were chosen non-cooperatively, then only the privately less costly type-b input would be exerted.

For any given output vector $q = (q_1, q_2)$, the non-cooperative Nash equilibrium conditional input levels will generically differ from the cost-effective ones, since equations (25) and (26) differ from equations (17) and (18). Thus, whenever the state governments have the power to decide conditional input levels, the input levels will not be cost effective.

In the first stage of regulation, a Nash equilibrium in outputs would arise in which each state would choose its output level to maximize its own utility given the output choice of the other state and in anticipation of the conditional input choices that would be made in stage two.[31] The stage-one maximization problem for each state i would thus be:

$$\begin{aligned} \max_{q_i} U^i &= v_i \ln(q_i) - c_a a_i - c_b b_i \\ \text{s.t. } a_i &= A_i - \alpha_i a_j \quad \forall i, j \neq i \\ b_i &= B_i \quad \forall i \\ A_i &= A_i(B_i, q_i) \quad \forall i \\ B_i &= B_i(A_i, q_i) \quad \forall i \quad , \end{aligned} \tag{29}$$

where the appropriate conditional effective input level functions $A_i(B_i, q_i)$ and $B_i(A_i, q_i)$ would be given by equations (25) and (26), respectively, when $\rho < 1$ and by equations (27) and (28) when $\rho = 1$. The first-order conditions are:

$$q_i = \frac{v_i}{\left(c_a + c_b \widetilde{\widetilde{B}}_i'(A_i)\right) \widetilde{\widetilde{A}}_i'(q_i)} \quad \forall i \tag{30}$$

when $\rho < 1$ and

$$q_i = \frac{v_i}{\left(c_a \widetilde{\widetilde{A}}_i'(B_i) + c_b\right) \widetilde{\widetilde{B}}_i'(q_i)} \quad \forall i \tag{31}$$

when $\rho = 1$.

Under state control, both the input policies and the output standards are chosen non-cooperatively. As a consequence, states fail to internalize externalities in both stages of the regulatory process. These externalities will be further analyzed later in this paper.

4.4 Federal Control

Under federal control, the federal government has input power and output power over all states. In the second stage of regulation, the federal government chooses conditional input levels in a coordinated fashion to minimize total costs. Because benefit functions do not affect the conditional input choice problem (15), the federal government's conditional input choice problem is the same as that of the social planner. Thus, even if the federal government's benefit function were to diverge from social welfare, the federal government's

[31] I assume that states always (and only) incur the entire costs of their own input policies, even if these policies were chosen by the federal government. It is because of this assumption that an output choice externality exists.

conditional input choice would still be cost-effective.

In the first stage of regulation, the federal government would solve a similar problem to that of the social planner, with one exception: owing to an agency problem, it would weigh the true benefit function for each state i by η_i instead of 1. Anticipating a cost-effective conditional input choice in stage two, the federal government chooses output for both states simultaneously to maximize total federal benefit minus total costs, yielding as first-order conditions:

$$q_i = \frac{\eta_i v_i}{\left((1-\alpha_j)\, c_a + c_b \widetilde{B}_i'(A_i) \right) \widetilde{A}_i'(q_i)} \quad \forall i \quad . \tag{32}$$

Under federal control, there is thus an agency problem that arises in the first stage of regulation because the federal government uses the federal benefit functions instead of the true benefit functions. This agency problem will be further analyzed later in this paper.

4.5 Conjoint Federalism

Under conjoint federalism, the state governments have input power while the federal government has output power. In the second stage of regulation, a Nash equilibrium in inputs would arise in which, for any given vector of outputs, each state would choose the input levels that minimize its own costs of implementing its target output subject to the input levels chosen by the other state. The states would solve the same second-stage problem under conjoint federalism as they would solve under state control. The conditional input choices are therefore given by equations (25) and (26), respectively, when $\rho < 1$ and by equations (27) and (28) when $\rho = 1$. Thus, just as under state control, the conditional input choices under conjoint federalism are not cost effective.

In stage one, the federal government would choose outputs in a coordinated fashion, while anticipating a non-cooperative conditional input choice by the states in stage two. Owing to an agency problem, however, the federal government would weigh the true benefit function for each state i by η_i. The first-order conditions from its first-stage problem are thus given by:

$$q_i = \frac{\eta_i v_i}{\left((1-\alpha_j)\, c_a + c_b \widetilde{\widetilde{B}}_i'(A_i) \right) \widetilde{\widetilde{A}}_i'(q_i)} \quad \forall i \tag{33}$$

when $\rho < 1$, where $\widetilde{\widetilde{A}}_i(\cdot)$ and $\widetilde{\widetilde{B}}_i(\cdot)$ are the Nash equilibrium conditional input levels given by equations (25) and (26), respectively, and

$$q_i = \frac{\eta_i v_i}{\left((1-\alpha_j)\, c_a \widetilde{\widetilde{A}}_i'(B_i) + c_b \right) \widetilde{\widetilde{B}}_i'(q_i)} \quad \forall i \tag{34}$$

when $\rho = 1$, where $\widetilde{\widetilde{A}}_i(\cdot)$ and $\widetilde{\widetilde{B}}_i(\cdot)$ are the Nash equilibrium conditional input levels given by equations (27) and (28), respectively.

Under conjoint federalism, there is thus an externality that arises from the states' uncoordinated input choice as well as an agency problem that arises from the federal government's output choice.

4.6 Reverse Conjoint Federalism

Under reverse conjoint federalism, the federal government has input power while the state governments have output power. In the first stage of regulation, the federal government chooses conditional input levels in a coordinated fashion to minimize total costs. Just as with federal control, the benefit functions do not affect the conditional input choice problem (15), so the federal government's conditional input choice problem is the same as that of the social planner. Thus, the federal government makes the cost-effective conditional input choice.

In stage one, a non-cooperative Nash equilibrium in outputs would arise in which the state governments choose output levels in anticipation of a coordinated conditional input choice by the federal government in stage two. They thus use the cost-effective conditional input choice equations in their stage-one maximization problem, yielding as first-order conditions:

$$q_i = \frac{v_i}{\left(c_a + c_b \widetilde{B}_i'(A_i) \right) \widetilde{A}_i'(q_i)} \quad \forall i \ . \tag{35}$$

Under conjoint federalism, there is thus an externality that arises from the states' uncoordinated output choice.

I now turn toward describing the externalities and the agency problem in more detail.

4.7 Types of Inefficiency

There are three types of regulatory inefficiency in my model: one that arises in the second standard-meeting stage, and two that arise in the first standard-setting stage.

In the second standard-setting stage of regulation, the one inefficiency is the following. If states were given input power, they would fail to internalize an **input choice externality**: conditional on the output levels $q = (q_1, q_2)$ chosen in stage 1, each state i does not account for the effect that its choice of input (a_i, b_i)

has on the cost, and therefore the utility, of the other state. Changes in state i's choice of input levels will change the input levels that state j needs to exert in order to meet state j's output standard q_j and therefore changes the cost to state j of implementing q_j. For any given air quality standard, individual states would choose to overallocate their input policy towards the individually less costly policy of reducing automobile tailpipe emissions. An input choice externality arises whenever states have input power.

In contrast, if the federal government were given input power, no additional inefficiencies would arise. For the standard-meeting stage, the optimal allocation of power is clear: the federal government is weakly preferred as the tier of government to decide how to meet the standard.

For the standard-setting stage, there is a trade-off between the externality that makes local control inefficient and the agency problem that makes central control inefficient. If states were given output power, they would fail to internalize an **output choice externality**: in stage 1, given the other state's choice of output q_j, each state i does not account for the effects that its choice of output q_i has on the cost, and therefore the utility, of the other state. A change in state i's choice of output changes the levels of input in both states, and therefore changes the cost to state j of meeting its own output q_j. For example, in choosing its own air quality standard, Maine might set a more stringent standard than a social planner would because it anticipates that its standard would be met in part by reductions in power plant emissions from upwind states such as Ohio, reductions it would not need to pay for itself. An output choice externality arises whenever states have output power, regardless of which tier of government has input power.

If, on the other hand, the federal government were given output power, then an **agency problem** would arise because the federal government's preferences over the output diverge from social welfare. In particular, the benefit functions used by the federal government to value the output good differ from the true local benefit functions.[32]

The optimal allocation of the power to set the standard should therefore depend on the relative magnitude of the externality that arises from local governments' non-coordinated decision about standards and the agency problem that arises when the central government sets the standards, and should therefore vary from case to case depending on the values of the parameters.

My two central findings then follow directly. Standards set by a central government are better met by the central government rather than by local governments, since the federal government is the weakly preferred tier to meet the standards: it is for this reason that conjoint federalism is often dominated by complete centralization. Moreover, if the agency problem is sufficiently severe that it outweighs the externality that would arise if local governments set the standards, then it may be best to let local governments each decide

[32] Because the federal government's preferences diverge only over the output benefits, but not the input costs, an agency problem arises if and only if the federal government has output power, regardless of which tier of government has input power.

their own standard, rather than let the central government, whose preferences differ, decide for them; as a consequence, reverse conjoint federalism may be the most efficient.

The intuition behind my results can also be easily gleaned from Figure 2, which displays the inefficiencies that arise in each decentralization scenario. First, notice that while federal control only suffers from an agency problem, conjoint federalism suffers from not only an agency problem but also an input choice externality as well. This simple observation that conjoint federalism suffers from an additional inefficiency that does not plague federal control is the reasoning behind my result that conjoint federalism is often dominated by federal control.

Second, note that both state control and conjoint federalism suffer from two inefficiencies each – more than that of any of the other two decentralization scenarios. Both state control and conjoint federalism suffer from an input choice externality, but each has a different second inefficiency. It is therefore possible for conjoint federalism to be the *least* efficient distribution of power if its second inefficiency – an agency problem – is worse than the second inefficiency in state control – an output choice externality.

