EXPERIMENTATION IN FEDERAL SYSTEMS*

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We develop a model of policy experimentation in federal systems in which heterogeneous districts choose both whether to experiment and the policies to experiment with. The prospect of informational spillovers implies that in the first best the districts converge in their policy choice. Strikingly, when authority is decentralized, the equilibrium predicts the opposite. The districts use their policy choice to discourage other districts from free-riding on them, thereby inefficiently minimizing informational spillovers. To address this failure, we introduce a dynamic form of federalism in which the central government harmonizes policy choices only after the districts have experimented. This progressive concentration of power induces a policy tournament that can increase the incentive to experiment and encourage policy convergence. We compare outcomes under the different systems and derive the optimal levels of district heterogeneity. *JEL* Codes: D78, H77.

I. INTRODUCTION

Just as people learn from each other, so do governments. While people learn from each other about nice restaurants and good schools, governments learn from each other about effective policies. Governments observe their neighbors, as well as states and countries further afield, imitating their policy successes while avoiding their policy failures.

The spread of policies in this way—known as policy diffusion—has most famously been documented as a strength of federal systems. Yet these benefits need not be limited to federal systems as information can flow across national borders equally well. In recent times, researchers have begun to document these flows, moving beyond their mere existence to characterize the

*We benefitted from the audiences at the 2012 Nemmers Conference, the 2012 NYU-LSE conference on political economy, the 2012 Symposium on Collective Decisions at the University of Hamburg, Stanford GSB, Yale University, University of Namur, Paris School of Economics, ETH Zurich, APSA, MWPSA, the Australasian Econometric Society Meetings, the Priorat Workshop in Theoretical Political Economy, and in particular the comments of Joe Aldy, David Austen-Smith, Hande Mutlu-Eren, Sarah Soule, Jon Skjærseth, Daniel Sturm, Dan Treisman, Jørgen Wettestad, Glen Weyl, and Lin Zhang, and the able research assistance of Anders Hovdenes. This revision has benefitted from the comments of Elhanan Helpman, Robert Barro, and four referees. Harstad's research received funding from the European Research Council under the EU's 7th Framework Programme, ERC GA n° 283236.

The Quarterly Journal of Economics (2015), 951–1002. doi:10.1093/qje/qjv008.
Advance Access publication on February 4, 2015.

rate, extent, and channels through which policy information passes. Within the U.S. federal system, Volden (2006) shows that the principal channel by which policy successes spread is across states that are similar. This channel is also prominent for cross-country information flows. Buera, Monge-Naranjo, and Primiceri (2011) show how learning from similar countries accounts for a majority of the movement toward market policies and economic growth throughout the late twentieth century.

Despite this progress, much remains unknown about policy experimentation. That policy successes exist at all confirms that free-riding—the classic concern of the literature—doesn't eliminate experimentation altogether. Yet this doesn't speak to whether the quantity of experimentation undertaken is the efficient amount. More subtly, the positive finding that similar states can learn from each other hides a deeper pathology of policy experimentation. If policies spread only across similar states, then they are not spreading to dissimilar states and, consequently, the informational benefits of policy experimentation are more limited than was previously thought. In fact, that different policies may benefit states unequally raises the novel question of whether the policy experiments undertaken are the right type of experiments. That is, are the policy experiments that are undertaken those that cast off the most useful information to the broadest array of states? Until now, the theoretical literature has focused exclusively on the quantity of policy experimentation, ignoring the question of the type of the policies that are actually experimented with. In a world of similar and dissimilar states—as is typically assumed in models of political economy—this question is of central importance.

The objective of this article is to shed light on exactly this question. We present a simple model of policy experimentation with political units that we refer to as districts, although they can equivalently be interpreted as states, nations, and so on. Differences between the districts are captured by the standard left-right dimension of policy, with the districts having different ideal points. To this we add a quality dimension to policy, where quality is beneficial for everyone. To take a simple example in environmental policy, districts may disagree on whether pollution abatement programs should be market-based, but, fixing a particular instrument, they all benefit if emission reduction is achieved at low cost.

The key novelty in our model is that we allow districts to choose both whether to experiment at all with policy—the quantity of experimentation—as well as the policy with which to experiment, what we refer to as the type of policy to implement. A successful experiment improves the quality of the policy outcome, and therefore its usefulness varies according to a district's preference. For instance, a success at a conservative policy benefits a liberal district less as the high quality is tempered by a policy type far from its ideal. Our primary interest is how the choice of policy type interacts with the classic questions of free-riding and the quantity of experimentation in federal systems.

We study and compare two institutional settings. We begin with decentralized systems in which two districts are free to make their own policy choices. For this case, we first find that preference heterogeneity delivers some positive news: The incentive to free-ride is mitigated by heterogeneity, declining the more different are the districts. This is an intuitive result. The less similar a neighboring district is to another, the less useful is information revealed by each other's experiments and the more inclined is each to engage in its own experiment.

Within this positive result, however, lurks a deeper inefficiency. The districts, free to choose the policy with which to experiment, are also free to take the free-riding problem into their own hands. Whereas efficiency calls for the districts to experiment with policies more favorable to their neighbors, we find that in equilibrium the districts deliberately choose policies that are less attractive to each other. We show that they do this even to the degree that they sacrifice their own immediate welfare by experimenting with policies other their own ideal policies. Specifically, the equilibrium policy choices diverge and are Pareto inefficient.

Strikingly, the degree of policy divergence increases as heterogeneity declines and the districts become more alike. The increase in divergence is in an absolute and not just a relative sense, leading to the surprising conclusion that similar districts actually benefit each other less with informational spillovers. This result runs counter to prevalent theories of federal systems as, in our model, districts with a degree of heterogeneity—and not those that are most similar—foster the most efficient policy choices.

The inefficiency of policy experimentation with decentralized authority raises the question of whether alternative institutions can be better. We thus introduce a central authority into the federal system. When the central decision maker is insensitive to the preferences of other districts, centralization implies policy harmonization (just like in the literature discussed later). We depart from the literature, however, in conceiving of the centralization of authority as a dynamic process. Authority resides initially with the districts and only later—after experiments have been undertaken—does power concentrate in the center. We show that this dynamic notion of federalism may create incentives for more efficient policy experimentation, despite the experimental choice remaining entirely in the hands of the individual districts.

The logic of this result turns on the distinction between ex post outcomes and ex ante incentives. By imposing ex post inefficiency through policy harmonization—as a district may be forced to implement the less desired policy of a neighbor—the ex ante incentive to experiment may be enhanced as each district seeks to win the favor of the central authority. In this way, a dynamic federalist system creates a sort of policy tournament. Our principal insight is to show that the ex ante incentive benefit does outweigh the ex post cost of harmonization when policy experiments are very uncertain (in the sense that they are more likely to fail than succeed). In this way, dynamic federalism operates as an incentive mechanism.

Although the view of dynamic federalism we present is novel in the literature, the underlying policy dynamic is frequently observed in practice. Political scientists refer to the movement of policies between lower and higher levels of government as vertical diffusion.[1] Shipan and Volden (2006) provided the first comprehensive analysis of this phenomenon, documenting the vertical diffusion of antismoking laws from local to state governments (see Boeckelman 1992; Oates 1999, pp. 1132–33; and Karch 2012 for more examples). The contribution of our model is to show that this dynamic is more than merely a symptom of changing institutional preferences but in fact can be a key driver of incentives within the federal system. Indeed, our model predicts that vertical diffusion will follow in lock-step with policy experimentation, a comovement documented by Rabe (2004, 2006) for the case of the United States. To better see the relevance of this mechanism, we analyze two particular examples in depth

1. Karch (2007). See Graham, Shipan, and Volden (2013) for a review of the literature. Sociologists have identified similar vertical dynamics in settings inside and outside of politics, what Tarrow (2010) refers to as scale shifts and Schneiberg and Soule (2005) label contested multilevel processes.

in the following section, showing how experimentation affects incentives and can drive the vertical diffusion (or not) of policy.

The idea that a federalist system facilitates policy experimentation has a long history (for an account, see Treisman 2007). Formal analysis was pioneered by Rose-Ackerman (1980) who describes how electoral incentives can undermine experimentation in a decentralized system. Cai and Treisman (2009) compare this outcome to that possible under a fully centralized government as the candidates seeking national office attempt to construct majority winning coalitions. Their focus is on how the construction of winning majorities can itself undermine efficiency, a point we do not address here.

A few papers in this literature include heterogeneity in preference, but none permit the districts to choose the type of policy they experiment with. Our combination of a standard left-right dimension with a dimension of common interest follows the approach of Volden, Ting, and Carpenter (2008) and Gilardi (2010) in the policy experimentation literature, as well as numerous other papers in political economy (e.g., Callander 2008). Gilardi (2010) offers the example of the death penalty, which is evaluated on the basis of deterrence (quality) and its compatibility with notions of human rights (type). However, these papers fix the choice of policy type to be binary, instead focusing on the important point that policy diffusion is often difficult to distinguish from private policy learning. Strumpf (2002) offers an alternative specification in which each district faces the classic two-armed bandit set-up (with one safe and one risky arm).[2]

Our model also connects to the literature on multiarmed bandits, in particular to multiagent environments as first modeled by Bolton and Harris (1999). Although simple, our model suggests how free-riding and distortions in experimentation can arise in broader economic environments when heterogeneity is present. The mechanism of dynamic centralization that we identify, moreover, suggests how a principal may mitigate these inefficiencies when tasked with inducing agents to experiment.

2. An interesting computational approach is proposed by Kollman, Miller, and Page (2000). They show that decentralized parallel search outperforms centralized search on problems of moderate complexity. Qian, Roland, and Xu (2006) study experimentation in organizations more broadly, although from a team-theoretic approach and a focus on coordination difficulties across production units.

By comparing decentralization with dynamic centralization we also contribute to the literature on federalism more generally. Throughout the literature, a ubiquitous modeling issue is how to model the central government. If the central government were benevolent and held complete information, it could match and improve on our decentralized outcome and thereby dominate as a system of government. Oates (1972, 1999) argues that such an approach would be unrealistic, and his suggested recourse is to view the central government as "clumsy," subject to informational imperfections or political pressures that dictate it can only impose policies uniformly across districts. Although this approach has been criticized (Lockwood 2002; Besley and Coate 2003), it is frequently assumed, has considerable empirical support, and has obtained a rigorous theoretical foundation.[3] We follow Cremer and Palfrey (2000) who assume policies are harmonized because the decision maker at the central level is insensitive to the preferences of other districts. Our key departure from the literature is our notion of dynamic federalism, whereby authority moves between levels of government rather than being assigned to one level or the other, as is typically assumed. By presenting conditions for when this induces districts to experiment more we uncover a new benefit of centralization. Interestingly, at the same time that he defends the uniformity assumption, Oates (1999, p. 1134) argues for "a lot more work on the implications of fiscal decentralization for both the amount and kinds of policy experimentation and innovation." In addressing this need, we show how uniformity, despite being costly ex post, can be beneficial ex ante.

The trade-off faced when allocating power between local and central governments is mirrored in the literature on the number and size of countries. In an influential newspaper article, Robert Barro (1991) noted that "a large country is also likely to have a diverse population that is difficult for the central government to satisfy." Subsequently, Alesina and Spolaore (1997) presented a formal theory where a large country provides coordination benefits and returns to scale, but the country's uniform policy is costly

3. Theoretically, harmonization can be an equilibrium phenomenon if local preferences are local information (Harstad 2007; Kessler 2014). For evidence, see Strumpf and Oberholzer-Gee (2002) or Karch (2007). Harmonization is also "a typical way in which the EU implements policies" (Alesina, Ignazio, and Etro 2005, p. 602), thanks to Article 94, Treaty of the European Community, calling for an "approximation of laws, regulations or administrative provisions."

when preferences differ. Relatedly, in Alesina and Barro (2002) the cost of a large currency union is that it is less sensitive to local preference shocks. To all this we add the districts' incentive to experiment, showing how it hinges on whether districts are independent or in a federal union. Our model thus uncovers a benefit of dynamic centralization different from existing theories of political integration. Spolaore (2013, pp. 135–36) discusses chain reactions related to "the long-standing functionalist view that preferences and behavior endogenously converge following integration." Our theory provides a different causal story, showing how the shadow of future ever-closer integration induces more convergent policy choices before centralization actually occurs, and this preemptive convergence is essential for integration to be beneficial.

