Understanding the Science-Policy Gap:
A Formal Principal-Agent Delegation Model

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Abstract

In response to the COP 21 Paris Agreement, policy shifts and interventions are going to take different shapes in different countries. It will vary depending on the types of regimes, level of development, availability of resources, and the nature of the involved stakeholders, among other things. This study introduces a Principal-Agent spatial model of delegation which examines the circumstances under which the science-policy gap closes, is improved upon, or left unresolved, while responding to the Climate Change agreement commitments. Given the tight interconnections between climate and water, and their respective policies, this study will also reflect on the implications of the change in that gap on water resources in different cases.

As policy makers, the Principal (P) works towards setting the needed legislation. They are likely to seek support from an Agent (A) who is expert on climate change mitigation and adaptation. Both players are driven by different value systems which are characterized by varying weights representing the players' relative interests to place policy in favor of business prosperity, resource sustainability, and social welfare. The developed model considers those weights as representative of the players' views towards the importance of shifting policy towards the benefit of each of the three elements. It maps those weights on a single policy dimension which places business prosperity at one end of the continuum, and resource sustainability and public welfare at the other end of the continuum.

The aim of the model, and main purpose of the study is to examine the extent to which this list of value system parameters and exogenous parameters (characterized by crises/shocks), play a role in leading to convergence/divergence between policy makers and scientists. The developed spatial delegation model will help understand circumstances under which the gap widens or closes between a policy maker and a scientist, under various types of shocks. It will investigate the impact of technological advancement and natural crises scenarios on the level of convergence between both players regarding appropriate policy actions, in response to water policy and climate change.

We find that a principal (government) will provide their agent (bureaucracies) with authority to regulate for water policy and climate change when the principal has a stronger preference for sustainability and welfare than current laws dictate (status quo, sq), thereby closing a science-policy gap. But deregulation and business promotion may also close a science-policy gap in the event that the principal views delegation will improve business interests compared to current law and policy, and the agent views the status quo as overly protective of sustainability. Technological shocks which improve resource sustainability could eliminate the need for regulation, thereby improving on the science-policy gap without legislative intervention. But technology shocks may also serve to induce the conditions under which regulation is needed to close the science-policy gap. Resource shocks function similarly to technology shocks by changing the status quo, but resource shocks are substantively different. Political shocks, however, change the underlying preferences of actors rather than the status quo, and thereby serves to change the conditions under which the science-policy gap may widen or close. We discuss these findings in the context of hypothetical situations as well as real world examples including Saudi Arabian wheat production, the Australian drought during the 2000's, Kiribati flooding, the Fukushima nuclear disaster in Japan, the growth of renewable energy in Germany, and climate change policies in the United States under Obama and Trump Administrations.

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1 Introduction

In December 2015, 195 Nations reached an agreement to adopt the first universal and legally binding global climate deal in Paris, as part of the United Nations Conference of Parties (COP 21). This deal was most recently signed by Heads of States at the UN Headquarters in New York, on Earth Day, April 2016. This agreement reaffirms the governments' commitment to keep the increase in global temperature below 2 degrees Celsius. As part of the agreement, governments also are committing to extend the current goal of mobilizing $100 billion per year to support reaching that target. Policy shifts and interventions are bound to take different shapes in different countries. Even though the goal is global, implementing it will take a much more local approach. It will vary from one country to another, depending on the types of regimes, level of development, availability of resources, and the nature of the involved stakeholders, among others. As a policy maker, a Principal (P) works towards setting the needed policies and interventions to respond to those commitments, they are likely to seek support from Agents (A), who are experts on climate change mitigation and adaptation. Both players are driven by different value systems represented by varying preferences towards different short and long term interests. The principal benefits from delegating to a more informed agent, yet the trade-off they would be accepting is the potential risk of policy drift.

The model discussed and conceptualized in this paper is inspired by formal models of the principal agent relationship in the bureaucratic politics literature (Bendor and Meirowitz 2004; Gailmard and Patty 2012) the Bendor and Meirowitz 2004 delegation model, as well as the work by Gillmard and Patty 2012 on Formal Models of Bureaucracy. In the context of setting suitable policies to meet climate change commitments, this paper will assume that the Principal and Agent have varying weights regarding their relative interest to place policy in favor of 1) business prosperity, 2) resource sustainability, and 3) social welfare. The envisioned model considers those weights as representative of the players' views towards the importance of shifting policy towards the benefit of each of the three elements. Those weights will be referred to as endogenous preferences for each of the players.