Third, note that both federal control and reverse conjoint federalism suffer from only one type of inefficiency each. As a consequence, reverse conjoint federalism can be the *most* efficient if its type of inefficiency – an output choice externality – is less severe than the type of inefficiency in federal control – an agency problem.

Types of Inefficiencies

	Input choice externality	Output choice externality	Agency problem
State Control	X	X	
Federal Control			X
Conjoint Federalism	X		X
Reverse Conjoint Federalism		X	

Figure 2: This table indicates the types of inefficiencies that arise in each of the four decentralization scenarios.

Thus, as can be seen readily from Figure 2, it is possible for conjoint federalism to be the *least* efficient scenario and for a reverse form of delegation to be the most efficient, especially if the agency problem is more severe than the output choice externality. These results are particularly ironic since conjoint federalism is the regulatory structure used for many regulations in the United States and in the European Union.

Of course, the actual signs and magnitudes of the inefficiencies will depend on the functional form and parameter assumptions, as well as on the power allocation, even though the basic intuition is robust to the particular assumptions chosen. I now analyze each of the inefficiencies in more detail under the functional form and parameter assumptions of the basic model.

4.7.1 Input choice externality

The reason why states do not make the cost-effective conditional input choice if given the power in the second stage of regulation is that there is an input choice externality: each state does not account for the effects of its conditional input choice on the costs and therefore on the utility of the other state. Thus, while each state minimizes its own costs, the total costs of the two states are not necessarily jointly minimized. In contrast, when the conditional input levels are chosen in a coordinated fashion by the federal government, the input choice externality is internalized.

I define the *input choice externality imposed by state i* as the effect on total welfare of a change in state i's conditional effective input levels from their cooperative levels to their non-cooperative levels.[33] Formally, let the input choice externality $\chi^I_{i,OB=Z}$ imposed by state i when the output boss for both states is $Z \in \{\mathbb{S}, \mathbb{F}\}$ be defined as the difference between the welfare $W^{IB_i=i,IB_j=\mathbb{P}}_{OB=Z,\eta=(1,1)}$ that arises when the conditional effective input levels for state i are at their non-cooperative Nash equilibrium levels, and the welfare $W^{IB_i=\mathbb{P},IB_j=\mathbb{P}}_{OB=Z,\eta=(1,1)}$ that arises when they are at their cooperative levels, holding the output boss for both states constant at Z and the conditional effective input levels of state j constant at their cooperative levels, and assuming that there is no agency problem (i.e., $\eta = (1,1)$):[34]

$$\chi^I_{i,OB=Z} \equiv W^{IB_i=i,IB_j=\mathbb{P}}_{OB=Z,\eta=(1,1)} - W^{IB_i=\mathbb{P},IB_j=\mathbb{P}}_{OB=Z,\eta=(1,1)}. \tag{36}$$

The sign of $\chi^I_{i,OB=Z}$ corresponds to the sign of the externality; the more negative $\chi^I_{i,OB=Z}$ is, the more negative the input choice externality.

To convey the intuition behind the input choice externality, Figures 3 and 4 present a graphical exposition of the externality when the production function is nonlinear (i.e., $\rho < 1$) and when the following additional assumption holds:

Assumption B2. The marginal cost of type-b input is equal to one: $c_b = 1$.

Figure 3 displays the Nash equilibrium conditional input choice that arises under assumptions A1-A4 and B1-B2, given the target output vector $q = (\overline{q_1}, \overline{q_2})$ chosen in stage one. The Nash equilibrium first-order condition (24) requires that each state i chooses its effective input levels (A_i^{NE}, B_i^{NE}) so that its (private) budget constraint is tangent to its $q_i = \overline{q_i}$ isoquant. Under B2, the slope of the private budget constraint is $-\frac{c_a}{c_b} = -c_a$. Since type-b input does not spill over, the individual type-b input levels that arise are

[33] I define the input choice externality imposed by state i in terms of the effect of a change in state i's input levels on total welfare rather than on the utility of state j only in order to measure the net welfare effects of a non-cooperative conditional input choice.

[34] In defining the input choice externality imposed by state i, I do not hold the output levels constant but rather let the output boss correctly anticipate whether state i's input levels are chosen cooperatively or not; doing so enables me to capture the full ramifications of a change in conditional input levels from the cooperative to the non-cooperative levels.

simply equal to the effective type-b input levels chosen: $b_i^{NE} = B_i^{NE}$ $\forall i$. Moreover, by B1, there is no type-a effective input spillover from state 1 to state 2, so state 2's type-a individual input level is equal to its type-a effective input level as well: $a_2^{NE} = A_2^{NE}$. However, because state 2's type-a input level spills over to state 1, state 1's type-a individual input level is less than its type-a effective input level, and is given by $a_1^{NE} = A_1^{NE} - \alpha_1 a_2^{NE}$. From B2, the cost C_2^{NE} to state 2 is given by the b_2-intercept of its tangent isocost curve, while the cost C_1^{NE} to state 1 is given by the b_1-intercept minus the cost savings $c_a \alpha_1 a_2^{NE}$ resulting from the spillover from state 2.

Figure 4 compares the Nash equilibrium conditional input choice (denoted with a superscript "NE") with the cooperative conditional input choice (denoted with a superscript "coop") given the same target output vector $q = (\overline{q_1}, \overline{q_2})$. The cooperative first-order condition (16) requires that each state i chooses its effective input levels (A_i^{coop}, B_i^{coop}) so that its social budget constraint is tangent to its $q_i = \overline{q_i}$ isoquant. From B1-B2, the slope of the social budget constraint is $-c_a$ for state 1 and $-(1-\alpha_1)c_a$ for state 2. For state 1, the cooperative conditional effective input choice coincides with the Nash equilibrium conditional effective input choice, since its private budget constraint is the same as its social budget constraint. For state 2, however, the social budget constraint is less steep than its private budget constraint, requiring a higher type-a effective input level and a lower type-b effective input level in the cooperative case than in the Nash equilibrium. The cooperative solution allocates relatively more of state 2's conditional input towards type-a input because the benefits of its type-a input spill over to state 1. Such a change increases state 2's cost from C_2^{NE} to C_2^{coop}, but, because it reduces the amount of type-a input state 1 needs to exert, it *reduces* state 1's cost from C_1^{NE} to C_1^{coop}. Thus, because state 2 does not internalize the input choice externality that arises because its type-a input spills over to state 1, it may inefficiently overallocate its input towards the privately less costly type-b.

4.7.2 Output choice externality

The output choice externality arises when each state government sets its own standard and fails to account for the effect of its choice on the utility of the other state. I define the *output choice externality imposed by state i* as the effect on total welfare of a change in state i's output level from its cooperative level to its non-cooperative level.[35] Formally, let the output choice externality $\chi^O_{i,IB=Z}$ imposed by state i when the input boss for both states is $Z \in \{\mathbb{S}, \mathbb{F}\}$ be defined as the difference between the welfare $W^{OB_i=i, OB_j=\mathbb{P}}_{IB=Z, \eta=(1,1)}$ that arises when the output level for state i is at its non-cooperative Nash equilibrium level, and the welfare $W^{OB_i=\mathbb{P}, OB_j=\mathbb{P}}_{IB=Z, \eta=(1,1)}$ that arises when it is at its cooperative cost-effective level, holding the input boss for both

[35] I define the output choice externality imposed by state i in terms of the effect of a change in state i's output level on total welfare rather than on the utility of state j only in order to measure the net welfare effects of a non-cooperative output choice.

states constant at Z and the conditional effective output level of state j constant at its cooperative level, and assuming that there is no agency problem (i.e., $\eta = (1,1)$):

$$\chi^{O}_{i,IB=Z} \equiv W^{OB_i=i,OB_j=\mathbb{P}}_{IB=Z,\eta=(1,1)} - W^{OB_i=\mathbb{P},OB_j=\mathbb{P}}_{IB=Z,\eta=(1,1)}. \tag{37}$$

The sign of $\chi^{O}_{i,IB=Z}$ corresponds to the sign of the externality; the more negative $\chi^{O}_{i,IB=Z}$ is, the more negative the output choice externality.

To convey the intuition behind the output choice externality, Figures 5 and 6 present a graphical exposition of the externality when the states have input power, the production function is nonlinear (i.e., $\rho < 1$), and the additional assumption B2 holds.[36] Figure 5 presents the non-cooperative Nash equilibrium output choice $(\overline{q}_1^{NE}, \overline{q}_2^{NE})$ that arises when the output bosses anticipate that the conditional input levels would be chosen non-cooperatively by the states. This non-cooperative output choice arises from the non-cooperative first-order condition (30) for output, and results in costs C_1^{NE} and C_2^{NE} for the two states, respectively.

Figure 6 compares this Nash equilibrium output choice (denoted with a superscript "NE") with the cooperative output choice (denoted with a superscript "coop"). The cooperative output choice arises from the cooperative first-order condition (33) for output. In order to internalize the output choice externality resulting from the spillover of state 2's type-a input onto state 1, the output level for state 2 is higher in the cooperative solution so that the input boss for state 2 will choose a higher type-a conditional input level, thus enabling state 1 to exert less type-a input and thus reducing state 1's costs. There is a negative output choice externality that state 2 does not internalize whenever the welfare from the cooperative output choice is greater than that from the non-cooperative output choice.

4.7.3 Agency problem

In addition to the output choice externality, the second type of inefficiency that arises during the output choice stage of regulation is the agency problem. This inefficiency arises when the federal government is the output boss. When the federal government has output power, output choice is inefficient because the federal government uses a benefit function to value the output good that diverges from the true benefit function.