The next section presents two examples which motivates our choice of model in Section III. Section IV solves the game for the decentralized regime, Section V investigates centralization, and Section VI compares the two institutions. Section VII informally discusses coordination benefits and other extensions before a concluding section suggests where to go next. Proofs and details are relegated to the Appendix.

II. Examples

II.A. *Diffusion of Environmental Policies*

1. The Policy Space and Uncertainty. Not long ago, the standard environmental policy instrument was command-and-control or technological standards (Tietenberg 2006, p. 5). Following Coase (1960), economists showed that allowing for trade in emission permits reduces the costs of achieving a given emission reduction. It has since become clear that there is practically a continuum of different policy types ordered by flexibility. Trading programs vary widely according to geographical restrictions on trades, banking and borrowing opportunities, and the set of industries or pollutants that is covered (Betsill and Hoffman 2011; Newell, Pizer, and Raimi 2013). This degree of flexibility corresponds to what this article refers to as the type of policy.

While flexibility reduces costs, opponents say it creates price volatility, higher consumer prices, large costs to firms, and rent-seeking. Policy makers have thus different ideal points regarding flexibility. For example, in the United States, cap-and-trade has been favored by conservatives such as Presidents Ronald Reagan, George H. W. Bush, and George W. Bush (Schmalensee and Stavins 2013, p. 112).

Once the type of regulation is chosen, revising the details or tightening the standard further constitutes an experiment, since one may not know in advance the environmental benefits or the costs to industry. This distinction between policy type and whether one experiments with the policy is clear, for example, when it comes to motor vehicle fuel efficiency standards in the United States. While keeping the policy type constant, California has repeatedly experimented by tightening the standard. Upon proving successful, the policy has diffused to the federal government (Vogel 1995).

2. Acid Rain—Divergence. In the 1970s and '80s, acid rain emerged as a problem on both sides of the Atlantic. Although acid rain is caused by SO_2, a local pollutant that hardly crosses the Atlantic, both continents happened to face the problem at the same time. Consistent with our model of a decentralized regime, the two continents reacted by choosing widely different policy instruments. In Europe, each country's emission target was based on the concept of "critical load," the amount of acid rain each ecosystem can manage. Combined with RAINS (an integrated assessment model), one calculated the maximal emission from each source (Menz and Seip 2004). The United States, in contrast, introduced a nationwide flexible emission trading program (Title IV of the 1990 Clean Air Act Amendments).

Both policies were new, with unknown costs and benefits, and they were thus experimental. Even in the United States, it was not the type of policy itself that was experimental: after all, the United States had already experience with trading permits for controlling lead in gasoline as well as ozone-depleting gases (Tietenberg 2006). Instead, it was the scale and the ambitious cuts that made it "the grand policy experiment" (Stavins 1998). It has in retrospect been judged "a great success by almost all measures."[4]

4. Chan et al. (2012, p. 419). Schmalensee and Stavins (2013, p. 106) write "the SO2 allowance trading program performed exceptionally well along all relevant dimensions"; "Cost savings were at least 15 percent" (p. 107), and the "grand experiment in public policy continues to enjoy its reputation around the world as a great success" (p. 117). Since that time, however, additional state-level constraints

3. Climate Change—Imitation. When another environmental problem, climate change, was debated at the international arena in the 1990s, the United States insisted on the flexibility provided by a tradable emission permit system. The EU was initially resistant to this type of policy. At the end of the 1990s, however, the EU made a sharp U-turn and unilaterally established the European Emission Trading System (ETS). The ETS began operating in 2005 and is still the largest emissions trading program for greenhouse gases.

The EU's U-turn has been referred to as quite a puzzle,[5] but it is consistent with our results. On the one hand, the EU failed to agree on a carbon tax in the 1990s. On the other hand, while the success of the U.S. acid rain policy did not necessarily mitigate EU's distaste for this type of market-based solution, its success rendered it sufficiently attractive for the EU to abandon its own most preferred type of policy and voluntarily imitate the U.S. policy. Confirming that policy indeed did diffuse across borders rather than the EU experimenting independently, Christiansen and Wettestad (2003, p. 7) report that the EU "recruited economists having detailed knowledge and experience with emissions trading from the USA." Since the establishment of the ETS, there is a convergence on emissions trading as the favored climate policy tool in quite a few countries.[6]

4. Harmonization. The United States opted out of the Kyoto agreement. However, the Northeastern states have experimented on their own by developing the Regional Greenhouse Gas Initiative (RGGI). This cap-and-trade program contrasts the traditional Californian approach focusing on fuel efficiency standards,[7] but in 2013, California started its own cap-and-trade program. The convergence may be explained by the success

have made the federal quota a nonbinding constraint (Schmalensee and Stavins 2013, pp. 115–116).

5. Skjærseth and Wettestad (2009, 2010), Woerdman (2004), Christiansen and Wettestad (2003).

6. New Zealand, China, Japan, South Korea, and Mexico have all started or planned trading programs (see Newell, Pizer, and Raimi 2013, p. 131). Betsill and Hoffman (2011, p. 97) have identified 32 instances (in addition to the Kyoto Protocol) where policy makers have given serious consideration to cap and trade for greenhouse gases.

7. "California has been advancing energy efficiency through utility-run demand-side energy efficiency programs for decades and considers energy

demonstrated by other programs so far, but even in an experimental phase, our model may predict convergence in a setting with a central government and where regions may anticipate that policies will be harmonized later. In such a situation, each region hopes that its policy will be the one most appealing to others. Advocates of RGGI have indeed tried to sell it as a template for a national plan, and such a harmonized policy almost passed Congress in 2009–2010.[8] Harmonization has increased over time also in the EU. This dynamic form of centralization is consistent with our model in Section V.

II.B. Abortion Policy in the United States

Government authority over abortion was traditionally reserved for the states. This held until 1973 when the Supreme Court famously asserted federal authority over abortion policy in the case of *Roe v. Wade*. Moreover, the court imposed a national policy of legal abortion on *all* states, forcing harmonization that—to this day—remains undesirable to many states. This vertical diffusion from states to the federal government matches the equilibrium prediction from our model of dynamic federalism. Moreover, as we describe in more detail later, the Court's action followed a period of intense experimentation at the state level,

efficiency the bedrock upon which climate policies are built," according to http://www.westernclimateinitiative.org/designing-the-program.

8. In his report to Congress, Ramseur (2013, p. 16) writes that "RGGI's activities may create examples and/or models that will prove instructive for federal policymakers crafting more widespread applications. Moreover, the program has provided a training ground for personnel from multiple states and various professions to develop a specific expertise in emissions trading issues. This knowledge base would be useful if a federal system were developed." Such a federal emission trading program (the Waxman-Markey bill) passed the House in 2009, but failed the Senate. In 2010, another (Kerry-Lieberman) bill with emission trading was proposed, but ultimately failed. If approved, the bill would have forbidden regional emissions trading systems. Following the failed attempts of introducing a cap-and-trade program for U.S. greenhouse gases, President Barack Obama instructed the Environmental Protection Agency (EPA) to regulate emission of greenhouse gases. These developments seem to be consistent with our model of centralization in Section V, where we do allow for uncertainty regarding the federal decision. Regarding RGGI's desire to be seen as a national template, see http://www.nytimes.com/cwire/2010/07/14/14climatewire-regional-carbon-cap-gets-second-look-as-temp-89444.html.

with the federally mandated policy hewing closely to that of a successful state-level experiment.

1. The Policy Space and Uncertainty. Although the issue of abortion is often portrayed with a clear divide, preferences over abortion rights are typically more nuanced. Few Americans have zero tolerance for abortion, with most finding it acceptable in the case of rape, incest, or when the pregnancy imposes a threat to the health of the mother. Similarly, at the other end of the debate, no supporters of abortion rights argue for unrestricted access to abortion, with the interests of the mother superseding those of the fetus up until birth. For most people, concern for the fetus must be traded off against a woman's ability to control her own body, with disagreements coming down to where to draw the line—does maternal mental health qualify, for instance? Abortion policies, therefore, differ in the restrictions that are placed on when and why a woman may abort her pregnancy. We interpret this dimension as the policy type in our model.

Within these policy differences, however, lies considerable common ground that fits the quality dimension of policy in our model. Despite advocating for abortion rights, pro-choice supporters typically stress their view that abortion per se is not desirable. Similarly, pro-life supporters, despite their advocacy against abortion rights, typically express a desire to minimize maternal harm from pregnancy. Both of these outcome measures come into focus when a particular abortion policy is implemented, for the general equilibrium effects of any policy are unclear until a policy is tried. In particular, any restriction on abortion leads to the emergence of an illicit market, and the rate of substitution between the legal and illegal markets is ex ante uncertain. As the illegal market leads to far worse outcomes for mothers—abortions are provided by unregulated and often untrained practitioners—a policy imposing tight restrictions on abortion may "fail" if the abortion rate is only marginally reduced yet outcomes on maternal health considerably worsened. Similarly, a permissive abortion policy may fail if it does not undermine the illegal market (through cost or ease of access) or actually leads to an increase in abortion as women substitute on-demand abortion for the use of contraceptives. Uncertainty about these indirect effects was substantial in the years before *Roe v. Wade*. For example, in evaluating the New York reforms of 1970, Harris et al. (1973, p. 409) report that estimates of the impact of the law on abortion demand "varied widely from 50,000 to as high as one million."[9]

2. Policy Experiments: Failures and a Success. In the middle of the twentieth century, the provision of medical care changed dramatically. One effect was that surgical abortions were performed in hospitals rather than a doctor's private office, thereby removing much of the discretion that family doctors held despite formal prohibitions. The result was a significant decrease in the provision of legal abortion for all but the very wealthy.

The changing external environment led to what was effectively a clean slate on the effectiveness of abortion policy, one that was ripe for experimentation. The status quo policy itself constituted an experiment as its effectiveness in the modern health care environment was unclear. For the states that retained the status quo policy, allowing social and legal institutions to adjust to the new reality, the outcome of this experiment was a clear failure. In these states the illegal abortion market mushroomed in size, and the quality of health outcomes for women declined commensurately.

At the same time, a minority of states implemented experiments with different types of policies. Fourteen states pursued moderate reforms between 1967 and 1970 that were far from legalization, permitting abortion only in cases of rape, incest, fetal deformity, and to protect the physical and mental health of the mother. Significantly, similar efforts at reform did not pass in other states at the same time, including in Arizona, North Dakota, Iowa, and Minnesota, reflecting the preference differences across the states. Where these moderate reforms were implemented they failed. As Segers and Byrnes (1995, p. 3) document, "It soon became evident, however, that reform laws did not significantly reduce the number of illegal abortions."

Four states went further with reform, experimenting even more to the left on the continuum of policy type, to the point of repealing abortion restrictions altogether for early stage pregnancy. These experiments enjoyed considerably more success, constituting a "public health triumph" according to some commentators (Pollitt 1997; Reagan 1997). Repeal was first

9. Indeed, the uncertainty surrounding the effects of abortion policy—particularly long-term effects—is clearly evident in the more recent scholarly debate over the link between abortion and crime (Donohue and Levitt 2001).

undertaken in New York in 1970, and the results were immediate. As detailed in policy evaluations (Harris et al. 1973; Tietze 1973), the maternal mortality rate in New York dropped by 45% within the first year of repeal, with significant reductions in neonatal mortality and other measures of health as well. Perhaps more revelatory, the increase in abortion was not found to lead to a reduction in contraceptive use, as many opponents feared, and indirect evidence suggests that contraceptive usage actually increased following repeal.[10]

3. Vertical Policy Diffusion. Following this successful experiment, abortion policy diffused vertically to the federal level with the famous trimester framework of the *Roe* decision closely following the New York law. In his majority opinion, Justice Harry Blackmun cited the experience of New York and endorsed the Uniform Abortion Act drafted by the American Bar Association that had been based on the New York act and was intended as a template for other states (Section VI.8).[11]

III. Model and Benchmarks

III.A. The Model

Our basic model consists of two agents and three stages. Each agent can be thought of as a political unit, a state in a federal system, or one of two independent countries. We refer to them as districts.

To distinguish between the quantity and the type of experimentation, we propose the following timing. First, each district $i \in \{A, B\}$ simultaneously decides the type, or location, of its initial

10. These experiments were not perfectly simultaneous, as specified in our model. Nevertheless, the pursuit of multiple experiments, and the eventual vertical diffusion of the only successful experiment, capture the essential force of our model.