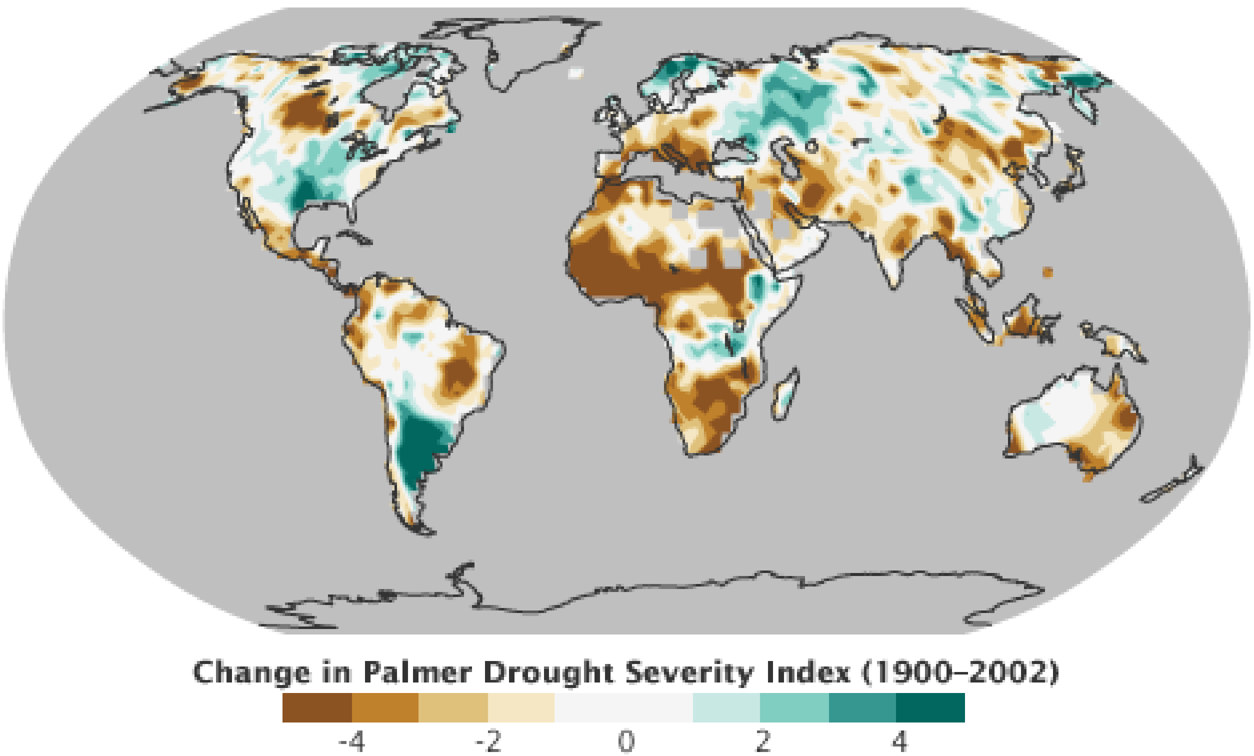
The aim of the model, and the overarching question it attempts to answer is the extent to which these endogenous parameters (characterized by the preferences/weights of policy makers and scientists towards the three "potentially competing" elements) and exogenous parameters (characterized by crises/ shocks), play a role in leading to convergence/divergence between science and policy. The goal is to provide a better understanding of the role in which different players' value systems play in determining delegation outcomes, when players are fully informed, in addition to the role of external shocks in this process.

2 Climate Change, Water, and Economic Development

According to the World Economic Forum's Global Risk report (WEF 2017), water crises and climate change related challenges rank among the top 5 risks for year 2017. Both risks are tightly interlinked; in fact, seventy five percent of the climate plans presented by 185 countries did mention water adaptation (Walton 2015). Even though different projection models differ in quantifying the extent of climate change effects on various regions of the world, there is a general consensus among scientists that precipitation will become more variable, with higher risk of floods and droughts. Dry subtropical regions are projected to get drier, and other wet regions projected to get wetter (Pachauri and Meyer 2014).

Water, being more tangible, usually gets more attention when it comes to the urgency of addressing the challenges associated with it. As the links between water related challenges and climate change are becoming more frequent and visible, particularly with droughts and floods, more political momentum has been able to take place, responding to the urgency of putting the right policies in place. The model presented in this paper will allow for better understanding that dynamics exist between the scientific and police spheres leading to the identification of those policies.

Figure 1: Increase in drought severity between 1900-2002 (Pachauri and Reisinger 2016)



3 Theoretical Model

The principal P and a scientist agent A have different preferences over policy outcomes in $\mathbb{R}$. P's utility function is equal to $-|x_P - y|$, and the agent utility function is represented by $-|x_A - y|$, where x_P and x_A represent the principal and agent's ideal points, respectively, and y is the policy outcome. The principal represents the government, such as the chief executive, legislature, or both. The agent represents a bureaucratic agency which has policy expertise. The ideal points of the policy maker (P) and agent (A) vary according to their underlying valuation of competing interests: business; resource sustainability; social welfare. How each actor values each characteristic is defined by the parameters, β for business or regulated community interests, γ for resource sustainability, and α for social welfare. For simplicity, we assume that the principal and the agent have equivalent interests in social welfare, $\alpha_P = \alpha_A$, which allows us to represent policies on a single dimension between business β interests and resource sustainability γ. Henceforth, we only refer to business interests, β, and resource sustainability, γ.