Formally, I define the *agency problem* Λ_i *with state* i as the difference between the welfare that arises when the federal benefit function diverges from the true benefit function for state i but not for state j, and the welfare that would arise if the federal benefit functions did not diverge from the truth for either state:

[36] The graphs for the case in which the output power is allocated to the federal government rather than to the state governments are similar.

$$\Lambda_i \equiv W^X_{\eta_j=1} - W^X_{\eta_i=1,\eta_j=1}. \quad (38)$$

The worse the agency problem with state i is, the more negative is Λ_i.

5 Results for the Basic Model

For the general case of a two-sided externality for both input types, the actual expressions for the externalities and the agency problem are derived and analyzed in Appendix A; the analogous expressions for this more basic case of a unique one-sided spillover can be obtained by setting $\alpha_2 = \beta_1 = \beta_2 = 0$.[37] I now examine the results that arise in this basic model. In particular, I attempt to compare the welfare arising from the four decentralization scenarios.

First, I examine whether it is ever the case that one decentralization scenario is always preferred to another. It turns out that, for the basic model of a unique one-sided externality, federal control is weakly preferred to conjoint federalism:

Proposition 1 *With a unique one-sided spillover (assumption B1) and under A1-A4, federal control weakly dominates conjoint federalism. The domination is strict when* $\rho \notin \{-\infty, \frac{1}{2}\}$.

Proof. Under A1-A4 and B1, $\Delta^{FC} = -\chi^I_{2,OB=\mathbb{F}}$ by direct calculation. By Corollary 16, Δ^{FC} is thus weakly positive and is strictly positive when $\rho \notin \{-\infty, \frac{1}{2}\}$. ■

Thus, with a one-sided spillover, federal control is always weakly more efficient than conjoint federalism is. Intuitively, federal control dominates conjoint federalism because while conjoint federalism suffers from both an input choice externality and an agency problem, federal control only suffers from an agency problem: the difference between the two is the input choice externality, which, by Corollary 16 (in Appendix A), is weakly negative.

While one cannot sign the other relative welfares Δ^{XY} without making additional assumptions on the parameters, it is still possible to intuit which inefficiencies will govern the sign of each by referring to Figure 2.[38] For instance, the relative welfare $\lim_{\rho\to 1}\Delta^{RF}$ of reverse conjoint federalism over federal control is determined by the trade-off between the output choice externality and the agency problem: reverse conjoint federalism is plagued by the former inefficiency while federal control is plagued by the latter. The relative welfare $\lim_{\rho\to 1}\Delta^{SC}$ of state control over conjoint federalism is determined by the trade-off between the agency

[37] The actual expressions for input, output, welfare, and deadweight loss for each decentralization scenario, as well as the expressions for the relative welfares for each pair of scenario are given in Appendix B of Lin (2004b).

[38] The arguments presented here are heuristic and should not be interpreted literally; the actual value for the relative welfare for any given pair of scenarios is not necessarily simply the difference between the values of the inefficiencies plaguing each scenario in the pair.

problem and the output choice externality, as well as by how the input choice externality varies with the allocation of output power. The relative welfare $\lim_{\rho\to 1}\Delta^{FS}$ of federal control over state control is determined by the trade-off between the agency problem that plagues the former decentralization scenario and the two externalities that plague the latter. Similarly, the relative welfare $\lim_{\rho\to 1}\Delta^{RC}$ of reverse conjoint federalism over conjoint federalism is determined by the trade-off between the output choice externality that plagues reverse conjoint federalism, and the input choice externality and agency problem that plagues conjoint federalism.

The relative welfare of federal control over conjoint federalism is the only relative welfare that maintains the same sign for all values of the parameters. I now attempt to sign the other relative welfares under certain values of the parameters. For example, it turns out that some of the other welfares can be signed in the extreme case in which the federal government puts no weight on the benefits of at least one state:

Proposition 2 *With a unique one-sided spillover (assumption B1) and under A1-A4, if the federal government does not value the benefits of at least one state (i.e., $\exists i$ s.t. $\eta_i = 0$), then $W^S > W^F \geq W^C$ and $W^R > W^F \geq W^C$. Moreover, both state control and reverse conjoint federalism are infinitely more efficient than both federal control and conjoint federalism.*

Proof. Under A1-A4 and B1, $\lim_{\eta_i\to 0}\Delta^{SC} = \lim_{\eta_i\to 0}\Delta^{RF} = -\lim_{\eta_i\to 0}\Delta^{FS} = \lim_{\eta_i\to 0}\Delta^{RC} = \infty$. By Proposition 1, $W^F \geq W^C$. Thus, $W^S > W^F \geq W^C$ and $W^R > W^F \geq W^C$. ■

Thus, if, for reasons about which I remain agnostic, the federal government does not value the benefits to at least one of the states, then conjoint federalism is the *least* efficient allocation of power, and either state control or reverse conjoint federalism is second-best efficient. Although this is an extreme case, the result applies more generally as long as the weights (η_1, η_2) are sufficiently low.

In addition to the weight vector (η_1, η_2), another parameter that can be varied in order to sign the relative welfares is the parameter ρ of the CES production function. I now attempt to sign the relative welfares for special cases of this function.

One special case of the CES production function is linear production ($\rho = 1$). In this case, the elasticity of substitution becomes infinitely large: the two input types are perfect substitutes. When the production function is linear, we can unambiguously sign two of the relative welfares:

Proposition 3 *With a unique one-sided spillover (assumption B1) and a linear production function, and under A1-A4,*

(i) reverse conjoint federalism dominates state control, and

(ii) federal control dominates conjoint federalism.

Proof. Under A1-A4 and B1, (i) $\lim_{\rho\to 1}\Delta^{RS} = \alpha_1\nu_2 > 0$ and (ii) $\lim_{\rho\to 1}\Delta^{FC} = -\nu_2 \ln(1-\alpha_1) > 0$. ■

Both of these results arise from the input choice externality, as can be seen readily from the table of inefficiencies in Figure 2. Reverse conjoint federalism dominates state control because while state control suffers from both an input choice externality and an output choice externality, reverse conjoint federalism suffers from an output choice externality; the difference between the two is the input choice externality. Similarly, federal control dominates conjoint federalism because while conjoint federalism suffers from both an input choice externality and an agency problem, federal control only suffers from an agency problem: again, the difference between the two is the input choice externality.

It turns out that we can also weakly sign another relative welfare when the production function is linear, as follows:

Proposition 4 *With a unique one-sided spillover (assumption B1) and a linear production function, and under A1-A4, state control weakly dominates conjoint federalism. The domination is strict if there is an agency problem.*

Proof. Under A1-A4 and B1, $\lim_{\rho \to 1} \Delta^{SC}$ is zero when $\eta = (1, 1)$ and positive otherwise. ■

The intuition for the result is as follows. While both scenarios suffer from an input choice externality, conjoint federalism also suffers from an agency problem. From Corollary 19 (in Appendix A), there is no additional output choice externality under state control when the states are input bosses and the production function is linear.[39]

While one cannot sign the other relative welfares Δ^{XY} in the case of a linear production function without making additional assumptions, the trade-offs that govern these signs are similar to those described above for general CES production, except for one. When the production function is linear, the relative welfare $\lim_{\rho \to 1} \Delta^{FS}$ of federal control over state control is determined only by the trade-off between the agency problem that plagues the former decentralization scenario and the input choice externality that plagues the latter. From Corollary 19, there is no additional output choice externality under state control when the production function is linear because the states are input bosses.

When is delegation the second-best efficient decentralization choice when the production function is linear? As seen from Propositions 3 and 4, conjoint federalism is never second best with a one-sided externality and a linear production function because it is strictly dominated by federal control and weakly dominated by state control. However, we also see from Proposition 3 that the reverse form of delegation – reverse conjoint federalism – dominates state control. In fact, under certain values of the parameters, reverse conjoint federalism can actually be second-best.

[39] It turns out in this special case that the input choice externality exactly cancels out even though the output bosses differ and the values derived for the input choice externality differ. This is because the inefficiencies do not necessarily enter linearly into the expressions for deadweight loss and therefore for relative welfare.

Proposition 5 *With a unique one-sided spillover (assumption B1) and a linear production function, and underA1-A4, reverse conjoint federalism is second-best if the agency problem with both states is worse on net than is the net output choice externality imposed by the two states on each other when the federal government has input power (i.e., if* $\sum_i \Lambda_i < \sum_i \lim_{\rho \to 1} \chi^O_{i,IB=\mathbb{F}}$*).*

Proof. (Under A1-A4 and B1, $\sum_i \Lambda_i < \sum_i \lim_{\rho \to 1} \chi^O_{i,IB=\mathbb{F}} \Leftrightarrow \lim_{\rho \to 1} \Delta^{RF} > 0 \Longleftrightarrow W^R > W^F$. From Proposition 3, $W^R > W^S$ and $W^F > W^C$. If $W^R > W^F$, then $W^R > W^F > W^S$ so $W^R = \max\{W^S, W^F, W^C, W^R\}$. ■

Another case in which reverse conjoint federalism is second-best under linear production is when the federal government puts little weight on the benefits of at least one of the states:

Proposition 6 *With a unique one-sided spillover (assumption B1) and a linear production function, and under A1-A4, if the federal government puts no weight on the benefits to at least one of the states (i.e., if* $\exists i$ *s.t.* $\eta_i = 0$*), then* $W^R > W^S > W^F > W^C$*.*

Proof. Under A1-A4 and B1, if $\exists i$ s.t. $\eta_i = 0$, then $\lim_{\rho \to 1} \Delta^{SC} = \lim_{\rho \to 1} \Delta^{RF} = -\lim_{\rho \to 1} \Delta^{FS} = \lim_{\rho \to 1} \Delta^{RC} = \infty$. When combined with Proposition 3, this means that $W^R > W^S > W^F > W^C$. ■

Thus, with a one-sided spillover and linear production, if the federal government puts little weight on the benefits of at least one of the states, then delegation via reverse conjoint federalism is the *most* efficient decentralization scenario and, moreover, delegation via conjoint federalism is the *least* efficient. The latter results is particularly ironic since conjoint federalism is the form of power distribution often used in regulation. Although putting zero weight on one state's benefits is an extreme form of the agency problem, the result that reverse conjoint federalism is second-best efficient when the agency problem is sufficiently severe hold more generally for less extreme cases as well.