11. Our model is at work whether the federal policy is implemented by the legislature or by a court. Moreover, pro-choice activists, who championed reform and experimentation at the state level, saw the opportunity for federal law to come through the courts: "In 1965, the Supreme Court's use of constitutional privacy rights to invalidate a Connecticut birth control statute in Griswold v. Connecticut led reformers to wonder whether they could logically extend a woman's constitutional privacy to protect abortion as well as contraception" (Segers and Byrnes 1995, p. 3).

policy or experiment. This location is simply a point on the real line, $x_i \in \mathbb{R}$.

Second, each district decides on the binary quantity of experimentation. That is, a district can play it safe or experiment with the policy. With probability $p \in (0, 1)$, an experiment succeeds and raises the quality of the policy by 1. The cost of the experiment is $k > 0$. Parameter k can represent the benefit of the safe option relative to the expected benefit of the risky option, but it can also simply measure the investment cost of developing and enhancing the value of a policy. For simplicity, we assume that the probability of success is independent of both the policy location and the other districts' experimental outcome.[12]

Third, after the districts have observed the outcomes of both experiments, each district i decides on its final policy location, y_i, to implement. We assume that a district must implement one of the two policies developed at the first stage, so $y_i \in \{x_A, x_B\}$. This is natural if adopting a completely new policy requires sufficiently high additional costs (these costs can then be abstracted from here).[13]

The districts may have different ideal points regarding the type of policy. Each district (or its representative) has an ideal point t_i that is a point on the real line and $h \geq 0$ measures the heterogeneity or the distance between the ideal points, $h = t_B - t_A$. Without loss of generality, we let $t_A < t_B$ and place the origin halfway between the ideal points. This implies $t_A = -\frac{h}{2} \leq 0$ and $t_B = \frac{h}{2} \geq 0$. The parameter h reflects all heterogeneity in the economy, and its size relative to the common benefit of a successful experiment (that is normalized to one) represents the relative

12. Relatedly, we also assume that the information gleaned from a successful experiment is not transferable to other policies, even those nearby. We make these assumptions purely for simplicity. Allowing for imperfect transferability, such as in the manner modeled in Callander (2011), does not substantively change our results so long as the transferability is not too great. The assumptions may also be realistic in our motivating environmental example. For tradable pollution permits, the details are indeed very important and one cannot guarantee success if the policy is slightly modified from one that has proven to work: Goulder (2013, p. 98) writes that several "concerns show that cap and trade needs to be carefully designed to assure lower costs than other regulatory alternatives." Betsill and Hoffmann (2011, p. 100) concude that "the design can determine whether the program yields efficiency gains."

13. We can endogenize this assumption if selecting a new policy requires a set-up cost larger than $c(a_i)$, referring to notation (as well as the equilibrium) discussed below.

importance of disagreements over policy versus common interest.[14]

It is useful to define a_i as the extent to which district i accommodates the neighbor by experimenting on a policy that is closer to the center than i's ideal point:

$$a_A \equiv x_A - t_A \text{ and } a_B \equiv t_B - x_B.$$

Putting the pieces together, the payoff to district $i \in \{A, B\}$ is:

$$u_i = I_{y_i} - c(y_i - t_i) - J_i k, \tag{1}$$

where the index-function $I_{y_i} \in \{0, 1\}$ equals 1 if the policy y_i, chosen by i at stage three, has proven successful. The index function $J_i \in \{0, 1\}$ equals 1 if i decided to experiment at the second stage. To simplify, we let the preference over location be represented by a disutility function that is symmetric around the ideal point: $c(y_i - t_i) = c(t_i - y_i)$. We assume $c(\cdot)$ to be convex, U-shaped, and differentiable, so $c'(0) = 0$.

III.B. The First-Best Outcome

As a benchmark, consider first the case of autarky with only one district. At the third stage, district i must necessarily stick to the location picked at the first stage, so $y_i = x_i$. Anticipating this, i always prefers to choose the policy at its own ideal point to minimize the distance cost; thus, $y_i = x_i = t_i$. At the second stage, the district finds it optimal to experiment ($J_i = 1$) if the cost k is smaller than the expected benefit from the experiment:

$$p > k,$$

which is henceforth assumed to hold. The equilibrium is thus $(x_i, J_i, y_i) = (t_i, 1, t_i)$ and this implements the first-best outcome when there is only one district.

With two districts the efficient outcome is not so straightforward. Each experiment is a public good that potentially provides a positive externality to the other district. This externality is stochastic and beneficial when one district's experiment succeeds and the other fails (or is not attempted). In this case, the latter district with the failed experiment may abandon its own policy

14. We follow Volden (2006) in allowing a broad interpretation of heterogeneity. One possible interpretation is the classic ideology space; Grossback, Nicholson-Crotty, and Peterson (2004) provide evidence that ideological similarity predicts successful policy diffusion.

and adopt the successful policy of the other district. This policy imitation will involve a distance cost for the switching district, and consequently these costs must be accounted for in determining the first best. For moderate levels of district heterogeneity, the set of socially optimal experiments actively reduces these costs by requiring positive policy accommodation or convergence.

The following proposition presumes it to be optimal that both experiment even if locations should be identical.[15]

PROPOSITION 1. The first-best outcome is characterized as follows. There exists $\overline{h}_b \in (0, \infty)$ such that:

(i) For $h \in [0, \overline{h}_b]$, both districts experiment, with the same degree of accommodation, $a \in [0, \frac{h}{2})$, satisfying:

$$\frac{c'(a)}{c'(h-a)+c'(a)} = p(1-p), i \in \{A, B\}. \tag{2}$$

Consequently, $\frac{\partial a}{\partial h} \in (0,1)$ and $a \to 0$ when $h \to 0$. The districts implement the other district's policy only if their own policy fails and the other succeeds.

(ii) For $h \geq \overline{h}_b$, both districts locate and experiment at their ideal points. They implement their own policy regardless of experimental outcomes.

(iii) Payoffs are maximized when $h = 0$.

For all proofs and details (such as the definitions h-thresholds), we refer to the Appendix.

In case (i) each experimenting district accommodates the other, thereby imposing a cost on itself. Whenever it implements its own policy in the final stage, it must pay a distance cost that could have been avoided. This behavior is nevertheless socially optimal, as by the concavity of utility over policy type, the accommodation saves the other district more in distance cost should it wish to imitate the successful district, such that the net effect is positive.

Part (ii) exposes the limits of federalism. For sufficiently heterogeneous districts ($h > \overline{h}_b$) the distance costs overwhelm the externalities from successful experimentation and the benefits

15. This holds if $2p(1-p) > k$. If $2p(1-p) < k$, the first-best requires that only one district experiments if and only if h is sufficiently small.

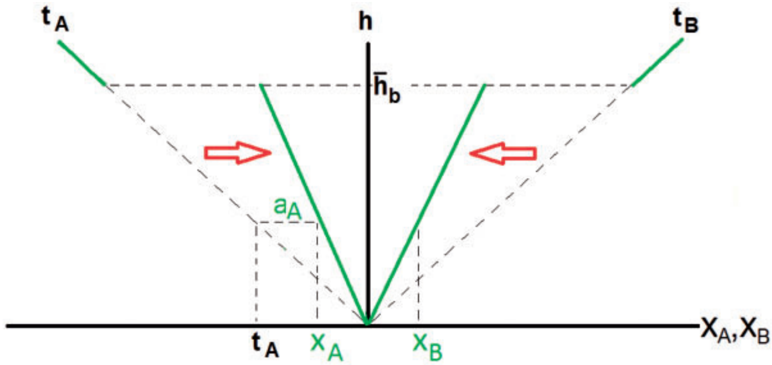

FIGURE I

The bold lines show locations of experiments (on the horizontal axis) as functions of h, on the vertical axis. In the first-best, policy positions converge relative to the ideal points.

of federalism become strained. In this case, the efficient outcome is the same as for an autarky: the districts experiment on their own and learn nothing (useful) from the experiments of others. This result aligns with the established literature that federalist systems are best composed of homogeneous districts. Indeed, part (iii) states that social welfare is maximized when heterogeneity disappears and the districts are identical.

The first-best policy choice as a function of heterogeneity are depicted in Figure I. The horizontal axis represents the type space of policy and the vertical axis district heterogeneity. The partly dotted 45-degree lines denoted t_A and t_B translate heterogeneity into ideal points on the horizontal axis. The actual policy locations are given by the bold lines. The convergence of these lines for every $h \leq \overline{h}_b$ represents the convergence of policy positions in the first best.

Before moving on, it is worth understanding the trade-offs that drive the first-best as the same trade-offs that drive equilibrium behavior. Of all the combinations of experimental outcomes, the most important is when the outcomes are mismatched. When both districts succeed—or fail—there is no reason for one to imitate the other. Only in the event where one succeeds and the other fails (or doesn't experiment)—when outcomes are mismatched—does the externality deliver value. It is for this reason that the quantity $p(1-p)$ appears in the first-order condition of case (i) in the proposition. It is also for this reason that convergence of experimental policies is not complete. The externality is only probabilistic, whereas the distance cost is paid in all events, thus the benefit of convergence is bounded.

IV. Decentralization

We now turn to equilibrium policy choices when authority is completely decentralized to the districts. The districts do not internalize the informational externality from their own experiment. Nevertheless, this does not imply that the externality is irrelevant to their choices. We proceed by backward induction to derive all subgame-perfect equilibria.

At stage three, the choice facing districts is quite trivial. With sunk investment costs and policies fixed, each district $i \in \{A, B\}$ picks the final policy that maximizes its utility:

$$y_i = \arg \max_{x_j \in \{x_A, x_B\}} I_{x_j} - c\big(x_j - t_i\big). \tag{3}$$

Each district will stick to its own policy if it succeeds whenever $|a_i| < |h - a_j|$, which always will hold in equilibrium. The only choice to be made, effectively, is when a district's own experiment fails and the other district succeeds. In this situation, i prefers to switch policy if and only if:

$$c\big(h - a_j\big) - c(a_i) \leq 1.$$

Note that this set of choices is efficient, conditional on earlier choices. As district j is indifferent to whether district i imitates it (an assumption that is relaxed in Section VII), the choice of district i is the same that would be made by a social planner. This equivalence does not extend to earlier stages, as we will now explain.

IV.A. The Quantity of Experimentation

At stage two, the decision to experiment depends on whether the other district is experimenting as well as the policy positions. The incentive compatibility condition that ensures a district experiments (even when the other does) is given by the following.

PROPOSITION 2. Taking locations as given, both districts experiment with their policies if and only if:

$$c(h - a_j) - c(a_i) \geq \frac{k - p(1-p)}{p^2} \;\; \forall i, j \in \{A, B\}, i \neq j. \tag{4}$$

Not surprisingly, a district is willing to experiment as long as the distance to the other district's experiment is not too attractive. To understand the expression, it is helpful to rewrite it as:

$$\left[c(h - a_j) - c(a_i)\right]p^2 + p(1-p) \geq k. \tag{5}$$

The right-hand side is the cost of experimentation, and the left-hand side the marginal benefit. The marginal benefit of experimenting accrues only when the experiment is a success (as a failure leads to a third stage identical to not having experimented) and the size of the benefit depends on whether the other district's experiment is a success or a failure. If the other district's experiment is a success, a success by district i changes the policy it implements (from j's to its own) but doesn't change the valuation of one. This event saves the distance cost and occurs with probability p^2, corresponding to the first term on the left-hand side. On the other hand, if the other district's experiment is a failure, then district i does not change the policy it implements at stage three (its own) but it does receive a quality boost of one. This event occurs with probability $p(1-p)$ and corresponds to the second term on the left-hand side.

If the policies fully converged ($x_A = x_B$), the incentive compatibility condition reduces to $p(1-p) - k \geq 0$. To render the free-riding problem meaningful, we hereafter assume that this condition fails and that $k - p(1-p) > 0$. This implies that there exists an unique $h_d^* > 0$ that satisfies:

$$c(h_d^*) \equiv \frac{k - p(1-p)}{p^2}. \tag{6}$$

To interpret this value, h_d^* is the heterogeneity such that if the districts located at their ideal policies, they would both be indifferent between experimenting and not (conditional on the other district experimenting). Note that the larger is the cost of experimenting, k, the larger is the necessary heterogeneity to make sure both districts experiment when located at ideal points. We use the subscript d hereafter to denote the decentralized choice.