The model assumes P has interest in putting a greater weight on businesses and the regulated community. By regulated community, we mean those private entities to which regulation is applied which restricts their activities. For water policy, this community may be farmers, commercial fishing vessels, commercial bottling companies, or any other private interest which utilizes water resources on a large scale. P benefits from keeping businesses prosperous, as they are a major source of job creation. Businesses also are an important source of funding for public-private partnership projects. Placing policy at a point which guarantees business interest as a priority contributes to the overall health of the economy. By doing so, P prefers putting a higher relative weight over short term goals, compared to policies that ensure long term resource sustainability, which might be unpopular among businesses and society in the short term. In the climate change policies context, at the time when the agent might be proposing alternatives that are costly and aggressive for businesses in the short term - through imposing carbon taxes for companies, or enforcing expensive emission control technologies, for example - the principal might be more in favor of a more gradual transition.

The potential policies which can be enacted are represented according to a continuum between pure business interests β and pure resource sustainability interests γ. Since we model that policies are on a single continuum, without loss of generality (meaning no normative assumption), we assume the principal values business interests more than the agent does, such that $\beta_P > \beta_A$. Keeping in mind P's interest in being re-elected, it values putting more weight towards businesses, than sustainability, which is more long term. Alternatively, the scientist agent gives more weight to resources sustainability. The agent values resource sustainability more than the principal, $\gamma_A > \gamma_P$. The agent has more expertise with regard to the severity and likelihood of possible future threats, and would as a result generally prefer to place policy more in favor of long term sustainability. This ensures that the principal will also prefer policies which are less than the agent's preferences in the policy space, $x_P < x_A$. Then, we represent each actor's expected utilities of any outcome policy, y, according to the following functions:

$$EU_P(y) = -|x_P - y| = -|\gamma_P - \beta_P - y| \tag{1}$$

$$EU_A(y) = -|x_A - y| = -|\gamma_A - \beta_A - y| \tag{2}$$

The principal considers whether to delegate policy authority to an agent or not. The benefit of delegating to the agent is that the agent is able to offset any implementation shock, $\Omega = [-\omega, \omega]$. Consider the implementation shock as a state of the world which causes policy outcomes to occur at $y = x + \omega$ when the principal attempts to set policy at x but the policy outcome is y. One way to think about it is that the principal would benefit by delegating to a more informed agent with higher technical expertise. When a policy is implemented, a draw from the distribution of the shock is made. The exact draw is only known to the agent because of its expertise, but the principal knows that Ω is normally distributed with mean 0 and variance V_ω. By assumption, the V_ω is always large enough that the principal does not introduce policies itself in which it would attempt to obtain its ideal point. This is because the principal does not have the ability to offset the implementation shock, and views setting policy itself without delegation as more risky than doing nothing. This simplifies the analysis to principal decisions to delegate or do nothing, without unnecessary complications of analyzing the technical expertise of the principal. This is a reasonable assumption especially because the policy domains for science-policy gaps are where technical expertise is required to understand the consequences of policymaking.

When delegation occurs, then the policy outcome y obtains at the agent's preferred policy because the agent is able to perfectly offset the implementation shock, $y = x_A + \omega - \omega$. This means that the principal can expect to receive a policy at the agent's ideal point whenever delegation occurs, $EU_P(y, delegation) = -|x_P - x_A + \omega - \omega| = -|x_P - x_A|$. When the principal does not delegate , then the status quo is the policy outcome, and the principal receives the difference between it's ideal point and the status quo, $EU_P(y, no\ delegation) = -|x_P - sq|$.

The status quo, sq can be thought of as current law and regulation (or no laws if none are enacted) within a policy environment. When there is a large amount of regulation which is benefiting sustainability at the expense of the business community, then the status quo lies towards the right end of the continuum. If for instance a shock to the status quo occurs, such as the principal or government eliminates regulation which reduces the burden on businesses and the regulated community, then the status quo sq moves leftward on the continuum.

Figure 2: Science-Policy Gap

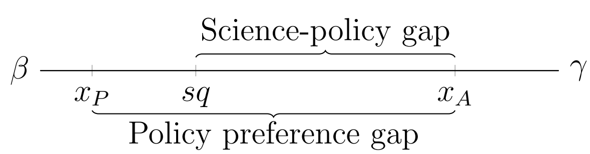


Figure 3: Closed Science-Policy Gap

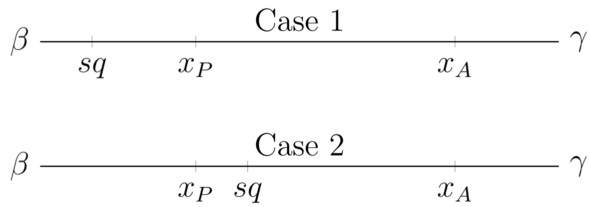
The science-policy gap exists when the status quo is out of line with the preferences of the agent. This means that the gap is closed when the agent has set the policy, because the agent represents scientific policy opinion in the model. Figure 2 illustrates the science-policy gap in one possible situation. The distance between the status quo and the agent's preferences represents the size of the gap. Figure 3 represents a closed gap according to the model. Both Figures 2 and 3 also contain a gap between the policy preferences of the actors.