In addition to linear production, another special case of the CES production function is Leontief production ($\rho = -\infty$).[40] In this case, the elasticity of substitution equals zero. The two types of input are perfect complements. The main result under Leontief production, which does not depend on Assumptions A1-A4 or B1, is as follows:

Proposition 7 *If the production function is Leontief, then the allocation of input power has no effect on welfare:* $W^S = W^R$ *and* $W^F = W^C$*.*

Proof. The result falls simply from direct calculation. ■

[40] A third special case of the CES production function is Cobb-Douglas ($\rho = 0$). Unfortunately, aside from the relative welfare of federal control over conjoint federalism, which was signed for all values of ρ in Proposition 9, none of the other realtive welfares can be unambiguously signed when $\rho = 0$ without making additional restrictions on the parameters.

Thus, given the allocation of output power, it does not matter who the input boss is. The intuition is as follows. When the production function is Leontief, the conditional input levels chosen to minimize individual costs to meet a given vector of output targets are also the same conditional input levels that would be chosen to minimize total costs. Thus, given the output target, the Nash equilibrium conditional input levels are cost-effective. It therefore does not matter whether the conditional input levels are chosen cooperatively or not. One main implication of this result is that when the two input types are perfect complements, there is no case for delegation: the welfare under either form of delegation can always be achieved without delegation. Delegation is never the unique second-best decentralization scenario.

In summary, there are two main results from my base case of a unique one-sided spillover. First, conjoint federalism is weakly dominated by federal control and sometimes by state control as well, and it can be the *least* efficient decentralization scenario under certain values of the parameters. This is an ironic result because conjoint federalism is the power structure often used in regulation. My second main result is that a reverse form of delegation is often the *most* efficient.

I now examine two extensions to my basic model: one in which contractibility depends on the allocation of power, and another in which there are two-sided spillovers from both input types.

6 Delegation when Contractibility Depends on Power Allocation

According to the results of my basic model, a case can be made for why reverse conjoint federalism is second best. One institutional modification that would guarantee that reverse conjoint federalism were *first* best would be to make output contractible when the federal government has at least one form of power. In other words, (a_i, b_i) is never contractible; q_i is not contractible unless the federal government is included in the regulatory hierarchy. Under these assumptions, the distribution of power is important because it determines which tier of government can make decisions about input, decisions that are not contractible, and because it determines whether or not output is contractible.

One justification for why granting the federal government power would render output contractible is that unlike individual states, which each have an incentive to obfuscate its output level from the other because of spillovers, the federal government, which accounts for the utility of both states, albeit possibly incorrectly, has no such incentive and can standardize measurement equipment to observe and verify output. Since I assume that the federal government has no information problems, its measurement of output would be correct and states would be able to contract on it.

If including the federal government in the regulatory hierarchy enables output to become contractible, then reverse conjoint federalism would be first-best efficient. The reasoning is as follows. When the federal government retains input power but delegates output power to states in reverse conjoint federalism, states can contract with each other to choose the welfare-maximizing output. Thus, output levels could be chosen efficiently by the states, circumventing both the output choice externality and the agency problem. Moreover, conditional on the states' output choice, the federal government would choose the cost-effective conditional input levels. Thus, both output levels and conditional input levels would be chosen efficiently. As a consequence, reverse conjoint federalism would implement the first-best outcome.

Thus, with the contractibility of output when the federal government has power, reverse conjoint federalism is the first-best decentralization scenario. If, in addition, the two input types are not perfect complements so that the Nash equilibrium conditional input levels are not cost-effective, reverse conjoint federalism will be the unique first-best decentralization scenario.

7 General Model of Two-Sided Spillovers from Both Inputs

7.1 Assumptions of General Model

I now generalize my simple base-case model to allow for two-sided spillovers from each input type. As before, the type-a "effective" input A_i in each state i is a weighted sum of the type-a "individual" inputs exerted in both states: $A_i \equiv a_i + \alpha_i a_j$, where now $\alpha_i \geq 0 \ \forall i$. Moreover, the type-b "effective" input B_i in state i is no longer simply equal to state i's type-b individual input, but is instead a weighted sum of the type-b "individual" inputs exerted in both states: $B_i \equiv b_i + \beta_i b_j$, where the *type-b effective input spillover* β_i from state j to state i is nonnegative: $\beta_i \geq 0$. I assume that, for each type of input, input does not completely spill over for both states, where by "complete" spillover I mean a spillover equal to one: $1 - \alpha_i \alpha_j \neq 0$ and $1 - \beta_i \beta_j \neq 0$.

While the expressions for the marginal private costs (MPC^A, MPC^B), the relative marginal cost parameter γ, and the marginal social cost MSC_i^A to state i of producing output via type-a input remain unchanged, the marginal social cost to state i of producing output via type-b input is now given by $MSC_i^B = \frac{1-\beta_j}{1-\beta_i\beta_j} \frac{c_a}{\frac{\partial f_i}{\partial A_i}}$ and the marginal social cost parameter is now given by $\kappa_i = \frac{1-\beta_i\beta_j}{1-\alpha_i\alpha_j} \frac{1-\alpha_j}{1-\beta_j}$.

With this more general model, I still make the assumptions A1-A4. In particular, assumption A2 that type-a input is socially less costly to implement puts restrictions on the values of the spillovers $\{\alpha_i, \beta_i\}_{i=1,2}$.[41]

[41] As long as A1-A4 are satisfied, the expressions for the solution to my model do not require that the spillovers be nonnegative. However, because general results on the signs of the relative welfares are harder, if not impossible, to obtain without any restrictions on the signs of the spillovers, I have chosen to restrict the spillovers to be nonnegative.

The basic method of solving the two-stage regulatory game remains unchanged when the model is generalized.[42]

7.2 Results from the General Model

In this section, I summarize the main results that arise from the general solution.[43] In particular, I present four results that are generalizations of analogous results from the basic model.

The first result from the basic model that generalizes when there are two-sided spillovers from both input types is the tendency for conjoint federalism to be dominated by federal control. However, unlike for the basic model, the domination no longer holds for all cases of the CES production in the general model. One case in which the domination does hold is linear production:

Proposition 8 *Under assumptions A1-A4, federal control weakly dominates conjoint federalism when the production function is linear. If, in addition, $\exists i$ such that $\kappa_i \gamma < 1$, then federal control strictly dominates conjoint federalism.*

Proof. $\lim_{\rho \to 1} \Delta^{FC} = \sum_i [-\nu_i \ln(\kappa_i \gamma)] \geq 0$ since $\nu_i > 0$ and $\kappa_i \gamma \leq 1$. The inequality is strict if $\exists i$ such that $\kappa_i \gamma < 1$. ■

Thus, conjoint federalism, the form of delegation currently in place for air quality regulation in the United States, is less efficient than federal control when the two input types are perfect substitutes. The intuition is as follows. Federal control weakly dominates conjoint federalism because while both scenarios suffer from an agency problem, conjoint federalism also suffers from an input choice externality, as can be seen in the table of inefficiencies in Figure 2. Moreover, as established by Corollary 17 (in Appendix A), this input choice externality is the unique determinant of the welfare difference between these two scenarios when the production function is linear. In this case, the cooperative conditional input choice yields a corner solution in which all the input is allocated toward the type-a input, while the Nash equilibrium conditional input choice yields a corner solution in which all the input is allocated toward the type-b input. Thus, except in the knife-edge case in which $\kappa_i \gamma = 1$ so that all conditional input choices satisfy the cooperative first-order condition, the Nash equilibrium choice is not cost-effective, the input choice externality is therefore non-zero, and federal control is more efficient than conjoint federalism when the production function is linear.

[42] For the interested reader, the details of how to solve the more general problem are available from the author upon request; details for a similar problem are also given in Appendix A of Lin (2004b).

[43] The general solution to the two-stage regulatory problem and the relative welfares under the various decentralization scenarios for three special cases of the CES production function are given in Appendix B and Appendix C, respectively, of Lin (2004b).

A second result that generalizes from the basic model is the results that both state control and reverse conjoint federalism are infinitely better than either federal control or conjoint federalism in the limit as the federal government puts no weight on the benefits of at least one state:

Proposition 9 *Under A1-A4, if the federal government does not value the benefits of at least one state (i.e., $\exists i$ s.t. $\eta_i = 0$), then both state control and reverse conjoint federalism are infinitely more efficient than both federal control and conjoint federalism.*

Proof. *Under A1-A4,* $\lim_{\eta_I \to 0} \Delta^{SC} = \lim_{\eta_I \to 0} \Delta^{RF} = -\lim_{\eta_I \to 0} \Delta^{FS} = \lim_{\eta_I \to 0} \Delta^{RC} = \infty.$ ■

A third results that generalizes from the basic model is the result that it is possible for delegation by reverse conjoint federalism to be the *most* efficient decentralization scenario.