IV.B. The Type of Experimentation

We are now ready to analyze the choice of policy positions. It is immediately clear that with self-interested districts, the incentive to converge that characterizes the first-best is entirely absent. Policy convergence delivers an informational externality that benefits the other district at the expense of the convergent district, and the very convergence itself may undermine the willingness of the other district to experiment, further harming the convergent district.

In fact, this desire to benefit from the experiment of the other district may induce the districts to deviate from their own ideal policies. However, in contrast to the first best, the districts deviate to the outside rather than toward each other.

PROPOSITION 3. There exists a $\underline{h}_d \in \left(0, h_d^*\right)$ such that for each $h \geq \underline{h}_d$, there is a unique equilibrium in which both districts experiment. The equilibrium is symmetric and characterized by $a_i = a_j = a$, such that:

(i) For $h \in \left[\underline{h}_d, h_d^*\right)$, policies diverge:

$$x_A < t_A < t_B < x_B \Leftrightarrow a < 0, \tag{7}$$

and the level of divergence satisfies

$$c(h-a) - c(a) = \frac{k - p(1-p)}{p^2}, \forall i \in \{A, B\}. \tag{8}$$

(ii) For $h \geq h_d^*$, the districts always experiment at ideal points ($a = 0$).

(iii) For $h < \underline{h}_d$, only one district experiments. The experimental location is at the experimenter's ideal point.

The decentralized equilibrium is very different from the first best. Only for extreme heterogeneity do the requirements coincide. For all other cases, the first best demands policy convergence, whereas in equilibrium they either remain at their ideal policies or they diverge. The equilibrium policy positions as a

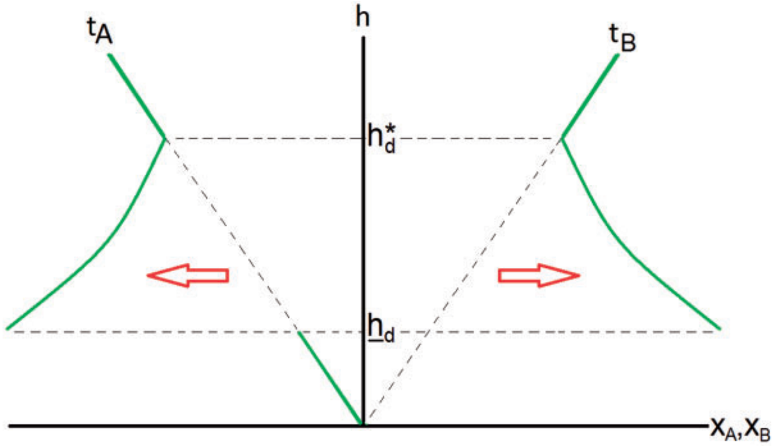

FIGURE II

When heterogeneity declines, locations may diverge.

function of heterogeneity are depicted in Figure II (with the same axes as Figure I). For large h, experiment locations, given by the bold lines, are at the ideal points. For smaller heterogeneity, locations diverge, and divergence is larger the smaller is h. For a sufficiently small h, it becomes too costly to satisfy the incentive constraint. For even lower levels of heterogeneity ($h < \underline{h}_d$), only one district experiments, and it does so at its ideal point.[16]

The amount of divergence is given by the requirements of Proposition 2. Each district diverges enough to ensure that the other district experiments but no more. Divergence in policies arises in the cases where the ideal points of the districts are not different enough to ensure this incentive to experiment (and satisfy the requirement of Proposition 2).

16. If $h < \underline{h}_d$, there are multiple equilibria but all require that exactly one district experiment and, in all pure-strategy equilibria, that the experimenting district experiments at its ideal point. A large set of locations for the nonexperimenting district can then be supported in equilibrium via off-equilibrium-path beliefs. The beliefs necessary are that following any moderate deviation, it is the deviating district alone that is expected to carry the burden of experimentation. There are certain constraints on locations for the nonexperimenting district in these equilibria, but we have chosen to not report on these here.

The divergence in policy choice is clearly inefficient. The set of choices is Pareto dominated in the sense that both districts would be better off if they simply agreed to experiment at their own ideal policies (or closer). However, such an agreement is not self-enforcing. By definition, decentralized federalism precludes the ability of the districts to commit to this agreement.

The degree of policy divergence can be significant. If we differentiate equation (8) we get that when $h \in (\underline{h}_d, h_d^*)$,

$$\frac{\partial a}{\partial h} = \frac{c'(h-a)}{c'(h-a)+c'(a)} > 1,$$

which, in turn, implies that

$$\frac{\partial(x_B - x_A)}{\partial h} = \frac{\partial(h-2a)}{\partial h} < -1.$$

As heterogeneity declines, not only are the districts more divergent but their policy positions get further apart in absolute terms. This point suggests that efficiency may be lower if the districts are similar, than when they are different. This is confirmed in the next subsection.

IV.C. Optimal Heterogeneity

For very heterogeneous districts ($h > h_d^*$), the districts experiment at their own ideal points as the free-riding incentive is sufficiently weak. Districts may still use a successful experiment of the other district, but they do not need to distort their policy to ensure the other district experiments. In this case, more heterogeneity leaves the districts worse off, strictly so while they still receive an externality from each other's experiments, and weakly so after the point where they are effectively autarkic and the logic of federalism irrelevant.

On the other hand, for more moderate levels of heterogeneity, $h \in (\underline{h}_d, h_d^*)$, decreasing heterogeneity leads to ever greater distortions in policy choice. Proposition 4 shows that this distortion leaves the districts, in aggregate, worse off such that welfare is maximized in this range when $h = h_d^*$. In fact, if the cost of experimentation is low enough, this level of heterogeneity produces the global maximum of welfare, dominating cases in which the districts are arbitrarily similar in preference or even identical. Thus, with self-interested districts and the freedom to choose both policy location and whether to experiment, the standard result[17] that more similarity among districts produces better federalism is overturned.

PROPOSITION 4. Equilibrium payoffs are strictly higher at $h = h_d^*$ than at any other $h \geq \underline{h}_d$. In fact, h_d^* is a global optimum if and only if $k \leq \frac{2p(1-p)}{2-p}$.

V. CENTRALIZATION

We turn now to the setting where policy authority progressively moves to the central government, what we refer to as dynamic centralization. The game is amended as follows. The first two stages stay the same as before. In the third and final stage, when it is publicly known which experiment succeeded and which failed, the central government assumes authority and chooses policies.

Note that if such a central government were benevolent and aggregated the sum of payoffs, it could do nothing better than under decentralization. At stage three in the game, the two districts are themselves making the socially optimal decisions under decentralization, since there is no externality from one district's decision onto another at that stage. However, rather than presuming a benevolent central government, we adhere to our model by assuming that the decision maker at the central level, C, has the same type of utility function (1) as do A and B and we let t_C represent C's ideal point. To us it is irrelevant whether C comes from district A or B or is a new and third type of player in the game (possibly a third district). In any case, C's payoff and power has two implications.

First, the decision maker C, no matter where she resides, will be insensitive to the preferences of other individuals or districts. Thus, if she prefers x_A to x_B, she weakly prefers both districts to implement x_A rather than x_B. Following the reasoning of Cremer and Palfrey (2000), the outcome is a federal mandate where both districts end up with the same policy, despite having

17. Here we are referring to the literatures on fiscal federalism and the size of nations, discussed in the introduction. The logic of this result was confirmed, as a start, in our description of the first best (Proposition 1(iii)).

different preferences. In our setting, C's preference for such harmonization will be strict rather than weak if the game is slightly perturbed: with some (arbitrarily small) benefit of coordinating the policies across the districts, then if C prefers x_A to x_B in one district she also strictly prefers both districts to implement x_A, and the unique Condorcet winner is the pair $\{y_A, y_B\} = \{x_A, x_A\}$. Section VII explains and explores such coordination benefits in detail. Thus, under centralization, equation(3) must be replaced by:[18]

$$y_A = y_B = \arg\max_{x_j \in \{x_A, x_B\}} I_{x_j} - c(t_C - x_j). \tag{9}$$

Second, whether C prefers A's or B's policy may depend on which of x_A and x_B that is closest to t_C. If exactly one of the two experiments succeeds, then C prefers the successful policy at stage three,[19] but when $I_{x_A} = I_{x_B}$ and $x_A < x_B$, equation (9) implies that x_A is chosen with probability

$$z_A = \Pr(|t_C - x_A| < |x_B - t_C|) = \Pr\Big(t_C < \frac{a_A - a_B}{2}\Big) = F\Big(\frac{a_A - a_B}{2}\Big). \tag{10}$$

Note that we allow t_C to be uncertain and distributed according to F. The cdf F is nondecreasing by definition, so A's policy is more likely to be chosen by C if A accommodates more relative to B. Similarly, B's policy is chosen with probability

18. The idea that centralization implies harmonization is in line with the literature discussed in the introduction. Section II documents that real-world environmental policies are also in line with this assumption. Schmalensee and Stavins (2013, p. 108) write: "Recall that the program came into being mainly in response to concerns about acid rain in the US Northeast. Although it was clear at the time the program was enacted that emissions from different plants had different impacts, the Title IV emissions trading scheme ignored this fact." Finally, note that the federal government selects a "winner" even when both local policies fail. This assumption is in line with Volden (1997, p. 81) who reviews the empirical literature and concludes "that the federal government is about as likely to adopt programs that failed in the states as it is to adopt state policy successes."

19. In this case, C does indeed prefer to select the single successful policy in equilibrium (since locations will be symmetric), and also off the equilibrium path if just the two locations are "sufficiently similar," meaning that $1 \geq |c(t_C - x_A) - c(x_B - t_C)|$.

$z_B = 1 - F\left(\frac{a_A - a_B}{2}\right)$. When we assume t_C to be symmetrically distributed around zero, then $F(0) = \frac{1}{2}$.

Intuitively, an uncertain t_C means that, before stage three, one may not know the exact identity, residence, or ideal point of the future central decision maker. Uncertainty may also arise if it is in advance unclear whether the federal decision maker will be a politician, the Supreme Court (as for abortion policies), or the bureaucracy (as for U.S. environmental policies). Alternatively, the uncertainty could be derived from small shifts/shocks in everyone's ideal points or the policies' popularity/payoffs. Note that such small shocks would in any case not influence the analysis of the decentralized regime: while the federal decision maker C is (close to) indifferent when both policies succeed or fail, there is no such indifference under decentralization.[20]

Technically, for a fixed and known t_C, the probability z_A would be a discontinuous function, and so would A's and B's objective function. There would then be no equilibrium in pure strategies, and just as in traditional probabilistic voting models (for an overview, see Persson and Tabellini 2000), it is necessary with a minimal amount of noise or uncertainty to guarantee an equilibrium that is reasonable and in pure strategies. In our setting, we require:

$$\sigma_0 \equiv F'(0) < \frac{c'\left(h - a_{IC}^c\right)}{(k - p[1-p])\left(\frac{2}{p} - 4\right)}, \tag{11}$$

where a_{IC}^c is defined below. At the end of Section VI, we explain how the results survive if instead $t_C \in \{t_A, t_B\}$.

V.A. *The Quantity of Experimentation*

Under centralization, the decision at stage three sets up a sort-of tournament for the districts in the earlier stages. At the

20. At stage three under decentralization, the local decision maker is strictly preferring his own policy unless only the neighbor succeeds. There is no indifference, and small preferences shocks would not alter the local decision maker's choice. A local decision maker can only be indifferent if h is exactly so large that the cost of switching $c(h)$ equals the benefit of 1. Perturbing this switching point does not influence the analysis above where this switching point plays no role. However, perturbing this switching point would slightly complicate the analysis of coordination benefits which we draw on in Section VII. For that reason, we have chosen to let only t_C be uncertain without introducing uncertainty also in t_A and t_B.

second stage, with policies fixed in place, the districts want to experiment to avoid being compelled to implement the other district's experiment. Nevertheless, this incentive has its limits as the costs of being so compelled can nevertheless still be dominated by the costs of experimenting. This is the basis of the following proposition.