Note that it is not necessary for policy preferences to converge in order for the science-policy gap to close. There is opportunity for closing the science-policy gap wherever a principal views delegating policymaking authority to science experts as preferable to status quo policies. In effect, the gap may close if the difference between the principal's policy preference and the agent's policy preference is smaller than the distance between the principal's policy preference and the status quo. In the next section, we discuss model the different conditions under which delegation occurs or does not.

4 Understanding the Science-Policy Gap

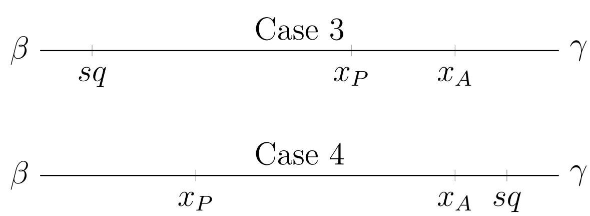
How to understand the placement of the status quo is very important to understanding the dynamic of delegation. When the status quo is to the left, or lower, than the principal's ideal point, this means that the current state of policy is more conducive to business or the regulated community's interests compared to resource sustainability than what the principal wants. This can be seen in Case 1. When the sq is to the left of x_P, delegation may occur if $|x_P - x_A| < |x_P - sq|$. But in Case 1, $|x_P - x_A| > |x_P - sq|$, and therefore delegation does not occur. This means that the distance between the principal's policy preference versus the agent, $|x_P - x_A|$, is less than the distance between the principal's policy preferences and the status quo, $|x_P - sq|$,. It does not matter to the principal in which direction the loss occurs, the principal does not favor policies being to its left or to its right, but rather favors policies which are closer to its ideal point.

Figure 4: Examples of when no delegation occurs: $|x_P - x_A| > |x_P - sq|$



In Case 2, the sq is between x_P and x_A. In such situations, delegation will not occur because there is no sq such that the status quo is between the ideal points of the actors, $x_P < sq < x_A$, and the agent's ideal point is nearer the principal's than is the status quo, $|x_P - x_A| < |x_P - sq|$. Conceptually, when $x_P < sq < x_A$ the status quo is already harming the regulated community in favor of sustainability more than the principal would prefer. In such situations, delegating authority to the agent would merely move policy further away from the principal's ideal point.

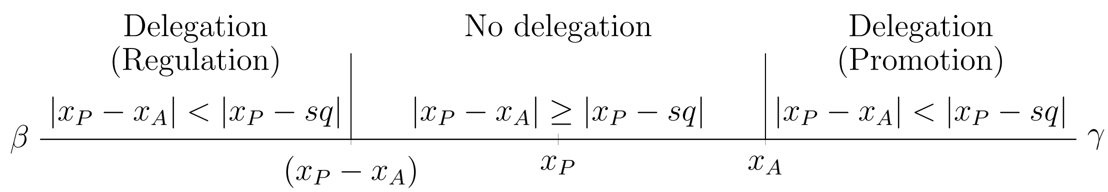
Figure 5: Examples of when delegation does occur: $|x_P - x_A| < |x_P - sq|$



There are also two situations in which delegation occurs. One situation occurs when $sq < x_P$ as in Case 3, and the other is when $x_A < sq$ as in Case 4. When the status quo is lower than the principal's preferences $sq < x_P$, but the distance is farther than the difference in the principal's and the agent's preferences $|x_P - x_A| < |x_P - sq|$, then delegation occurs. This is Case 3. Similarly to Case 1, $sq < x_P$, but because sq favors business much more than the principal would prefer, the principal would be better off allowing the agent to create policy. The outcome would be more regulation than the status quo, and more regulation than the principal prefers, but the principal's preferences towards sustainability compared to the status quo means that allowing the agent to set policy is the principal's best option.

In Case 4, the status quo is now much more favorable to sustainability than to the regulated community. One way to think about this situation is that both actors view the current policy environment as over-regulation. There are a few ways we might think about such a situation occurring, which we will discuss in the next section. But when the *sq* is to the right of the agent, the distance between the principal's preference and the agent's preference is very clearly shorter than the principal to the status quo. The principal will delegate policymaking to the agent to reduce the burden on businesses.

Figure 6: General frame for delegation by ideal points and status quo



We can now show how delegation occurs in a generalized graphic, Figure 6. There are two areas for the status quo to occur in which delegation occurs, and one area in which it does not occur. The figure makes clear that the status quo must be at one of the two extremes in order for delegation to occur. The current state of policy must be bad enough that the principal is willing to suffer policy loss due to agent bias, rather than continue with the current state of policy.

There are two types of delegation to the agent, regulation and promotion. The type of delegation of policy authority depends on whether the status quo is left of the agent's (and principal's) ideal point or whether it is to the right. In both forms of delegation, the resultant policy is set at x_A. But if the status quo is left of x_A, then delegation means the principal wants to improve the outcome to benefit sustainability. We generally think of regulation in this manner, and this is how we are defining it in this analysis. When the *sq* is to the right of x_A, then delegation represents a promotion of business activities, such as subsidies or other incentives for the business community.

We can use this general frame to understand how governments view policy needs. But this general frame only considers static situations. In the next section we introduce how shocks explain policy changes.