Proposition 10 *Under assumptions A1-A4, reverse conjoint federalism is the unique second-best decentralization scenario when production functions are linear if:*
(i) the input choice externality imposed by the two states on each other is negative on net when the states have output power (i.e., $\sum_i \lim_{\rho \to 1} \chi^I_{i,OB=\mathbb{S}} < 0$*), and*
(ii) the agency problem with both states is worse on net than is the net output choice externality imposed by the two states on each other when the federal government has input power (i.e., $\sum_i \Lambda_i < \sum_i \lim_{\rho \to 1} \chi^O_{i,IB=\mathbb{F}}$*).*

Proof. The two conditions are equivalent to $\lim_{\rho \to 1} \Delta^{RS} > 0$ and $\lim_{\rho \to 1} \Delta^{RF} > 0$, respectively. Under A1-A4, $\lim_{\rho \to 1} \Delta^{FC} \geq 0$ by Proposition 8, which means that $\lim_{\rho \to 1} \Delta^{RF} > 0 \Rightarrow \lim_{\rho \to 1} \Delta^{RC} > 0$. Thus, if $\lim_{\rho \to 1} \Delta^{RS} > 0$ and $\lim_{\rho \to 1} \Delta^{RF} > 0$, then under A1-A4 and when $\rho = 1$, $W^R = \max\{W^S, W^F, W^C, W^R\}$. ■

A fourth result that generalizes from the basic model pertains to the inconsequential nature of input power allocation when the two types of input are perfect complements, since Proposition 7 did not require any of assumptions A1-A4 or B1. Thus, as in the base-case model, delegation is never the unique second-best decentralization scenario when the production function is Leontief.

8 Concluding Remarks

Regulation often takes the form of a standard that can be met through the implementation of any of a number of different policies. This paper examines how the authority to set the standard and the authority to choose the combination of policies to meet the standard should be allocated between a central government and local governments, when neither setting nor meeting the standard is contractible. Is it ever second-best efficient to separately allocate the power to set the standard from the power to meet the standard? In other words, under what circumstances is it most efficient for the central government retain the power to either set or meet the standard, but not both, and delegate the power to make the remaining decision to the local governments?

According to my model, the optimal allocation of the power to set the standard depends on the relative magnitude of the externality that arises from local governments' non-coordinated decision about setting the standards and the agency problem that arises when the central government sets the standards, and should therefore vary from case to case depending on the values of the parameters. As for the power to meet the standard, however, the optimal allocation is unambiguous: the central government is weakly preferred to local governments who, for any given level of the standard, will choose to overallocate their policy mix towards the privately cheaper but socially more expensive policy.

My two central findings then follow directly. First, standards set by a central government are better met by the central government rather than by local governments, since the federal government is the weakly preferred tier to meet the standards: it is for this reason that conjoint federalism is often dominated by complete centralization, and can often be the least efficient. Second, if the agency problem is sufficiently severe that it outweighs the externality that would arise if local governments set the standards, then it may be best to let local governments each decide their own standard, rather than let the central government, whose preferences differ, decide for them; as a consequence, reverse conjoint federalism may be the most efficient.

So, can a case be made for delegation? The answer is "yes", but the form of delegation matters. While delegation via reverse conjoint federalism can be the most efficient distribution of power, delegation in its more typical form of conjoint federalism can also be the *least* efficient. Thus, contrary to common practice, it may be best to allow individual units to each choose set its own standard and then to have the central authority decide how each unit should meet its standard. For example, states should each decide their own air quality standard or test score standard, but the federal government should be the tier that decides how to regulate emissions sources and how to improve schools in order to meet these standards.[44] The federal government's role should be that of a facilitator.

My results therefore suggest that social welfare may be increased by reversing the form of delegation often used in regulations in such federations as the United States and the European Union. This is especially the case for situations in which the spillovers from the input types differ in magnitude and in which the central government's preferences for the output diverge from those of local constituents. In particular, reverse

[44] However, for cases in which federal and state preferences are well aligned and the agency problem is therefore negligible, federal control may be second-best efficient. For example, if the public good in question were voter turnout and civic participation, then since federal and local elections often occur simultaneously, the optimal regulatory structure may be for the federal government to decide both the voter turnout target for all states as well as the particular state programs that need to be implemented to achieve these targets. Moreover, if spillovers are non-existent and if the federal government suffers from an agency problem in costs rather than in benefits, then it is possible that the commonly used conjoint federalism may no longer be relatively inefficient.

conjoint federalism should be implemented if the federal government's objective function puts little weight on the benefits of the public good to at least one of the states: this may be the case, for example, during a Republican administration in the U.S. Thus, for many regulations including those involving air quality, the U.S. and the EU may have it reversed. The research presented in this paper may have important implications for the issue of optimally distributing governmental power in the provision of public goods as well as for any problem of organizational choice in the presence of interjurisdictional externalities.

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9 Appendix A: Characterizing the Inefficiencies in the General Model

In this Appendix, I derive and analyze the quantitative expressions for the three types of inefficiency – input choice externality, output choice externality and agency problem – for the general model.

9.1 Input choice externality

The quantitative expression for the input choice externality is given by the following Proposition.

Proposition 11 *Under A1-A4, the input choice externality imposed by state i that is not internalized when state i has the power to choose its conditional input levels is equal to*

$$\chi^I_{i,OB=\mathbb{S}} = -\nu_i \left(\begin{array}{c} \ln\left(\dfrac{\left(f_A+(\kappa_i\gamma)^{\frac{\rho}{1-\rho}} f_B\right)^{\frac{1}{\rho}} \left(f_A+\frac{1-\alpha_i\alpha_j}{1-\beta_i\beta_j}\gamma^{\frac{\rho}{1-\rho}} f_B\right)}{\left(f_A+\frac{1-\alpha_j}{1-\beta_j}(\kappa_i\gamma)^{\frac{\rho}{1-\rho}} f_B\right)\left(f_A+\gamma^{\frac{\rho}{1-\rho}} f_B\right)^{\frac{1}{\rho}}} \right) \\ +\left(1-\dfrac{(1-\alpha_j)\left(f_A+(\kappa_i\gamma)^{\frac{\rho}{1-\rho}} f_B\right)}{f_A+\frac{1-\alpha_j}{1-\beta_j}(\kappa_i\gamma)^{\frac{\rho}{1-\rho}} f_B} - \alpha_j \dfrac{f_A+\frac{\beta_j}{\alpha_j}\frac{1-\alpha_i\alpha_j}{1-\beta_i\beta_j}\gamma^{\frac{\rho}{1-\rho}} f_B}{f_A+\frac{1-\alpha_i\alpha_j}{1-\beta_i\beta_j}\gamma^{\frac{\rho}{1-\rho}} f_B}\right) \end{array} \right) \tag{39}$$

when states have output power and

$$\chi^I_{i,OB=\mathbb{F}} = -\nu_i \left(\begin{array}{c} \ln\left(\dfrac{\left(f_A+(\kappa_i\gamma)^{\frac{\rho}{1-\rho}} f_B\right)^{\frac{1-\rho}{\rho}} \left(f_A+\left(\frac{1}{1-\alpha_i\alpha_j}\right)^{\frac{1}{1-\rho}}\kappa_i^{-1}\gamma^{\frac{\rho}{1-\rho}} f_B\right)}{\left(f_A+\gamma^{\frac{\rho}{1-\rho}} f_B\right)^{\frac{1}{\rho}}} \right) \\ -\left(1-\dfrac{\left(f_A+\kappa_i^{-1}\gamma^{\frac{\rho}{1-\rho}} f_B\right)}{f_A+\left(\frac{1}{1-\alpha_i\alpha_j}\right)^{\frac{1}{1-\rho}}\kappa_i^{-1}\gamma^{\frac{\rho}{1-\rho}} f_B}\right) \end{array} \right) \tag{40}$$

when the federal government has output power.

Proof. The desired result follows simply from direct calculation using the definition of the input choice externality given in equation (36). ■

The next few Corollaries establish cases in which the input choice externality does not exist, and therefore cases in which it does not matter how input power is allocated.

Corollary 12 *There is no input choice externality when the production function is Leontief.*

Proof. $\lim_{\rho \to -\infty} \chi^I_{i,OB=Z} = 0 \; \forall i, Z \in \{\mathbb{S}, \mathbb{F}\}$. ■

This Corollary exactly mirrors Proposition 7, which derives the same result directly from the welfare expressions, and the intuition is the same. This result does not require assumptions A1-A4.

Corollary 13 *If $\kappa_i = 1$ and $\rho < 1$, then no input choice externality is imposed by state i.*

Proof. If $\rho < 1$, $\left(\chi^I_{i,OB=Z}\right)_{\kappa_i=1} = 0 \; \forall Z \in \{\mathbb{S}, \mathbb{F}\}$. ■

The intuition is as follows. If $\kappa_i = 1$, then $\kappa_i \gamma = \gamma$, which means that the first-order condition governing the cooperative conditional input choice for state i coincides with the first-order condition governing its non-cooperative conditional input choice. As a consequence, the Nash equilibrium conditional input choices for state i are also cost-effective, so it does not matter to total welfare whether or not state i chooses its conditional input levels cooperatively or not.[45]

Corollary 14 *If the production function is linear and the marginal social cost of producing output via the two types of input is equalized (i.e., $\kappa_i \gamma = 1$), then no input choice externality is imposed by state i.*

Proof. $\left(\lim_{\rho \to 1} \chi^I_{i,OB=Z}\right)_{\kappa_i \gamma = 1} = 0 \; \forall Z \in \{\mathbb{S}, \mathbb{F}\}$. ■

If $\kappa_i \gamma = 1$ and the production function is linear, then the first-order condition governing the cooperative conditional input choice for state i always holds, since the marginal social cost of producing output via type-a input will always be equal to the marginal social cost of producing output via type-b input. As a consequence, all conditional input choices for state i, including the Nash equilibrium conditional input choice, are also cost-effective. Thus, it does not matter to total welfare whether or not state i chooses its conditional input levels cooperatively or not.