PROPOSITION 5. Taking locations as given, both districts experiment if and only if:

$$c(h - a_j) - c(a_i) \geq \frac{k - p(1-p)}{\frac{p}{2} + \left(z_i - \frac{1}{2}\right)(2p-1)p}, i, j \in \{A, B\}, i \neq j. \tag{12}$$

This proposition says that the districts are willing to experiment if the location of the neighbor's experiments is not too attractive, similarly to Proposition 2 for decentralization. If locations are symmetric, the condition in Proposition 5 simplifies to:

$$c(h - a) - c(a) \geq \frac{k - p(1-p)}{\frac{p}{2}}. \tag{13}$$

To understand the condition, it is helpful to rearrange equation (13):

$$[c(h-a) - c(a)]\frac{1}{2}p^2 + p(1-p)\left[1 + \frac{1}{2}[c(h-a) - c(a)]\right] \geq k. \tag{14}$$

The right-hand side is the cost of experimenting. The left-hand side is the benefit. As before, this benefit has two components and accrues only if the district's experiment is successful, which occurs with probability p. If the other district's experiment succeeds then, with combined probability p^2, the district has its own policy implemented half the time, thereby avoiding the distance cost. If, on the other hand, the other district's experiment fails, which occurs with a combined probability of $p(1-p)$, a successful experiment ensures the successful district's experiment is always implemented, giving it not only a quality boost but also avoiding the distance cost from having to implement the other district's failed experiment half the time.

By comparing equation (13) with equation (4) in Proposition 2, we can see than for any symmetric locations, the incentive to experiment is larger under centralization if and only if $p < \frac{1}{2}$. Centralization adds the prospect of a district being compelled to implement a neighbor's policy even when it fails. When policies are speculative and experimental—when they are more likely to fail than succeed—this is the likely event (i.e., when $p < \frac{1}{2}$). Experimenting allows the district to reduce the chance of this fate, while at the same time delivering the same benefit of a potentially high-quality policy should the experiment succeed. On the other hand, when $p > \frac{1}{2}$ and policies are more likely to succeed than fail—capturing policy resilience or robustness rather than speculation—the incentive to experiment is dampened by centralization: the restraining force in this case is that a district cannot even be guaranteed of implementing its own experiment should it succeed as, if both experiments succeed, harmonization implies that one successful experiment will be discarded.

The condition in Proposition 5 depends on the heterogeneity and polarization of the districts. Recalling the maintained assumption (from Section III) that $k > p(1-p)$, there must exist a $h_c^* > 0$ that satisfies:

$$c\left(h_c^*\right) \equiv \frac{k - p(1-p)}{\frac{p}{2}}. \tag{15}$$

At heterogeneity level h_c^*, both districts are indifferent between experimenting and not if the policies chosen are the districts' ideal positions. This definition is the analogue of the definition of h_d^* for decentralized federalism.

V.B. *The Type of Experimentation*

To be attractive for the central decision maker, districts have an incentive to choose more moderate policies with which to experiment. However, the lesson of Proposition 5 is that such accommodation can discourage the other district from experimenting. The threshold at which this occurs is critical to equilibrium behavior. Yet surprisingly, rather than this defining the barrier that must be breached to ensure victory in the policy tournament, the threshold defines the limiting boundary of policy competition.

Proposition 6. There exist four thresholds $0 < \underline{h}_c < h_c^* < \tilde{h}_c$ and $\tilde{h}_c > h_c^*$ such that when $h \in \left(\underline{h}_c, \overline{h}_c\right)$, there exists a unique symmetric equilibrium in which both districts experiment, given by the following:

(i) If $h \in (\underline{h}_c, h_c^*)$, policies are divergent and $a < 0$ satisfies:

$$c(h-a) - c(a) = \frac{k - p(1-p)}{\frac{p}{2}}. \tag{16}$$

(ii) If $h \in (h_c^*, \min\{\tilde{h}_c, \overline{h}_c\})$, policies converge and $a > 0$ satisfies (16).

(iii) If $h \in (\tilde{h}_c, \overline{h}_c)$, policies converge and $a > 0$ satisfies:

$$c(h-a) - c(a) = \frac{\frac{c'(a)}{\sigma_0}}{p^2 + (1-p)^2}. \tag{17}$$

The policy tournament combines competition with restraint. The districts compete to win the federal tournament, but only up to the point at which further competition would drive their opponent from the tournament. This limit depends on the incentive to experiment characterized by Proposition 5. For districts of moderate or larger heterogeneity ($h > h_c^*$), this incentive is strong enough to not just overcome the incentive to diverge but also induce the districts to converge toward their opponent. In our terminology, this leads to equilibria with positive accommodation, although the incentive for doing so is not exactly hospitable. It is possible that the level of convergence is larger than what would be required by the first-best outcome.

The incentives for districts to compete—but not so much as to discourage free-riding—explain why convergence is not a universal behavior under dynamic centralization. As heterogeneity decreases ($h < h_c^*$), the distance required between experimental policies becomes wider than the distance between the districts' ideal policies. In this case divergence is again necessary to ensure that both districts don't free-ride and have the incentive to experiment. The equilibrium policy positions are depicted in Figure III.

Part (ii) of the proposition captures another limit to competition: districts may reduce convergence—the level of accommodation a—to not only discourage free-riding but also reduce the costs of pandering to the federal decision maker. When $h > h_c^*$ and $a > 0$ is large, reducing the size of a will reduce the likelihood of being selected only marginally, as described by equation (10). For a sufficiently large h (that is, when $h \geq \tilde{h}_c$), the level of a

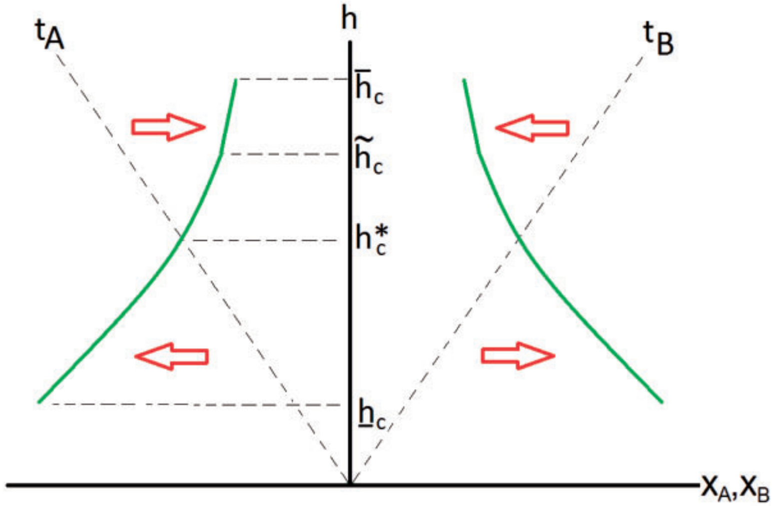

FIGURE III

With enough heterogeneity, locations converge.

satisfying equation (16) is so large that it is beneficial to pick a policy somewhat closer to the ideal point even though this reduces the probability of being selected. At this point, the incentive constraint (13) is no longer binding and instead the level of accommodation is determined by trading off the concern of being selected with the benefit of being close to the ideal point. The larger the uncertainty regarding the decision maker's ideal point (i.e., the smaller is σ_0), the less valuable is pandering and the smaller is a.

V.C. Optimal Heterogeneity

What is the optimal level of heterogeneity under dynamic centralization? Proposition 6 suggests that one gets positive convergence only if h is sufficiently large ($h > h_c^*$), and we know such convergence is necessary in the first-best outcome. If instead h is small, then policies diverge, and more so the smaller is $h \in \left(\underline{h}_c, h_c^*\right)$. This reasoning suggests that a large $h > h_c^*$ may increase payoffs.

As a counterargument, centralization implies policy harmonization and the cost of such uniformity is larger if the districts are very different. This traditional argument suggests that a small h may be better.

It turns out that these arguments are balanced when $h = h_c^*$. At the optimal level of heterogeneity, districts locate their policies at exactly their ideal points (as was the case, albeit for a different value of h, under decentralization).

PROPOSITION 7. For all $h \in [\underline{h}_c, \overline{h}_c]$, welfare is maximized when $h = h_c^*$.

By comparison, note that $h_c^* = h_d^*$ when $p = \frac{1}{2}$. If p is smaller (larger) than $\frac{1}{2}$, then the optimal heterogeneity is smaller (larger) under centralization than it would be under decentralization. The next section reveals the intuition for this comparison and derives when centralization increases payoffs relative to decentralization.

VI. COMPARING INSTITUTIONS

The two institutions differ only at stage three, when centralization requires harmonization. As this harmonization is often inefficient, whereas decentralization is equivalent to a benevolent social planner for this choice, the comparison between the systems at stage three is straightforward and always favors decentralization. Efficiency, of course, must account for behavior at *all* stages of the game, and when we allow for the incentive effects of centralization's ex post inefficiency, the comparison may be reversed.

To understand this possibility, recall that equilibrium policy choices are often determined by the indifference condition between experimenting and not at stage two. The comparison of institutions therefore begins with an analysis of which institution requires more divergence to sustain dual experimentation. A comparison of Propositions 2 and 5, or equations (8) and (13), reveals that the required level of divergence under decentralization (here referred to as a^d) is larger than the required level of divergence under centralization (a^c) when $p < \frac{1}{2}$. In this case, centralization moves policy choices closer to the first best and, as long as heterogeneity is not too high, this effect dominates and dynamic centralization is the more efficient federalist institution.

PROPOSITION 8. Suppose $h \geq \max\{\underline{h}_c, \underline{h}_d\}$.

(i) If $p \geq \frac{1}{2}$, decentralization dominates centralization.

(ii) If $p < \frac{1}{2}$ and $h \leq h_c^*$, then $|a^c| < |a^d|$ and $c(a^c) < c(a^d)$, and centralization is better when

$$c(a^d) - c(a^c) < k - p(1-p).$$

(iii) If $c(a) = \frac{qa^2}{2}$, centralization is better when $p < \frac{1}{2}$ and

$$h < \sqrt{\frac{k - p(1-p)}{qp^2} \frac{1 - 4p^2}{2 - 4p(1-p)}},$$

that is, for h small, q small, k large, and p small.

The reason the value $p = \frac{1}{2}$ provides the critical threshold is explained by the comparison of equation (13) with equation (4) and the discussion following Proposition 5: the incentive to experiment is larger under centralization if and only if $p < \frac{1}{2}$, and only then is it possible that centralization reduces equilibrium policy divergence (or increases convergence) by so much that this benefit outweighs the cost of harmonization. If $c(\cdot)$ is quadratic, we further get the intuitive result that centralization can be beneficial only if heterogeneity and the cost of preference differences (q) are small relative to the cost of experimentation (k). The condition of part (iii) is illustrated in Figure IV.[21]

This insight helps explain how our results generalize. In particular, rather than letting C's ideal point t_C have a continuous distribution, suppose that the central decision maker comes from district A (so $t_C = t_A$) or B (so $t_C = t_B$), each with probability $\frac{1}{2}$. There would then be no reason to pander to a more moderate decision maker, so there would be no convergence if $h > h_c^*$. However, Proposition 6 would continue to describe equilibrium divergence when $h \leq h_c^*$, and Proposition 5 and 7 remain unchanged. For these reasons, Proposition 8 would be unchanged as long as $h \leq h_c^*$.

21. The plot draws the threshold for h in the case where $c(a) = \frac{qa^2}{2}$, $q = 1$, and $k = \frac{1}{4}$, so $p \geq k \geq p(1-p) \Rightarrow p \geq 0.25$. To gain additional insight, with $p = \frac{1}{3}$ and $q = 1$ we have: $\underline{h}_d = 0.24$, $h_d^* = 0.5$, $\underline{h}_c = 0.18$ and $h_c^* = 0.41$. For the domain $h \geq \underline{h}_d = 0.24$, dynamic centralization dominates decentralization if and only if $h < 0.35$. With $q \neq 1$, the condition is instead $h\sqrt{q} < 0.35$.

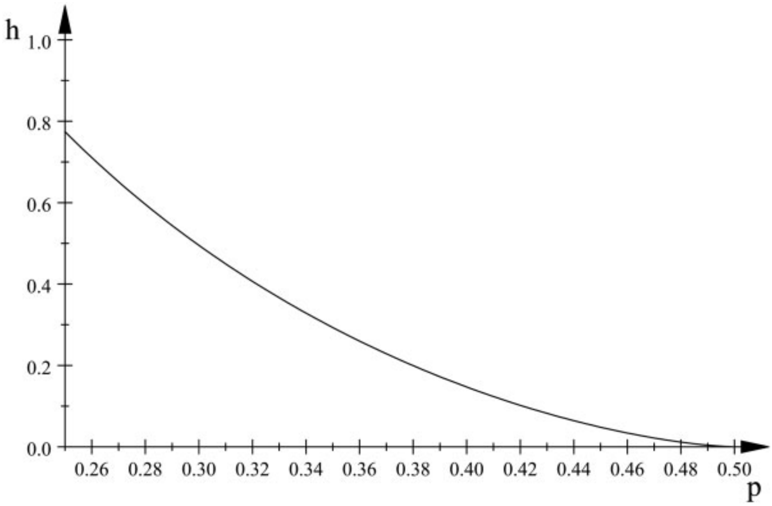

FIGURE IV

Centralization is better than decentralization in the area below the curve.