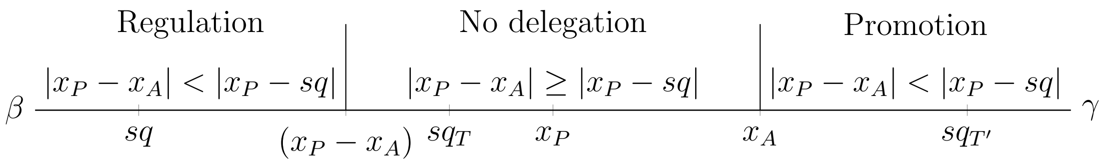
5 Technological, Resource, and Political Shocks.

A model, like a map, is meant to highlight particular characteristics while letting other characteristics be downplayed or ignored. How the spatial model in this analysis is represented could be conceptualized in different ways while explaining the same phenomenon. To represent shocks, the model will now allow either the political preferences to change or the status quo to change. By allowing either preferences or the status quo to shift, we are able to account for policy changes. We then apply the model to different real world cases involving water policy and climate change action.

5.1 Technology Shocks

We represent technology shocks not by shifts in preferences of the actors, but shifts in the status quo. When a technology shock occurs, it shifts what we believe is possible (or at least the marginal costs of production). These shifts can be either the introduction of a new technology which allows for more efficient production that creates less pollution, or the shocks can be reversals in which we come to believe an existing technology is riskier than previously thought. Since we represent technology shocks by changes in the status quo, such shocks are not changing actor's values or priorities but their decisions to make policy given the status quo.

Figure 7: Technology shocks



There are three status quo situations for technology shifts in Figure 7. sq is when delegation occurs because the status quo is too harmful to sustainability, sq_T is labeled in which delegation does not occur, and $sq_{T'}$ occurs when the status quo is too harmful to the regulated community. A shift from any one sq to any other represents a technology shift. For example, when $sq \rightarrow sq_T$, then a technology shock is allowing a reduction in the tradeoff between production from the regulated community and harm to human and environmental health. Such a shock for water policy could be the introduction of a more efficient irrigation system for farming crops, for climate change it could be an innovation in batteries that store power from renewable energy.

An example of a shift in policy in which the government reduces policy and removes agency authority could be Germany's recent shift in renewable energy policy. Due to an abundance of renewable energy brought on by government incentives, Germany has reduced these incentives in order to slow the growth of their renewable energy production. The growth in renewables was so large and the abundance of energy so great that it was beginning to crowd out other forms of energy in which Germany views as necessary for energy security (Porter 2016).

Another rightward shift could be sq_T to $sq_{T'}$, where no delegation had occurred under sq_T but the principal changes policy under $sq_{T'}$. In this scenario, a technological innovation would lead to a change in policy which would essentially reduce regulation. While we refer to this as delegation, it might be considered as the removal of regulatory requirements. For instance, if water usage technologies made water use so efficient that it no longer risked running out of water during shortages, then a government might eliminate restrictions and regulations on water usage. Or if energy technology advanced to the point that cars no longer ran on petroleum fuels, then governments may reduce emissions standards because the businesses may be overly regulated for the total amount of pollution being created.

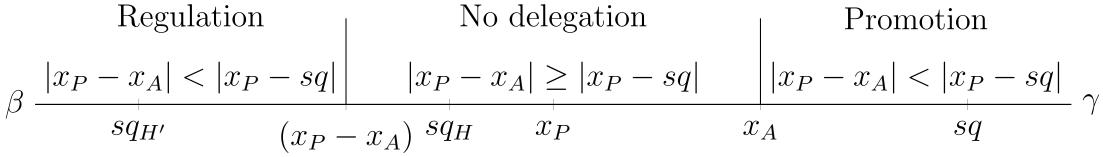
When we think of technology shocks, we tend to think only of the addition of new technologies because in general once we have a new technology, we never lose it. But reverse technology shocks can also occur, in which previously utilized technologies no longer become viable. Such situations may occur when the costs of using a technology where previously unknown, but once known then cause the technology to be less valued. Consider a hypothetical example. A government builds a desalination plant to supplement their water supply. The government plans that they can meet full water demand, thereby not allowing their bureaucracy to regulate water usage because they believe the additional supply is sufficient to meet demand. But upon implementation, the government finds that the operation of the desalination plant is causing high salinity, a large energy footprint, and chemical contaminants in local discharge which is damaging local fisheries. In order to reduce the demand load of the desalination plant, the government authorizes their agencies to regulate and restrict water usage. Such a hypothetical situation would correspond to a technology shift from sq_T to sq in Figure 7.

A real world example of a technology shock which reduces policy is Japan's energy policy reaction to the Fukushima nuclear crisis. When a tsunami landed at the site of the Fukushima nuclear reactor, causing a meltdown, the Japanese government responded by a major reduction in the number of nuclear reactors in operation (Krisch 2016). In essence, nuclear energy in Japan had been used as a clean, climate change friendly energy. While nuclear energy policy represents different dimensions than business interests versus sustainability, we can think of the change in Japanese energy policy as being a reduction in policy, or the elimination of delegation because of a technology shock.