Even if the input choice externality did exist, it would not necessarily be negative.[46] However, for a linear production function, the input choice externality imposed by state 2 is unambiguously negative:

Corollary 15 *With a unique one-sided spillover (assumption B1) and under A1-A4, the input choice externality imposed by state 2 is strictly negative when the production function is linear.*

Proof. Under A1-A4 and B1, $\lim_{\rho \to 1} \chi^I_{2,OB=Z} < 0 \;\; \forall Z \in \{\mathbb{S}, \mathbb{F}\}$. ■

In addition to a linear production function, another case in which the input choice externality imposed by state 2 is weakly negative is when the output power is allocated to the federal government:

Corollary 16 *With a unique one-sided spillover (assumption B1) and under A1-A4, the input choice externality imposed by state 2 is weakly negative if the federal government has output power: $\chi^I_{2,OB=\mathbb{F}} \leq 0$. If, in addition, $\rho \notin \{-\infty, \frac{1}{2}\}$, then the externality is strictly negative.*

Proof. Under A1-A4 and B1,

$$\chi^I_{2,OB=\mathbb{F}} \begin{cases} = 0 & \text{if } \rho = -\infty \\ < 0 & \text{if } \rho = 0 \\ = 0 & \text{if } \rho = \frac{1}{2} \\ < 0 & \text{if } \rho = 1 \end{cases} .$$

The derivative of $\chi^I_{2,OB=\mathbb{F}}$ with respect to ρ is given by:

$$\frac{\partial \chi^I_{2,OB=\mathbb{F}}}{\partial \rho} = v_2 \rho^{-2} \left(f_A + (1-\alpha_1)^{\frac{\rho}{1-\rho}} f_B\right)^{\frac{1-\rho}{\rho}} \ln\left(f_A + (1-\alpha_1)^{\frac{\rho}{1-\rho}} f_B\right).$$

The sign of this derivative is given by:

[45] Under A1-A4, this result does not hold for the linear case.

[46] The input choice externality is not necessarily negative because my definition for the input choice externality does not hold output levels constant, but instead allows the output boss to base its output choice on the allocation of input power. Thus, while the cost-effective conditional input choice yields more welfare than the Nash equilibrium input choice for any given output level, it is possible for the latter to be preferred if the output levels were allowed to depend on the input power allocation.

$$\frac{\partial \chi^I_{2,OB=\mathbb{F}}}{\partial \rho} \begin{cases} < 0 & \rho \in (-\infty, 0) \\ > 0 & \rho \in (0, \frac{1}{2}) \\ < 0 & \rho \in (\frac{1}{2}, 1] \end{cases} .$$

Thus, $\chi^I_{2,OB=\mathbb{F}}$ reaches a maximum value of zero at $\rho = -\infty$ and $\rho = \frac{1}{2}$, and is strictly negative for all other $\rho \in (-\infty, 1]$. ■

I now establish a relationship between the input choice externality and the relative welfare Δ^{FC} of federal control over conjoint federalism:

Corollary 17 *If (i) the type-a effective input spillover is one-sided (i.e., $\exists i$ s.t. $\alpha_i = 0$);*
(ii) the production function is Leontief; or
(iii) the production function is linear and A1-A4 hold,
then $\sum_i \chi^I_{i,OB=\mathbb{F}} = -\Delta^{FC}$.

Proof. $\sum_i \chi^I_{i,OB=\mathbb{F}} = -\Delta^{FC}$ if $\left(\frac{1}{1-\alpha_i\alpha_j}\right)^{\frac{1}{1-\rho}} = 1$. Both (i) and (ii) are each itself a sufficient condition for $\left(\frac{1}{1-\alpha_i\alpha_j}\right)^{\frac{1}{1-\rho}} = 1$. (iii) Under A1-A4, $\sum_i \lim_{\rho\to 1} \chi^I_{i,OB=\mathbb{F}} = -\lim_{\rho\to 1} \Delta^{FC}$. ■

9.2 Output choice externality

The output choice externality that arises in this general model is quantified by the following Proposition:

Proposition 18 *Under A1-A4, the output choice externality imposed by state i that is not internalized when state i has the power to choose its output level is equal to:*

$$\chi^O_{i,IB=\mathbb{S}} = \nu_i \left(\begin{array}{c} \ln \left(\frac{(1-\alpha_j)\left(f_A + \left(\frac{1}{1-\alpha_i\alpha_j}\right)^{\frac{1}{1-\rho}} \kappa_i^{-1} \gamma^{\frac{\rho}{1-\rho}} f_B\right)}{\left(f_A + \frac{1-\alpha_i\alpha_j}{1-\beta_i\beta_j}\gamma^{\frac{\rho}{1-\rho}} f_B\right)} \right) \\ - \left(1 - \frac{\left(f_A + \kappa_i^{-1}\gamma^{\frac{\rho}{1-\rho}} f_B\right)}{f_A + \left(\frac{1}{1-\alpha_i\alpha_j}\right)^{\frac{1}{1-\rho}}\kappa_i^{-1}\gamma^{\frac{\rho}{1-\rho}} f_B} - \alpha_j \frac{f_A + \frac{\beta_j}{\alpha_j}\frac{1-\alpha_i\alpha_j}{1-\beta_i\beta_j}\gamma^{\frac{\rho}{1-\rho}} f_B}{f_A + \frac{1-\alpha_i\alpha_j}{1-\beta_i\beta_j}\gamma^{\frac{\rho}{1-\rho}} f_B}\right) \end{array} \right) \tag{41}$$

when states have input power, and

$$\chi^O_{i,IB=\mathbb{F}} = \nu_i \left(\ln\left(\frac{(1-\alpha_j)\left(f_A + (\kappa_i\gamma)^{\frac{\rho}{1-\rho}} f_B\right)}{\left(f_A + \frac{1-\alpha_j}{1-\beta_j}(\kappa_i\gamma)^{\frac{\rho}{1-\rho}} f_B\right)} \right) - \left(\frac{(1-\alpha_j)\left(f_A + (\kappa_i\gamma)^{\frac{\rho}{1-\rho}} f_B\right)}{f_A + \frac{1-\alpha_j}{1-\beta_j}(\kappa_i\gamma)^{\frac{\rho}{1-\rho}} f_B} - 1 \right) \right) \tag{42}$$

when the federal government has input power.

Proof. This results falls simply from direct calculation using the definition of the output choice externality given in equation (37). ■

I now establish a special case in which the output choice externality is non-existent:

Corollary 19 *Under A1-A4, when the production function is linear, then state i does not impose any output choice externality if*
(i) state í's type-b effective input does not spill over to state j (i.e., $\beta_j = 0$) and states have input power, or
(ii) state í's type-a effective input does not spill over to state j (i.e., $\alpha_j = 0$) and the federal government has input power.

Proof. (i) $\lim_{\rho \to 1} \chi^O_{i,IB=\mathbb{S}} = \nu_i \left(\ln(1-\beta_j) + \beta_j\right)$. $\beta_j = 0 \Rightarrow \lim_{\rho \to 1} \chi^O_{i,IB=\mathbb{S}} = 0$.
(ii) $\lim_{\rho \to 1} \chi^O_{i,IB=\mathbb{F}} = \nu_i \left(\ln(1-\alpha_j) + \alpha_j\right)$. $\alpha_j = 0 \Rightarrow \lim_{\rho \to 1} \chi^O_{i,IB=\mathbb{F}} = 0$. ■
The intuition is as follows. When the production function is linear, then under assumptions A1-A4, corner solutions for conditional effective input will arise: each state will allocate all its conditional effective input toward type-b input when it has input power, and the federal government will allocate conditional effective input toward type-a input when it has input power. Thus, in choosing the output level, the output boss can only affect the amount of input chosen, not the allocation of input between the two types. For instance, when states have input power, then the output boss for state i can only affect the amount of type-b conditional effective input that state i chooses, but has no control over the fact that state i will never exert any type-a input. Thus, whether or not state i's output level is chosen cooperatively or not will only matter if it state j is affected by the amount of type-b input exerted by state i: i.e., if state i's type-b input spills over to state j. Thus, when states are input bosses and the production function is linear, state i imposes an output choice externality on state j only if $\beta_j \neq 0$. Similarly, when the federal government is the input boss, then the output boss for state i can only affect the amount of type-a effective input chosen for state i, and whether or not the output choice is made cooperatively or not will matter only if state i's type-a input spills over to state j: i.e., $\alpha_j \neq 0$.

A special case of the output choice externality arises when the unique one-sided spillover is *complete*: that is, when $\alpha_1 = 1$ and $\alpha_2 = 0$:

Corollary 20 *Under A1-A4 and B1, if the unique one-sided spillover is complete (i.e., $\alpha_1 = 1$), then the output choice externality is weakly negative if the states have input power and infinitely negative if the federal government has input power.*

Proof. Under A1-A4 and B1,

$$\lim_{\alpha_1 \to 1} \chi^O_{2,EB=\mathbb{S}} = \begin{cases} \nu_2 \ln f_B \ < 0 & \text{if } \rho < 1 \\ 0 & \text{if } \rho = 1 \end{cases}$$

and $\lim_{\alpha_1 \to 1} \chi^O_{2,EB=\mathbb{F}} = -\infty \ \forall \rho \leq 1$. ■

9.3 Agency problem

The following Proposition quantifies the agency problem:[47]

Proposition 21 *Under A1-A4, the agency problem for state i arises only when the federal government is the output boss, and is given by:*

$$\Lambda_i = \nu_i \left(\ln(\eta_i) + 1 - \eta_i\right). \tag{43}$$

Proof. *Using the definition given in equation (38), the agency problem for state i is given by $\Lambda_i \equiv W^X_{\eta_j=1} - W^X_{\eta_i=1,\eta_j=1}$.*

If states are output bosses, then $W^X_{\eta_j=1} = W^X_{\eta_i=1,\eta_j=1}$ since neither output never input levels will depend on η, even if the federal government is the input boss. Thus, $\Lambda_i = 0$ when states have output power.