VII. COORDINATION BENEFITS AND OTHER EXTENSIONS

The previous sections revealed that harmonization generates a sort-of tournament between the districts, which may motivate them to experiment more and with policies that are more useful to others. This benefit contrasts with the traditional rationales for harmonization, where one instead points to coordination benefits or economies of scale (Alesina and Spolaore 1997). Although not necessary, coordination benefits are relevant to our setting, such as in our motivating example on environmental policy. Across borders, it is costly for both industry and governments to deal with a patchwork of environmental policies,[22] and if

22. When discussing the prospects of a national CO_2 permit program in the United States, Ramseur (2013, p. 16) concludes that “when business and industry have confronted a growing patchwork of state requirements, these sectors have historically preferred a national policy.” In the EU, the harmonized cap-and-trade system was introduced at the same time as some individual countries, such as Denmark, were on their way to introduce national trading systems. Christiansen and Wettestad (2003, p. 7) write that “for the EU institutions, the possibility of dealing with a patchwork of incompatible national trading schemes was perceived as a threat to the overarching goals of harmonisation and protecting the internal market.”

districts or countries coordinate on identical emissions trading programs then it becomes possible to link the various programs to exploit further gains from trade.[23] Alternatively, with similar policies one may continue to learn when neighbors are further experimenting and gaining experience with the policy.[24]

Our working paper (Callander and Harstad 2013) shows how coordination benefits naturally arises in a model with experiments over multiple periods. To briefly report on these findings, simply suppose that every district (or citizen) experiences the additional benefit $b > 0$ if and only if $y_A = y_B$. As mentioned previously, this benefit provides an easy rationale for why the federal decision maker strictly prefers harmonization at stage three. The analysis of the centralized regime is otherwise unchanged: since the benefit b is enjoyed regardless of the other decisions, it does not influence any choices. For a sufficiently large b, harmonization is beneficial even ex post, and centralization is then always dominating decentralization.

The coordination benefit has more interesting effects in the decentralized regime. In particular, suppose that $h > h_d^*$ is so large that even a successful policy is unattractive to a failed neighbor. Since an experimenting district prefers to enjoy the coordination benefits after a success, each district finds it optimal to accommodate somewhat (by increasing $a > 0$) to ensure that the policy, if successful, is attractive to the neighbor if the neighbor's experiment fails. For this reason, positive accommodation is possible even under decentralization when $b > 0$. Figure V illustrates such convergence for large levels of heterogeneity. As is also suggested by that figure, there are multiple symmetric equilibria when h is large ($h \in [\tilde{h}_d, \overline{h}_d]$), since it may be worth pandering to the neighbor if and only if the neighbor is also pandering in this way (since otherwise, the neighbor prefers its local policy just too much).

Coordination benefits have interesting effects also when there is little heterogeneity. Consider the case where $h < h_d^*$

23. Betsill and Hoffman (2011, p. 101) write that a proposed linkage between the EU's and Australia's trading systems failed thanks to different offset rules. They also write (p. 97) that "diverse cap and trade systems will complicate the task of linking systems and building a global market from the bottom up."

24. The RGGI states took lessons from the EU's ETS despite the fact that the EU had first learned from the American SO_2 market (Betsill and Hoffman 2011, p. 100). After all, "we are still in the learning phase about how to do cap and trade." (Betsill and Hoffman 2011, 99).

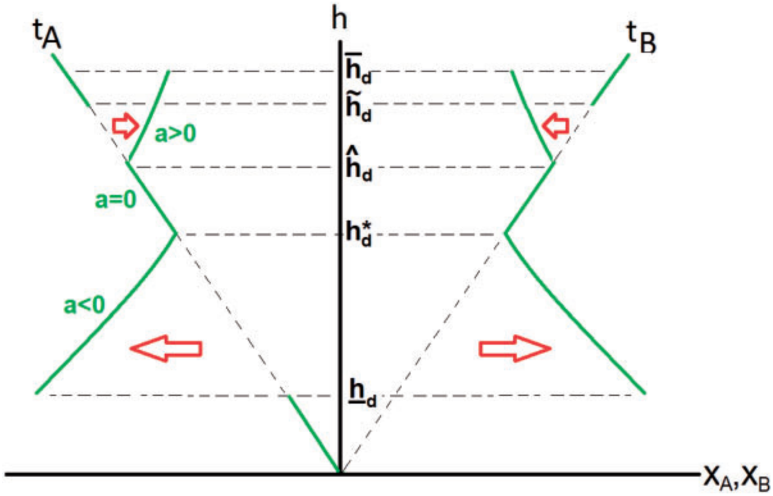

FIGURE V

Convergence is possible even under decentralization when there are benefits of coordinating the policy.

and policies diverge. On the one hand, a larger b makes it less costly for one district to fail and instead adopt the neighbor's policy, particularly if the neighbor is likely to succeed (i.e., if $p > \frac{1}{2}$). On the other hand, if the neighbor is likely to fail ($p < \frac{1}{2}$), a large b makes it more important to succeed to attract a failed neighbor. Thus, if $p > \frac{1}{2}$, a larger b makes free-riding more tempting and, as a response, $a < 0$ declines. Whereas if $p < \frac{1}{2}$, a larger b makes experimentation more attractive and a can be larger, without discouraging the neighbor from experimenting.

Since our model is simple and tractable, it can be extended in many directions. For example, it is straightforward to add imperfect transparency or correlation in our model. Imperfect transparency may mean that the full value of 1 is not necessarily enjoyed by a district adapting the neighbor's policy. Nevertheless, imperfect transparency can be quite beneficial in our model since it reduces the temptation to free-ride and thus the necessity to select policies that are less useful for the neighbor. Imperfect transparency is investigated in detail in our working paper (Callander and Harstad 2013), where we also generalize the framework to allow for multiple districts, intellectual property rights, transfers, or prizes going to the most successful district. Such transfers or prizes can further motivate districts to experiment and accommodate the neighbor's preference, so also this can motivate policy convergence under decentralization, as illustrated in Figure V. These extensions may be particularly relevant for applying the model to private entities such as firms.

VIII. Concluding Remarks

Although the study of federalism has a long and rich tradition—and the "laboratory of states" is frequently celebrated in popular and academic discourse—our understanding of why and when experimentation succeeds has been lacking. Our goal has been to enhance our understanding by introducing a novel model where districts decide on both the quantity and the type of policy experiments.

Our model also sheds new light on the question of why a federal system is helpful at all to create a laboratory of states. If states of a federation can learn from each other, why can't separate countries? This question is of first-order importance yet is often overlooked. For example, in offering his famous defense of federalism, Justice Louis Brandeis never explained why the federation was necessary: "It is one of the happy incidents of the federal system that a single courageous state may, if its citizens choose, serve as a laboratory; and try novel social and economic experiments without risk to the rest of the country" (U.S. Supreme Court. New State Ice Co. v. Liebmann, 285 U.S. 262 1932).

Our theory of dynamic federalism sheds light on this question. We show that by formally tying themselves together in a federation, the states can commit to future harmonization on appropriate issues, and this commitment can motivate states to experiment more and with policies that are attractive also to others.

The dynamic element in our theory does raise the question of whether over time power will not inexorably concentrate at the center.[25] Interestingly, in a landmark contribution to the study of

25. This connects to the long-standing question about the stability of federal systems; Bednar (1996), de Figueiredo and Weingast (2005).

federalism, Riker (1964) examined all federal systems since U.S. independence and found that those with increased centralization of authority outperformed those that moved toward more decentralization. This concentration need not be monotonic, however, and issues may churn between the levels of government. The logic of our model suggests this may happen when a policy is performing poorly and the central government wishes to ignite a policy tournament—and induce competitive experimentation—among the states. This most famously occurred for welfare reform in the 1990s under President Bill Clinton as "by the early 1990's, there was a sense that the federal government had run out of ideas, and that the country needed much more diverse experimentation in order to discover policy improvement" (Bednar 2011, p. 511).[26]

Our model also delivers a surprising connection to the famous result of Tiebout (1956), showing how district heterogeneity emerges endogenously as citizens sort into districts of like-minded people. According to the prevalent theories, the resulting heterogeneity between districts will impair the performance of the federation (Alesina and Spolaore 1997; Bolton and Roland 1997; Cai and Treisman 2005). Our result demonstrates how the heterogeneity can instead improve the efficiency by strengthening the incentives to experiment. Whether Tiebout-induced heterogeneity approximates the optimal solution remains on open question, however, suggesting that the effort to combine our approach with Tiebout-style sorting may prove profitable.

Although in our model of dynamic centralization districts are initially free to choose and try out new policies, there is no reason that the benefits of experimentation are limited to this kind of federal system. Indeed, perhaps the most significant experiment in federalism today is going on in China. The Chinese approach to policy experimentation, known as the "point-to-surface" approach, takes the idea of churn between the levels of government and elevates it to a guiding principle. In this approach, local governments are empowered by the central authority to experiment with policy, typically with directions on acceptable bounds and specific policy domains. The central government's role then is to feed the local experiences back into national policy formation. This practice is sufficiently endemic that Heilmann (2008, p. 12) argues that "the entire policy process must be

26. We thank Craig Volden for this example.

conceptualized as an oscillating multilevel interaction rather than as a dichotomized process of centralization vs. decentralization." (See Montinola, Qian, and Weingast 1996 for an early account.) Although the overawing power of the Chinese central government does not fit our model, the multilevel interaction resonates with our concept of dynamic federalism. Whether federalism Chinese-style succeeds or fails is a question of first-order importance. Adapting our model to the specifics of the Chinese context therefore presents a valuable direction for future work.

In this article we have applied our ideas exclusively to policy making, although the issue of free-riding and experimentation is of broader importance. Theorists within organizational economics are interested in joint control problem within firms where the players—such as the boss and workers or managers and owners—have preference differences. Experimentation and learning is also key to joint ventures and research partnerships between firms, such as oil exploration ventures and pharmaceutical research into new drug compounds. Our key insight on when centralization dominates decentralization is as applicable in these settings as it is in politics.

Appendix: Proofs and Details

This appendix presents the proofs of Propositions 1–8. In our working paper (Callander and Harstad 2013) we generalizes all the results and proofs to a more general setting where we allow for imperfect transparency, coordination benefits, and transfers.

Proof of Proposition 1

We assume that $2p(1-p) > k$, so it is optimal that both experiment even when locations are identical.

(i) Suppose both districts experiment and the following switching constraints are satisfied:

$$c(h - a_j) - c(a_i) \leq 1 \qquad (\mathrm{SC}_i). \tag{18}$$

The first-best then maximizes $u_{A,b} + u_{B,b}$, where for each $i \in \{A, B\}$

$$u_{i,b} = p^2(1-c(a_i)) - (1-p)^2 c(a_i) + p(1-p)\big(2 - c(a_i) - c(h-a_j)\big) - k$$
$$= p(2-p) - c(a_i) - p(1-p)\big[c(h-a_j) - c(a_i)\big] - k.$$

Clearly, first-order conditions imply $a_i = a_j = a$ satisfying:

$$c'(a) = p(1-p)[c'(h-a) + c'(a)] \Rightarrow (2).$$

The second-order condition, $-c''(a) - p(1-p)[c''(h-a) - c''(a)] < 0$, always holds.

(ii) If j's switching constraints are not satisfied, then $a_i = 0$ is the trivial local optimum, giving $u_i = p - k$. By comparison, payoffs are higher under equation (2) when

$$\text{(19)}\quad \begin{aligned} &p - k < p(2-p) - c(a) - p(1-p)[c(h-a) - c(a)] - k \Leftrightarrow \\ &p(1-p)c(h-a) + [1 - p(1-p)]c(a) < p(1-p). \end{aligned}$$

Note that we can rewrite equation (2) to:

$$h = f_b(a) \equiv a + c'^{-1}\left(\left[\frac{1}{p(1-p)} - 1\right]c'(a)\right),$$

where $f_b(a)$, as well as $h - a$, are increasing in a. Inserted into equation (19), we get

$$\text{(20)}\quad p(1-p)c\big(h - f_b^{-1}(h)\big) + [1 - p(1-p)]c\big(f_b^{-1}(h)\big) < p(1-p),$$

where the left-hand side is increasing in h. Define $\overline{h}_b$ such that equation (20) binds when $h = \overline{h}_b$, and note that $\overline{h}_b > 0$ since when $h = 0$, the left-hand side of equation (20) is zero. It follows that equation (20) holds if and only if $h < \overline{h}_b$. It is easy to check that it cannot be optimal with an asymmetric solution such that one switching constraint is satisfied but not the other.