5.2 Resource Shocks

Resource shocks are changes, or perceived changes in the state of the world that impact resource sustainability. Like technology shocks, we represent resource shocks as changes in the status quo. Also like technology shocks, resource shocks can shift policy into or out of any of the three zones from Figure 6. Resource shocks occur when the perceptions of the state of the world change because of new information or beliefs about what the status quo is and what policy should be. And also like technology shocks, since we represent resource shocks as changing the status quo, actor's underlying values are not changing. But policy changes as a result of the relationship of each actor's ideal outcomes in relation to the status quo.

Figure 8: Resource shocks



The most common and convenient way to think about resource shocks is when a government is not regulating a particular activity but a resource shock causes the government to reconsider the state of the world and the need for policy. Such a situation involves beginning at sq_H in which no delegation is occurring, and moving to $sq_{H'}$ in which the principal delegates policy authority to the agent. Droughts and water shortages can have an especially important impact on such situations, in which governments are reluctant to restrict water usage but are eventually forced to do so to conserve water for human health.

A prominent example of a drought as a resource shock which changed opinions of the state of the world, and created subsequent policy changes is the Australian drought in the beginning of the 21st century. In the early 2000s Australians had largely become climate skeptics, and politics reflected this fact. But a severe decade long drought made many Australians reconsider that climate change is real and was the cause of their drought. In reaction, they elected Prime Minister Rudd in 2007 who signed the Kyoto protocol and sought to reduce Australia's greenhouse gas emissions (WI 2016). In this case, lack of rain and water for irrigation signaled a shift from the status quo of $sq_H \rightarrow sq_{H'}$. For Australians at the time, climate change policy became viewed as a water policy because of the perceived connections between climate change and the drought.

When the status quo is sq in Figure 8, then both the agency and the government view that business interests could benefit from policy without creating undue harm to resource sustainability. But a resource shock which moves the status quo to sq_H will cause the principal to reduce the policy be removing authority from the agent. Such a situation is a reduction in policy, where the agent prefers that more regulation occur for and sustainability but the principal prefers neither more regulation nor more business incentives.

Consider a hypothetical example for fisheries. When fish were considered an inexhaustible resource, governments had incentive to provide fishing fleets with subsidies to increase fishing. Such a policy would represent a situation of sq in Figure 8 where the government had incentive to promote the business activity rather than regulate it. But as fish stocks decline it becomes apparent that fisheries are being over-harvested which leads to sq_H where the government decides to reduce the subsidies for fishing vessels. At sq_H, the government is neither subsidizing nor regulating the amount of fishing a fleet can collect. But if stocks continue to decline, the status quo may shift $sq_H \rightarrow sq_{H'}$ in which the government now has reason to introduce restrictions on fishing as a means of protecting the resource.[1]

A real world example of a resource shock which reduced government policy is Saudi Arabia's wheat farming. The Saudis have sought to be independent in the wheat trade as a means of political and food security. But in order to grow wheat in the desert, farming requires 100% irrigation. That Saudi government sought to incentivize wheat production meant that they perceived their status quo to be at sq in Figure 8. But water is scarce in Saudi Arabia, and the government has nearly depleted all of its aquifers (Blas 2015). Since it is running out of water due to its agricultural practices, the Saudi government has eliminated wheat production activities and began importing all of its wheat in 2016 (USDA 2016). This reduction in the government's support for wheat production was created by the elimination of their aquifers, which represents a resource shock from $sq \rightarrow sq_H$.

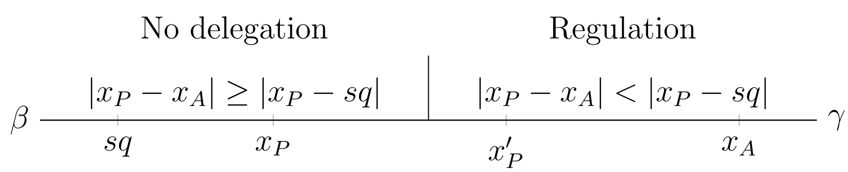
[1]While we have characterized the decline of fisheries as a resource shock, we might also consider that it could arise from technology shocks which enable vessels to catch more fish.

Again like technology shocks, reverse resource shocks could also occur. In the fisheries example, if the fish stocks were found to be thriving more than previously thought then the government might reduce regulation or increase subsidies. In either case of delegation, the resultant policy is set at x_A. Otherwise the policy remains at the status quo, which would be sq_H in Figure 8.

5.3 Political Shifts

An important source of variation in the science-policy gap is the shifting of political preferences of governments. This is most visible in democracies, where a government can have strong policies in one direction, get voted out of office, and be replaced by a government with completely different policy preferences which reverse all of the policies of the previous government. The model represents such political shocks as shifts from x_P to x'_P, and may occur in either direction. But note that we only have the difference between decisions to regulate or not delegate in Figure 9. This is due to the assumption that $x_P < x_A$, the principal always wants less regulation than the agent. Because of this, if $x_A < sq$ then the principal's ideal point does not affect its decision to delegate, because it always delegates to promote business activities in such situations.