If the federal government is the output boss, then let $q_i(\eta_i)$ denote output for state i as a function of η_i. The appropriate function for $q_i(\eta_i)$ depends on which tier of government has input power and on the linearity of the production function. Total welfare can thus be expressed in terms of $q_i(\eta_i)$; the case of no agency problem corresponds to $q_i(1)$. For instance, when $\rho < 1$, total welfare can be written as:

$$W = \sum_i \left[v_i \ln(q_i(\eta_i)) - c_a \left(\frac{A_i(q_i(\eta_i)) - \alpha_i A_j(q_j(\eta_j))}{1 - \alpha_i \alpha_j} \right) - c_b \left(\frac{B_i(A_i(q_i(\eta_i))) - \beta_i B_j(A_j(q_j(\eta_j)))}{1 - \beta_i \beta_j} \right) \right]$$

[47] Because the agency problem is independent of the input spillovers, the expression for the agency problem does not depend on the assumptions made on the spillovers. In particular, the same expression for the agency problem in the basic model of a unique one-sided spillover holds in the more general model of two-sided spillovers from both input types.

In this case, the agency problem can be derived as follows:

$$\begin{aligned}\Lambda &\equiv W^X_{\eta_j=1} - W^X_{\eta_i=1,\eta_j=1} \\ &= v_i \ln(\frac{q_i(\eta_i)}{q_i(1)}) - \left(\frac{1-\alpha_j}{1-\alpha_i\alpha_j}c_a + \frac{1-\beta_j}{1-\beta_i\beta_j}c_b B_i'(A_i)\right) A_i'(q_i)\left(q_i(\eta_i) - q_i(1)\right) \\ &= \nu_i\left(\ln(\eta_i) + 1 - \eta_i\right),\end{aligned}$$

where the second step uses the fact that the conditional type-a effective input $A_i(\cdot)$ is linear in q_i while the conditional type-b effective input $B_i(\cdot)$ is linear in A_i. The derivation of the agency problem for the case of $\rho = 1$ is similar, and uses assumptions A1-A4. ■

The expression for the agency problem leads to the following Corollary:

Corollary 22 *Under A1-A4, the agency problem with state i is non-existent when $\eta_i = 1$, but strictly negative otherwise. Moreover its magnitude increases with the distance $|\eta_i - 1|$ between η_i and 1.*

Proof. The result falls simply by inspection of equation (43). ■
Thus, if the federal benefit function puts unit weight on state i's true benefit function, then there is no agency problem with state i: $\Lambda_i = 0$; otherwise the agency problem is strictly negative and gets worse the further the weight η_i is from 1.

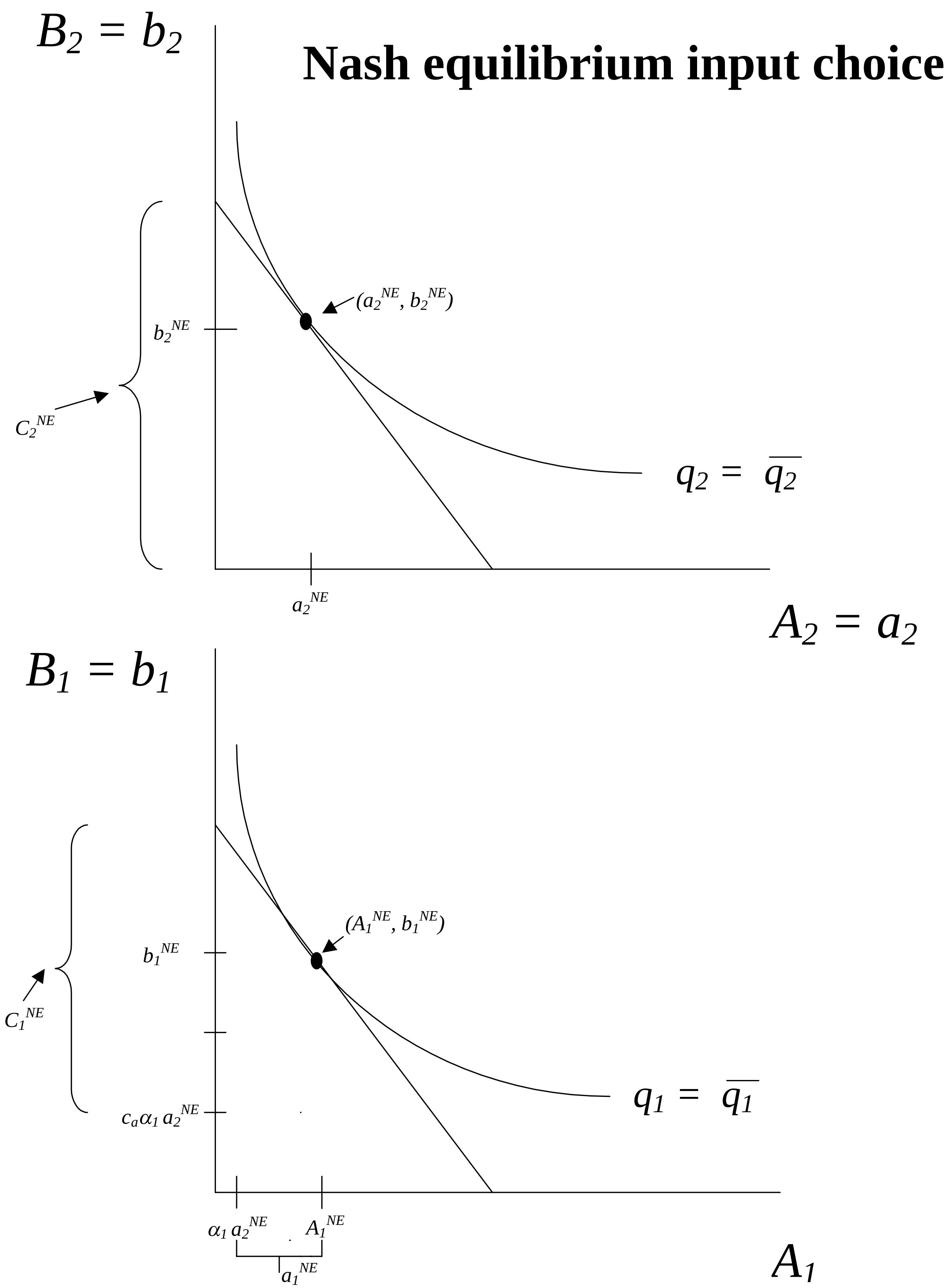

Figure 3: The Nash equilibrium conditional input choice that arises under assumptions A1-A4 and B1-B2, given the target output vector $q = (\overline{q_1}, \overline{q_2})$ chosen in stage one.