(iii) This part holds trivially (and it follows when maximizing $u_{i,b}$ w.r.t. h).

Proof of Proposition 2

It is easy to check that there is no equilibrium where both experiment if i actually prefer j's location, that is, if $|h - a_j| \leq |a_i|$ for some $i \in \{A, B\}$. From now we thus consider the natural case where $|h - a_j| > |a_i|$ for both districts.

Suppose first that SC_i holds. If the other district j experiments, i experiments as well if this gives i a higher payoff than by not experimenting:

$$p(1-c(a_i))+(1-p)\big[p\big(1-c\big(h-a_j\big)\big)-(1-p)c(a_i)\big]-k \geq p\big(1-c\big(h-a_j\big)\big)-(1-p)c(a_i) \Leftrightarrow \tag{21}$$

$$c\big(h-a_j\big)-c(a_i) \geq \frac{k-p(1-p)}{p^2} \qquad (\text{IC}_i). \tag{22}$$

This is the incentive constraint (IC) for i (IC_i). Note that when IC_i holds (binds), SC_i can still be (is) satisfied if

$$1-\frac{p-k}{p^2} \leq 1 \Leftrightarrow p > k,$$

which is already assumed to hold.

When SC_i is violated, then i always prefers to experiment and equation (22) holds also in this case.

Proof of Proposition 3

(i)–(ii) Anticipating the behavior of district i, described in the previous proof, we now derive district j's optimal location, given by a_j. Just as i's utility is given by equation (21), we can write

$$u_j = p\big(1-c\big(a_j\big)\big)+(1-p)\big[p(1-c(h-a_i))-(1-p)c\big(a_j\big)\big]-k$$

as long as both districts experiment (IC holds) and SC_j holds. For a given a_i, IC_i is satisfied when $a_j \leq a_j^d(a_i)$, where $a_j^d(a_i)$ is defined such that equation (22) binds:

$$c\Big(h-a_j^d(a_i)\Big)-c(a_i) = 1-\frac{p-k}{p^2}. \tag{23}$$

The left-hand side of equation (23) is decreasing in a_j. When IC_i holds, $a_j \leq a_j^d(a_i)$ and u_j is increasing whether $a_j \uparrow 0$ or $a_j \downarrow 0$. If $a_j^d(a_i) > 0$, j can indeed set $a_j = 0$ without violating IC_i. But if $a_j^d(a_i) < 0$, j needs to diverge, by selecting $a_j = a_j^d(a_i) < 0$ to satisfy IC_i. It follows that for the set of equilibria where IC_i holds,

$$a_j = \min\Big\{a_j^d(a_i), 0\Big\}. \tag{24}$$

Fixed points: To further characterize j's best response, as a function of a_i, note that a_j, as given by equation (24), is a continuous function. Differentiate the left-hand side of equation (23) to get:

$$-c'(h-a_j)da_j - c'(a_i)da_i = 0 \Leftrightarrow \frac{da_j}{da_i} = \frac{-c'(a_i)}{c'(h-a_j)},$$

which is an element in the interval $(0,1)$ when $a_i < 0 \Rightarrow c'(a_i) < 0$, but in $(-1,0)$ when $a_i > 0 \Rightarrow c'(a_i) > 0$ since $|c'(h-a_j)| > |c'(a_i)|$ when $|h-a_j| > |a_i|$, which we have already assumed. When IC_i does not bind, $a_j = 0$ so $da_j/da_i = 0$. Thus, the best-response functions are flat (flatter than the 45-degree line) and they cross exactly once. The equilibrium is thus unique. Since the best-response curves are identical, the unique equilibrium is also symmetric, so simply write $a_i = a_j = a$ and define the fixed point $a^d = a_j^d(a)$ using equation (23). By differentiating equation (23), we can see that a smaller h leads to more divergence:

$$c'(h-a)(dh-da) - c'(a)da = 0 \Leftrightarrow \frac{da}{dh} = \frac{c'(h-a)}{c'(h-a)+c'(a)} > 0. \tag{25}$$

By again referring to equation (23), note that $a^d = 0$ when $h = h_d^*$, given by

$$c(h_d^*) \equiv 1 - \frac{p-k}{p^2}. \tag{26}$$

(iii) *Lower threshold:* As $h < h_d^*$ decreases and also $a_j < 0$ decreases to satisfy IC_i, u_j decreases and, for a sufficiently small h (and a_j) it might be that j finds it too costly to satisfy IC_i. By instead increasing a_j, j is, at worst, risking that i will stop experimenting because equation (22) is violated. If so, j's payoff would be $p - c(a_j) - k$. Given this payoff, $a_j = 0$ would be the best choice for j. Thus, it can be optimal to pick $a_j = a^d$ satisfying IC only if j' payoff in this case equation (21) is larger than $p - k$:

$$p(1-c(a)) + (1-p)[p(1-c(h-a)) - (1-p)c(a)] - k \geq p - k \Leftrightarrow$$
$$(1-p)\left[1-\frac{k}{p}\right] \geq c(a), \tag{27}$$

where $a = a^d < 0$, ensuring that IC binds, is an increasing function of h. We can make this function explicit by rewriting equation (23) to get:

$$h = f(a^d) \equiv a + c^{-1}\left(1 - \frac{p-k}{p^2} + c(a^d)\right) \Rightarrow$$
$$a^d = f^{-1}(h).$$

Note that $h_d^* = f(0)$. Furthermore, equation (25) implies that f^{-1}, and thus f, are increasing functions. Inserting $a = f^{-1}(h)$ into equation (27), we get:

$$c\left(-f^{-1}(h)\right) \leq (1-p)\left(1-\frac{k}{p}\right) \Leftrightarrow f^{-1}(h) \geq -c^{-1}\left[(1-p)\left[1-\frac{k}{p}\right]\right] \Leftrightarrow$$
$$h \geq \underline{h}_d \equiv f\left[-c^{-1}\left((1-p)\left(1-\frac{k}{p}\right)\right)\right]$$
$$= -c^{-1}\left[(1-p)\left(1-\frac{k}{p}\right)\right] + c^{-1}\left[1-\frac{p-k}{p^2} + c\left(-c^{-1}\left[(1-p)\left(1-\frac{k}{p}\right)\right]\right)\right]$$
$$= c^{-1}\left[1-\frac{p-k}{p^2} + (1-p)\left(1-\frac{k}{p}\right)\right] - c^{-1}\left[(1-p)\left(1-\frac{k}{p}\right)\right].$$

So, there is an equilibrium where both districts experiment and locations strictly diverge ($a = a^d < 0$) if and only if $h \in [\underline{h}_d, h_d^*)$. Note that we always have $\underline{h}_d > 0$ (since when $h \downarrow 0$, $a^d \to -\infty$, violating equation (27)). Also, note that $\underline{h}_d < h_d^*$.

Example Q: If $c(a) = qa^2$, then $c^{-1}(\varphi) = \sqrt{\frac{\varphi}{q}}$, so

$$h_d^* = \sqrt{\frac{k-p+p^2}{qp^2}} \text{ and}$$
$$\underline{h}_d = \sqrt{\frac{(1-p)\left(1-\frac{k}{p}\right)}{q} + \frac{k-p+p^2}{qp^2}} - \sqrt{\frac{(1-p)\left(1-\frac{k}{p}\right)}{q}}.$$

Furthermore, when $c(h-a^d) - c(a^d) = qh(h-2a^d)$, we get:

$$h(h-2a^d) = \frac{k-p+p^2}{qp^2} \Leftrightarrow -a^d = \frac{k-p+p^2}{2qhp^2} - \frac{h}{2}.$$

Proof of Proposition 4

When $h \in [\underline{h}_d, h_d^*]$ and IC binds, each district receives the equilibrium payoff

$$u^d = p(1 - c(a^d)) + (1-p)[p(1 - c(h - a^d)) - (1-p)c(a^d)] - k$$
$$= 1 - \frac{k}{p} - c(a^d), \tag{28}$$

which is maximized (and equals $1 - \frac{k}{p}$) at $h_d^* \Rightarrow a^d = 0$. If $h > h_d^*$, IC does not bind but both districts are worse off since $c(h)$ increases: if $h \geq h_d^*$ and SC holds, then

$$u^d = p + (1-p)p(1 - c(h)) - k,$$

decreasing in h and approaching $1 - \frac{k}{p}$ when $h \downarrow h_d^*$. When SC fails, we have $u^d = p - k$, which is independent of h and smaller than $1 - \frac{k}{p}$.

If $h < \underline{h}_d$, only one district experiments and it does so at its own ideal point. The utilitarian sum of payoffs is therefore maximized at $h = 0$, giving an average payoff equal to $p - \frac{k}{2}$. By comparing to the payoff when $h = h_d^*$, $1 - \frac{k}{p}$, we get the proposition.

Example Q: If $c(a) = qa^2$,

$$u^d = 1 - \frac{k}{p} - q\left(\frac{k - p + p^2}{2qhp^2}\right)^2 \text{ if } h \in [\underline{h}_d, h_d^*]. \tag{29}$$

Proof of Proposition 5

Consider a district's decision whether to experiment. When both districts succeed or fail, we let $z_A \in [0, 1]$ represent the probability that A's policy is chosen by C when both experiments have the same outcomes. Similarly, $z_B = 1 - z_A$. These probabilities are functions of $\frac{x_A + x_B}{2}$:

$$z_A = F\left(\frac{x_A + x_B}{2}\right) = \Pr\left(t_m < \frac{x_A + x_B}{2}\right) \text{ when } x_A < x_B.$$

If the other district experiments, i does, as well, if this gives i a higher payoff than by not experimenting:

$$[z_i p^2 + p(1-p)](1-c(a_i)) + [(1-z_i)p^2 + p(1-p)](1-c(h-a_j))$$
$$-(1-p)^2 z_i c(a_i) - (1-p)^2(1-z_i)c(h-a_j) - k$$
$$\geq p(1-c(h-a_j)) - (1-p)[(1-z_i)c(h-a_j) + z_i c(a_i)], \tag{30}$$

which can be rewritten as:

$$[c(h-a_j) - c(a_i)]\left[\frac{p}{2} + \left(z_i - \frac{1}{2}\right)p(2p-1)\right] \geq k - [p-p^2]. \tag{31}$$

Proof of Proposition 6

We now investigate *j*'s choice of a_j given a_i and that *i*'s subsequent action is as described by Proposition 5 and its proof. Just as the left-hand side of equation (30) describes *i*'s payoff, *j*'s payoff can be written similarly:

$$u_j^c = [z_j p^2 + p(1-p)](1-c(a_j)) + [(1-z_j)p^2 + p(1-p)](1-c(h-a_i)) \\ -(1-p)^2 z_j c(a_j) - (1-p)^2(1-z_j)c(h-a_i) - k, \text{ where} \tag{32}$$

$$z_j = F\left(\frac{a_j - a_i}{2}\right). \tag{33}$$

A first-order condition approach: By taking the derivative of equation (32) we find that $\frac{\partial u_j^c}{\partial a_j} \geq 0$ if and only if

$$\frac{dz_j}{da_j}\left[p^2(1-c(a_j) - 1 + c(h-a_i)) + (1-p)^2[c(h-a_i) - c(a_j)]\right] \\ -c'(a_j)\left[z_j p^2 + p(1-p) + (1-p)^2 z_j\right] \geq 0, \tag{34}$$

It is easy to check that the second-order condition $\frac{\partial^2 u_j^c}{(\partial a_j)^2} < 0$ always holds locally for the symmetric case (as in probabilistic voting models, the second-order condition does not hold globally, so we check for other maximum points below). By inspection, u_j^c is strictly increasing in a_j for all $a_j \leq 0$. When the analogous first-order condition holds for a_i, we have two equations in two unknown, permitting the unique symmetric solution $a_i = a_j = a_{foc}^c > 0$, satisfying:

$$(35) \qquad c\left(h - a^c_{foc}\right) - c\left(a^c_{foc}\right) = \frac{\frac{c'\left(a^c_{foc}\right)}{F'(0)}}{p^2 + (1-p)^2}.$$

Note that the left-hand side of equation (35) decreases as $a^c_{foc} < \frac{h}{2}$ increases, so a^c_{foc} increases in $F'(0)$. Note that a^c_{foc} is minimized (over p) when $p = \frac{1}{2}$ (then, the denominator in equation (35) is smallest), so, the larger the probability that the two experiments have the same outcome, the more important it is to pander to C and so the larger is a^c_{foc}.