Figure 9: Political shocks



There is one type of situation in which political shifts change the principal's decision to delegate policy authority to the agent. As shown in Figure 9, when the principal is in a situation in which it does not delegate because $|x_P - x_A| \geq |x_P - sq|$, then a shift in the principal's preferences in which x_P moves closer to x_A makes delegation more likely. The situation $|x_P - x_A| \geq |x_P - sq|$ encompasses either Case 1 or Case 2 in which $sq < x_P$ and $sq > x_P$, respectively.

Moreover, recall that $x_P = \gamma_P - \beta_P$. The shift from x_P to x'_P represents either a decrease in β, an increase γ, or both. In other words, rightward movement represents a political shift in priorities for the principal away from the interests of the regulated community and towards the interests of resource sustainability. This rightward shift also can represent the closing or narrowing of the science-policy gap. If delegation is created, then the model suggests that the gap closes completely because the model simply assumes the agent is a science expert and sets policy at its ideal point. But the gap is also narrowing in terms of the preferences of the actors over policy.

The reverse shift is also represented by a shock in which x'_P moves to x_P. While delegation is occurring at x'_P, the principal changes policies at x_P. In such situations, the principal is shifting priorities towards business interests and away from sustainability, and the agent is no longer making policy. These rightward and leftward political shocks can represent the changing of governments, particularly in democratic countries. It is common for a government to be elected with preferences in one direction, only to be replaced by a government which seeks to remove the actions of the prior government.

Consider Kiribati, a small Pacific island nation which is under threat of being destroyed by rising seas. This is known to those who understand global warming and climate change, which includes the former Kiribatian President Tong who had put in place policies to help his citizens migrate to Fiji because the country is soon to be uninhabitable. But the Kiribatians, believing their deity would not allow their island to be lost, elected a new president in 2016 who would divert funds for climate change policies, such as migration to avoid floods, towards other policies (Ives 2016).

While the priorities of the new Kirbatian President are for health and education rather than the interests of regulated industry, we can understand this situation as a policy shift which occurred because the new government had different priorities. Those priorities were born from a disagreement over what should be valued, and at the heart of the matter is a disagreement over the effects of climate change on rising seas which in effect served to widen the science policy gap.

Note that we could have portrayed this situation as a difference in the perceptions of the status quo, and that the shift occurred in the perceptions of the status quo and not in the preferences of the principal. This alternative approach to modeling the same phenomenon is possible because what matters is the placement and distances of the actor's preferences and the status quo. Conceptually such an approach would model the exact same phenomenon. This is why we began this section by referencing that models are like maps, we highlight one factor and make another factor dim as a useful means of simplifying complex phenomenon.

6 Discussion

As we have formalized our model, the science-policy gap occurs between the status quo of law and policy and the policy preference of scientific experts. The size of the gap is also partially a function of the divergence in preferences between the principal and the agent. As the divergence in policy preferences increases, the space to which the science policy gap may occupy increases. In the model, the science-policy gap occurs whenever the principal decides not to delegate policy authority to the agent. This can occur under various scenarios, and we generalized when these scenarios occur in Figure 6.

The main intuition from the model is that the science-policy gap emerges when the principal views that their interest's would be harmed more by delegating to the agent rather than leaving law and policy at the status quo. This always occurs when the principal and agent have a disagreement over whether status quo regulations are set too strongly, which corresponds to Case 2 in Figure 4. In this case, the principal and agent agree that the status quo is set somewhere between both of their ideals point, which means they disagree over whether the status quo policies are too strong (principal) or too weak (agent). However, principals may agree that the status quo policies are too weak, yet the principal is unwilling to delegate authority to the agent. This is Case 1 in Figure 4. Despite the principal and agent both agreeing that more should be done to protect resource sustainability, the principal views that delegation would be too costly since delegation would result in policies being set at the agent's ideal point.

That the science-policy gap can remain in situations in which the principal and the agent both agree that the status quo overly favors business interests at the expense of resource sustainability, yet government officials disallow expert bureaucrats from changing status quo policies, underscores how the politics of science policy can be intractable. And as the distance between the government and experts grows, the situation can become objectively more dire since the status quo that the government-principal is willing to tolerate is increasing in the distance between policy preferences.

At this point, it is reasonable to ask why the agent does not negotiate a policy outcome with the principal or why the principal does not place limitations on agent-based policy outcomes. The answer to the first notion is that in the model, the agent does not have a credible commitment to uphold the negotiation once the principal delegates policy authority to the agent. While governments sometimes write laws which provide technical limitations to the policy authority delegated to agents, the ability for governments to have the expertise to write such technical laws is quite limited, hence bureaucratic expertise. In the model, we captured this dynamic by a state of the world mechanism in which the government, or principal, does not know how to accurately create technical laws which achieve an intended outcome. This means that the government is not fully able to control what actions the expert agent have taken. Moreover, judicial oversight of bureaucratic policy and actions in the US, referred to administrative oversight, does not review the content of the policy as much as whether an agency provided due diligence in setting a policy or whether it acted in an arbitrary and capricious manner. The result is that governments are limited in their ability to control agency actions because of imperfect oversight, and this is the heart of the principal agent problem.