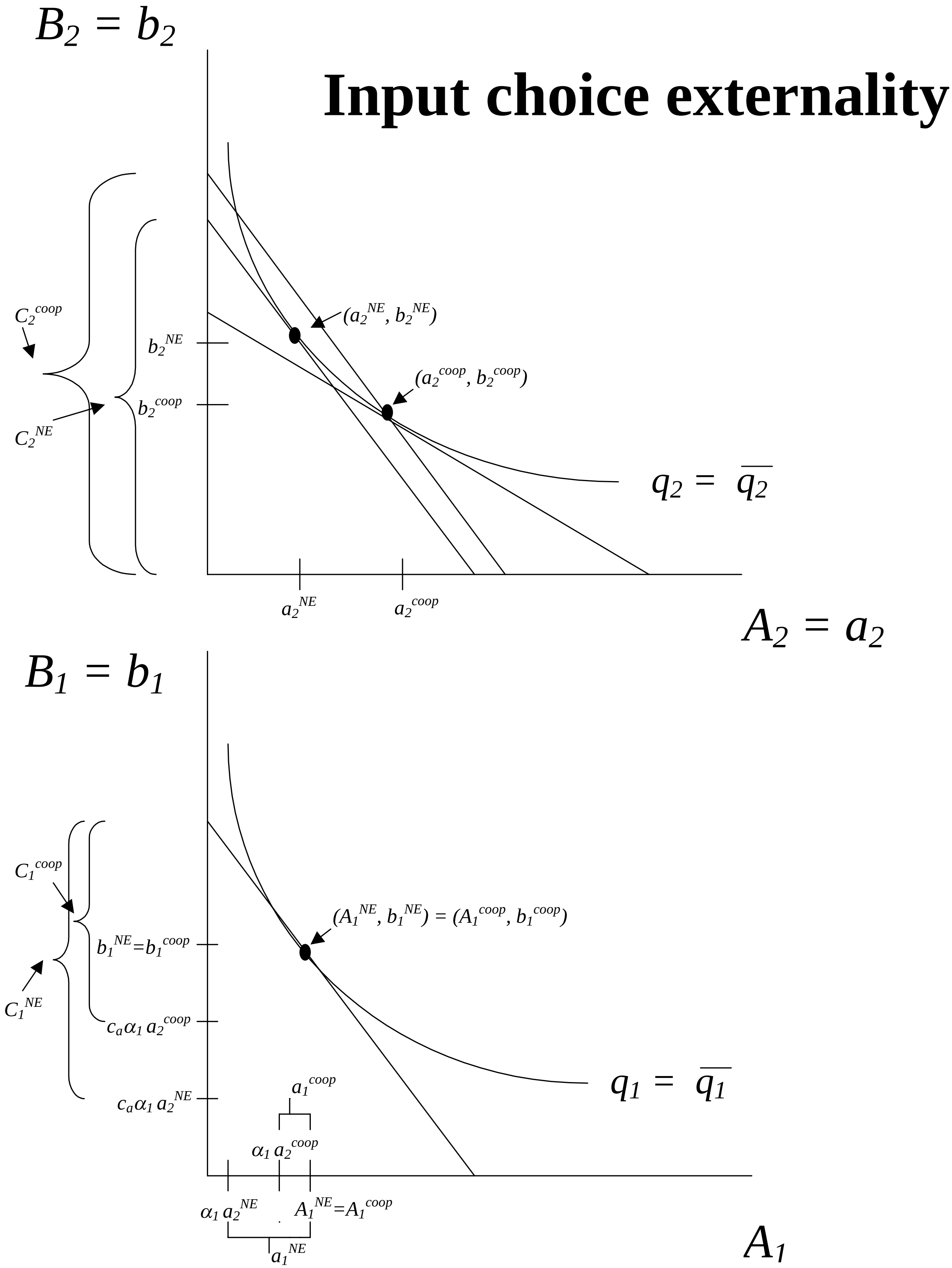

Figure 4: A comparison of the Nash equilibrium conditional input choice (denoted with a superscript "NE") with the cooperative conditional input choice (denoted with a superscript "coop") given the same target output vector $q = (\overline{q}_1, \overline{q}_2)$, under assumptions A1-A4 and B1-B2.

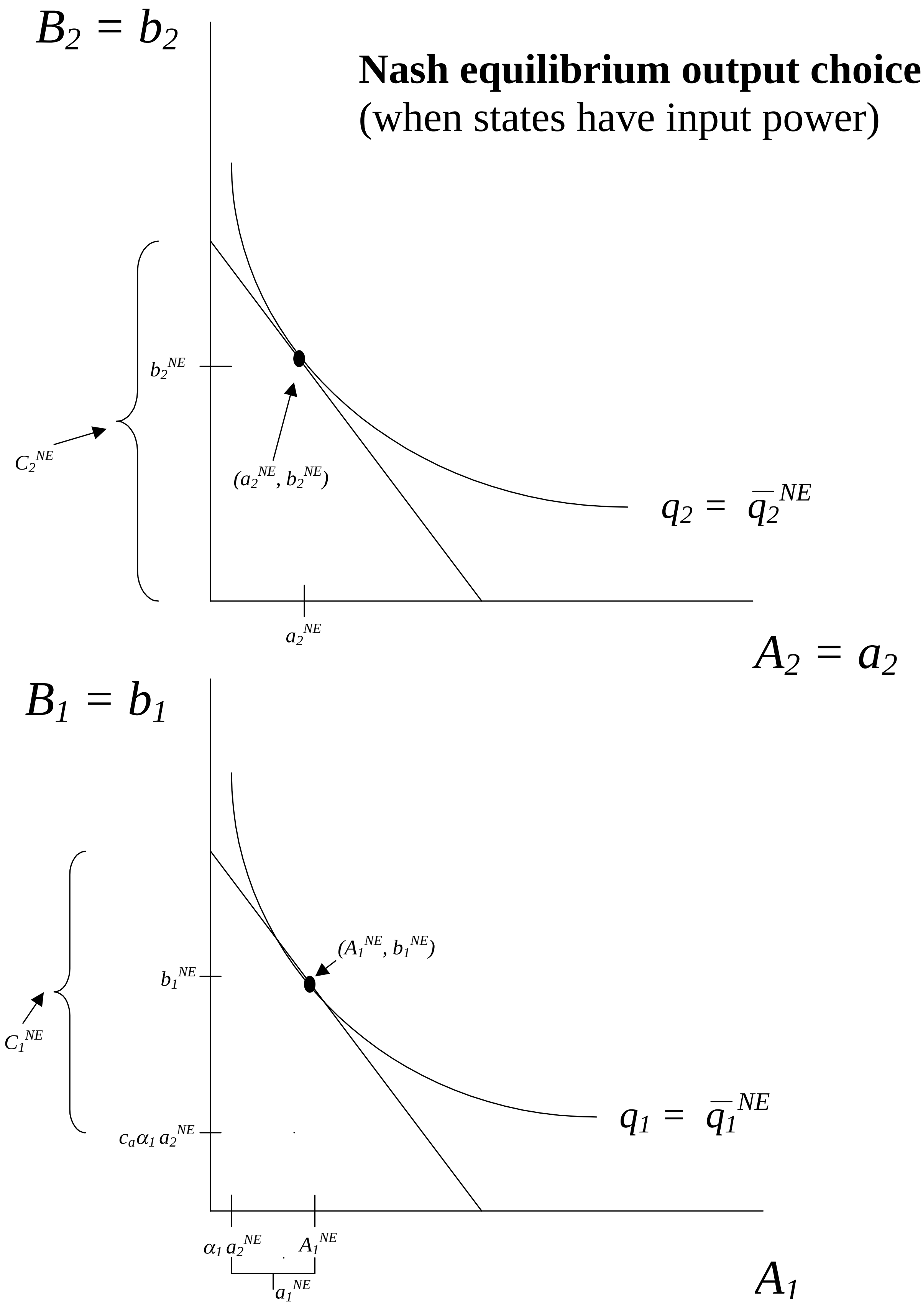

Figure 5: The non-cooperative Nash equilibrium output choice $(\bar{q}_1^{NE}, \bar{q}_2^{NE})$ that arises under assumptions A1-A4 and B1-B2 when the output bosses anticipate that the conditional input levels would be chosen non-cooperatively by the states.

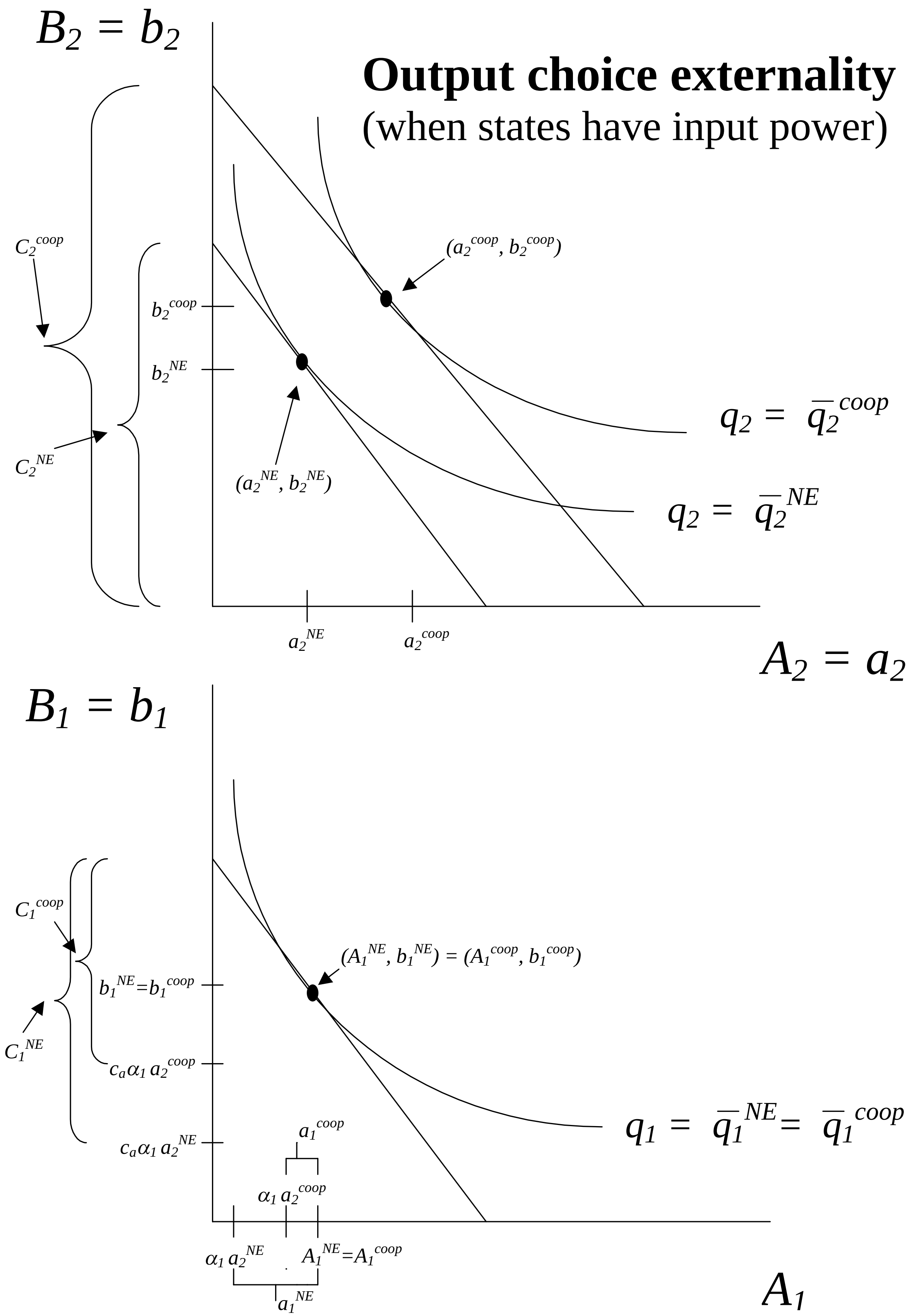

Figure 6: A comparison of the Nash equilibrium output choice (denoted with a superscript "NE") with the cooperative output choice (denoted with a superscript "coop") when output bosses anticipate that the conditional input levels would be chosen non-cooperatively by the states, under assumptions A1-A4 and B1-B2.