Adding IC constraints: The first-order-condition approach is ignoring the IC-constraint for i, equation (31). As a_j increases towards a^c_{foc}, equation (31) might be violated. When both the IC constraints bind in the symmetric model, the outcome is symmetric $a_i = a_j = a^c_{IC}$ and satisfies:

$$(36) \qquad c\left(h - a^c_{IC}\right) - c\left(a^c_{IC}\right) = \frac{k - p[1-p]}{\frac{p}{2}}.$$

Remark: When equation (31) binds, a marginally larger a_j does violate equation (31) if and only if:

$$-c'\left(h - a_j\right)\left[\frac{p}{2} + \left(z_i - \frac{1}{2}\right)p(2p-1)\right]$$
$$-\left[c\left(h - a_j\right) - c(a_i)\right]\left[\frac{F'(0)}{2}p(2p-1)\right] < 0,$$

which, in the symmetric equilibrium, holds if and only if

$$\frac{c'\left(h - a^c_{IC}\right)}{F'(0)} > \left[c\left(h - a^c_{IC}\right) - c\left(a^c_{IC}\right)\right](1-2p),$$
$$= \left[\frac{k - p(1-p)}{\frac{p}{2}}\right](1-2p),$$

which is always satisfied when the right-hand side is negative (for example when $p > \frac{1}{2}$), but if it is positive, we must require:

$$F'(0) < \overline{\sigma}(h) \equiv \frac{c'\left(h - a^c_{IC}\right)}{(k - p[1-p])\left(\frac{2}{p} - 4\right)},$$

where we may note that $c'\left(h - a^c_{IC}\right) \geq c'\left(\frac{h}{2}\right)$ for all $a^c_{IC} \leq \frac{h}{2}$. We henceforth assume $F'(0) < \overline{\sigma}(h)$. If $F'(0) > \overline{\sigma}(h)$, there would be no pure strategy equilibrium where both invested.

Returning to equation (36), note that $a^c_{IC} \leq 0$ if $h \leq h^*_c$ and $a^c_{IC} \geq 0$ if $h \geq h^*_c$.

Combined with the lessons from the first-order approach, we can conclude that as long as j indeed prefers that also i experiments, we have in a symmetric equilibrium that:

$$a^c = \min\left\{a^c_{IC}, a^c_{foc}\right\}.$$

So for $h < h^*_c$, $a^c = a^c_{IC} < 0 < a^c_{foc}$. Both a^c_{IC} and a^c_{foc} are increasing functions of h and so is thus $a^c = \min\{a^c_{IC}, a^c_{foc}\}$, which we may write as $a^c = \varphi(h)$. Note that a^c_{IC} increases in h faster than does a^c_{foc} when $a > 0$ (this follows from the term $c'(a^c_{foc})$ in equation (35)), we thus have $a^c_{foc} > a^c_{IC}$ if and only if the left-hand side of equation (35) is smaller than the left-hand side of equation (36), and this requires that $c'(a^c_{foc})$, and therefore a^c_{foc} and h, are sufficiently small.

To be precise, we have $a^c_{IC} > a^c_{foc}$ if and only if $h > \tilde{h}_c$, where $\tilde{h}_c$ ensures that $a^c_{IC} = a^c_{foc}$. Note that we can rewrite equation (36) to

$$h = f_c\left(a^c_{IC}\right) \equiv a^c_{IC} + c^{-1}\left[\frac{k - p[1-p]}{\frac{p}{2}} + c\left(a^c_{IC}\right)\right] \Rightarrow$$

$$a^c_{IC} = f_c^{-1}(h).$$

Substituting into equation (35), and combined with equation (36), $\tilde{h}_c$ is implicitly defined by:

$$\text{(37)} \qquad \frac{\frac{c'\left(f_c^{-1}\left(\tilde{h}_c\right)\right)}{F'(0)}}{p^2 + (1-p)^2} = \frac{k - p(1-p)}{\frac{p}{2}} \Rightarrow$$

$$\tilde{h}_c = f_c\left[c'^{-1}\left[F'(0)\frac{k-p(1-p)}{\frac{p}{2}}\left[p^2+(1-p)^2\right]\right]\right] \Rightarrow$$

$$= c'^{-1}\left[F'(0)\frac{k-p(1-p)}{\frac{p}{2}}\left[p^2+(1-p)^2\right]\right]$$

$$+ c^{-1}\left[\frac{k-p[1-p]}{\frac{p}{2}} + c\left(c'^{-1}\left[F'(0)\frac{k-p(1-p)}{\frac{p}{2}}\left[p^2+(1-p)^2\right]\right]\right)\right].$$

This equation is explicitly defining $\tilde{h}_c \in (h_c^*, \infty)$.

Lower threshold: As $h < h_c^*$ decreases, $a = a_{IC}^c < 0$ decreases to satisfy IC. This is costly for district j, which may be tempted to increase a_j, even if then IC_i should be violated and i would stop experiment. In this case, $z_i = F(\frac{a_{IC}^c}{2})$ if the two outcomes are the same. The payoff to j would then be:

$$p - (1-p)z_i c\left(h - a_{IC}^c\right) - k.$$

In contrast, the payoff from selecting $a_j = a_i = a_{IC}^c$ is:

$$2\left[\frac{p^2}{2} + p(1-p)\right] - \frac{c\left(a_{IC}^c\right) + c\left(h - a_{IC}^c\right)}{2} - k. \tag{38}$$

By comparison, j prefers to stick to a_{IC}^c if and only if:

$$p(2-p) - \frac{c\left(a_{IC}^c\right) + c\left(h - a_{IC}^c\right)}{2} > p - (1-p)z_i c\left(h - a_{IC}^c\right) \Rightarrow$$

$$p\left(1-\frac{p}{2}\right) - \frac{p^2}{2} > c\left(h - a_{IC}^c\right) - \frac{c\left(h - a_{IC}^c\right) - c\left(a_{IC}^c\right)}{2}$$

$$-(1-p)z_i c\left(h - a_{IC}^c\right) \Rightarrow$$

$$p\left(1-\frac{p}{2}\right) - \frac{p^2}{2} > c\left(h - a_{IC}^c\right) - \frac{k-p[1-p]}{p} - (1-p)z_i\left[c\left(h - a_{IC}^c\right)\right] \Rightarrow$$

$$\frac{k}{p} - (1-p)^2 > c\left(h - a_{IC}^c\right) - (1-p)c\left(h - a_{IC}^c\right)F\left(\frac{a_{IC}^c}{2}\right), \tag{39}$$

where the right-hand side becomes arbitrarily high (and the condition will fail) when $h \downarrow 0$ since then $a_{IC}^c \downarrow -\infty$. Thus, there exists a $\underline{h}_c > 0$ (implicitly defined such that equation (39) binds) such that both districts prefer to stick to $a_{IC}^c < 0$ only if $h \geq \underline{h}_c$.

Upper threshold: As $h > h_c^*$ increases, $a > 0$ increases since both districts try to please C. For a sufficiently large h and thus a, j prefers to give up on trying to be selected by C for the case where both experiments have the same outcomes.

We can derive the upper threshold implicitly for the special case where F is uniform with density σ. If the uncertainty regarding t_C is so large that $z_j > 0$ even when $a_j = 0$, then we know that switching to a_j cannot be an optimal choice for j: from equation (34) we have that $\partial u_j^c / \partial a_j > 0$ when $a_j = 0$. However, if $z_j = 0$ when $a_j \downarrow 0$, then it is no longer the case that $\frac{\partial u_j^c}{\partial a_j} > 0$ at $a_j = 0$, since j's policy would then never be chosen when $a_i = a^c = \min\{a_{IC}^c, a_{foc}^c\}$ and both experimental outcomes are the same. Instead, j's policy will only (and always) be chosen if i fails but j succeeds, and, for this situation, $a_j = 0$ is indeed the best choice, giving j the payoff:

$$p(1-p) + p - [1 - p(1-p)]c(h - a^c) - k.$$

By choosing a^c, j could instead receive the payoff:

$$2\left[\frac{p^2}{2} + p(1-p)\right] - \frac{c(a^c) + c(h - a^c)}{2} - k.$$

By comparison, j prefers a^c if

$$\left[\frac{1}{2} - p(2-p)\right]c(h - a^c) - \frac{1}{2}c(a^c) > 0, \tag{40}$$

When (36) binds, an increase in h leads to an increase in a, ensuring that (36) continues to bind. Therefore, (40) fails if $h > \overline{h}_c \in (h_c^*, \infty)$, where $\overline{h}_c$ is implicitly defined such that equation (40) holds with equality. So when $h \in (h_c^*, \overline{h}_c)$ and i selects $a^c > 0$, then j prefers $a_j = a^c$ to $a_j = 0$.

Example Q: If $c(a) = qa^2$, equations (35) and (36) give:

$$a_{foc}^c = \frac{qh^2}{2hq + \frac{\frac{2q}{F'(0)}}{p^2 + (1-p)^2}} \text{ and } a_{IC}^c = \frac{h}{2} - \frac{k - p[1-p]}{qhp}. \tag{41}$$

Proof of Proposition 7

If $h \in \left[\underline{h}_c, \tilde{h}_c\right]$,

$$u^c = \left[p^2 + 2p(1-p)\right] - \frac{c\left(a^c_{IC}\right) + c\left(h - a^c_{IC}\right)}{2} - k \quad (42)$$

$$= 1 + p(1-p) - k\frac{1+p}{p} - c\left(a^c_{IC}\right), \quad (43)$$

which is increasing as $h \to h^*_c$ and $a^c \to 0$. If instead $h > \tilde{h}_c$, $a < a^c_{IC}$, smaller than what is presumed in equation (42), and thus u^c is smaller as well.

Example Q: If $c(a) = qa^2$ and $h \in [\underline{h}_c, \tilde{h}_c]$, we get

$$u^c = 1 + p(1-p) - k\frac{1+p}{p} - q\left(\frac{h}{2} - \frac{k - p[1-p]}{qhp}\right)^2. \quad (44)$$

Proof of Proposition 8

Part (i) follows from the text. Part (ii) follows when comparing equations (28) and (43), giving (after a few steps) that:

$$u^c > u^d \Leftrightarrow c\left(a^d\right) - c(a^c) > k - p(1-p).$$

(iii) When $c(a) = qa^2$, consider first the case where IC binds for centralization as well as decentralization: $h \in \left[\underline{h}_c, \tilde{h}_c\right] \cap \left[\underline{h}_d, h^*_d\right]$. By comparing equations (29) and (44), we get $u^c > u^d$ if and only if:

$$h < \sqrt{\frac{k - p(1-p)}{q} \frac{1/4p^2 - 1}{\frac{1}{2} - p(1-p)}}.$$

Next, consider $h \geq h^*_d$. Suppose $h \geq \underline{h}_c$. If $a = a^c_{IC}$, we have from equation (43):

$$u^c = p(2-p) - \left[\frac{k - p[1-p]}{p}\right] - c\left(a^c_{IC}\right) - k.$$

If $h \geq h^*_d$,

$$u^d = p + p(1-p)\left(1 - qh^2\right) - k.$$

In this case, $u^d > u^c$, when (using equation (41)):

$$p(2-p)-\left[\frac{k-p[1-p]}{p}\right]-c\left(a_{IC}^{c}\right)-k<p+p(1-p)\left(1-qh^{2}\right)-k\Rightarrow$$

$$\left[\frac{k-p[1-p]}{p}\right]+q\left(\frac{h}{2}-\frac{k-p[1-p]}{qhp}\right)^{2}>p(1-p)qh^{2}\Rightarrow$$

$$qh^{2}\left(\frac{1}{4}-p(1-p)\right)+q\left(\frac{k-p[1-p]}{qhp}\right)^{2}>0,$$

which always hold. Furthermore, if $h > \tilde{h}_c$, we know $a^c < a^c_{IC}$, which reduces u^c still further and, again, we must have $u^d > u^c$. Thus, it is possible that $u^c > u^d$ only when $h < h^*_d$.

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