6.1 Gap Among Scientists

In our stylized model, the science-policy gap can be completely closed because we have the interest or opinion of scientific experts represented by a single ideal point. However, it is worthwhile to consider that the science-policy gap cannot be closed for all expert opinions simultaneously. Expert opinion is not a singular entity but rather a subjective agglomeration of the views of scientists. It was convieneint to represent expert opinion as a single entity in the model, but in reality each scientist has their own subjective view of what policy is correct. We use the term *subjective* here quite intentionally.

An individuals' scientific field, personal views about their field, and their views on the philosophy of science all inform that individual's scientific judgment. Gaps in preferences could exist within an agency or within the members of the scientific community itself. Consider the case of a hydrologist and economist. While a hydrologist might be in favor of implementing a new water treatment technology (desalination), in an attempt to reduce pressure on ground water abstraction, an economist might have an opposing view due to high production and maintenance costs that make such an investment less economically attractive. Both of these experts' opinions are based on science, but they come to different conclusions because of their underlying values and methodological approaches.

This thought, that the conclusions of science are subjective, is certainly not a new ideal in the philosophy of science. To conduct science, we want to have an objective means of discriminating between rejecting our hypotheses or not. But at what $p-value$ do we use to reject the null hypothesis? We create common standards based on consensus in our field, but the determination of exactly where to change our judgment is inherently subjective. It does not mean that the entire enterprise of science is subjective, but it does mean that any two given experts may draw different conclusions about the same problem. Because of this, whether the science-policy gap is actually closed or not depends upon the judgment of the individual.

6.2 Politics and Science

In the prior section, we discussed how political shocks can change principal preferences in ways which can change delegation decisions. We referenced elections as being opportunities to change these principal ideal points by electing principals with different value structures. Arguably, the election of Barak Obama to the US Presidency in 2008 represented a political shift toward resource sustainability. Once elected, Obama sought to reduce the US carbon footprint through executive actions such as regulating oil exploration. His predecessor, President George W. Bush stated his belief in climate change yet was unwilling to delegate policy authority to US agencies to combat climate change (Bush 2008). President Bush removed the US from the Kyoto Protocol, which President Clinton had signed. Then in 2016 Obama signed the Paris Agreement, and Trump is expected to again remove the US from the agreement (Dixon 2016). These political shifts can be understood as political shocks which move the ideal point of the US President into, and out of, the delegation equilibrium. The switch from Clinton to Bush represented a shift which moved the principal from a delegation equilibrium to a non-delegation equilibrium, Bush to Obama from a non-delegation equilibrium to a delegation equilibrium, and now it seems Obama to Trump will shift the principal from a delegation equilibrium to a non-delegation equilibrium.

But bureaucracies serve the president in the US, and the president has means of influencing agency actions. For instance, Trump's appointment for the head of the Environmental Protection Agency, as well as the pressures he has exerted on merit-based bureaucrats who have worked on climate change policies in the Department of Energy (DOE), shows an attempt to shift the agent's ideal point. Any resultant shift in the policy preference of an agent due to a politician changing the composition of an agency is not changing the preference point of a science expert but rather forcing a shift in the agency's ideal point through political interest. To relate the situation to the model, if the ideal point of the agent shifts then deregulation and promotion of private business interests are the equilibrium outcome when the agent's ideal point shifts to the right of the status quo. Trump undoubtedly views the current status quo of law and policy as being overly biased against business interests, but by shifting agency preferences he might be able to orchestrate even greater levels of deregulation.

Through shifting the agency preferences, the statements released by the agency regarding the science behind government policy will match with Trump's, making the appearance of science-policy convergence. However as we have suggested, a politically forced shift in agency policy preferences does not mean that the agency represents scientific understanding but rather political biases. While it was conceptually useful for the agent's preferences in our stylized model to be representative of expert opinions on science in order to illustrate the science-policy gap, politically induced shifts of agent preferences need to be understood as not truly reflecting expert opinions and therefore not actually representative of closing the science-policy gap when the agency is empowered to create policy.

7 Conclusion

We have constructed a model which helps to explain the conditions under which a science-policy gap emerges or closes. By providing a general model for various political circumstances and incorporating various types of shocks, the model is an efficient means of understanding the science-policy gap. By formalizing our theory, we have created a conceptual heuristic to which science policy phenomenon may be understood. We discuss the model in terms of the interests of the regulated community and resource sustainability in the policy realms of water usage and climate change. But because we have constructed a general model, it is flexible enough to apply to other policy spaces characterized by different competing values.

As nations plan to adopt new policies to reflect their new commitments towards an issue like climate change, being able to acknowledge the difference in endogenous preferences and their link to preferred policy outcomes would be a step towards a needed dialogue and negotiation among scientists and policy makers. That would allow both sides to avoid unintended consequences as they push in favor of one element over the other. There are rarely situations in which all sides come out as winners. Trade-offs need to be assessed for possible pathways and interventions. Better understanding of the dynamic in which the endogenous preferences of the policy and scientific spheres interact would help lead into constructive leaps of progress into a future we seek for ourselves and generations to come.

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