Paradigm flux: The contested politics of biofuel technologies in the United States and European Union

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This paper contributes to the literature on technological revolutions and policy paradigms by analyzing ideas surrounding biofuel technologies in the United States (US) and European Union (EU). Employing structural topic modelling and process tracing, we demonstrate that, despite having similar and multiple logics at their origins, the primary rationale for pursuing biofuels has differed across the cases. In the EU, the goal of environmental sustainability has been consistently dominant. In the US, attention has shifted away from environmental concerns to focus on the economic benefits of a domestic biofuels industry. Multiple and variable logics for sustaining biofuel technologies have made biofuel policies more resilient in the United States compared to the European Union. We believe differences between the two cases can be attributed to: (a) jurisdictional differences related to the scope of authority of EU and US legislative institutions; and (b) institutional differences related to access of environmental and industry interests to the policymaking process.

Key words: biofuels; policy paradigms; structural topic modelling; technological revolutions

1. Introduction

What happens when the old way of doing things is no longer acceptable? Demand theory suggests there will be incentives to develop alternative means of fulfilling needs. Yet, when prevailing practices are *paradigmatic* —that is, entrenched in cultures, worldviews, science, or technologies— alternative ways of doing things can take years, even decades, to replace the status quo. As is often the case, contenders compete against one another in the interim as proponents of particular alternatives vie to establish the superiority of their preferred solutions.

This paper examines the struggle to establish a new paradigm in transport fuels by investigating the emergence and resilience of biofuel technologies in the United States and the European Union: two jurisdictions with histories of biofuels promotion. Analysis of biofuels is illuminating for two reasons. First, the story of biofuels sheds light on how politics and policies facilitate or stifle the appearance of alternative technologies. Second, analysis of the politics surrounding biofuels is revealing of the obstacles involved in sustaining a contender paradigm in the face of technical challenges, or, alternatively, abandoning it when it proves unviable. Although technical challenges of producing commercial-scale conventional biofuels, such as ethanol from corn in the US and biodiesel from rapeseed oil in the EU, have been overcome, conventional biofuels are not cost competitive with fossil fuels. Technological and commercial challenges are even greater for advanced renewable fuels made from non-food feedstocks: for example, biodiesel from used cooking oil or cellulosic ethanol. The economic costs of biofuels as well as other concerns regarding their feasibility as an alternative to fossil fuels have resulted in considerable political contestation, with critics questioning the viability of a transport fuel paradigm based on biofuels (Wonglimpiyarat 2010). What is puzzling from the perspective of paradigm theory, however, is the difference in outcomes of this contestation across the two cases. Biofuel policies have been dialed back at the EU level, but they have been largely sustained in the US.

Although theories of technological innovation, which focus on the commercial feasibility of alternative technologies, are capable of explaining the appearance of conventional biofuels in the 1990s, they are unable to fully explain the resilience of policies promoting their development. Contributing to recent theoretical debates on paradigm change and stability, we contend the process of technological evolution cannot be understood without an appreciation of politics and policies: that is, of the role of 'policy entrepreneurs' in discursively sustaining or undermining paradigms as problems arise. Our explanation is equal parts interest-based, ideational, and institutional. We find biofuel policies have been maintained in the United States because attention was diverted toward economic benefits of biofuels early on, before environmental rationales for pursuing biofuels became suspect. By contrast, the tempering of government support for conventional biofuels in the EU can be attributed to a sustained focus on climate change mitigation, which gave rise to concerns over the negative effects of biofuels on land use.

Biofuel policies have thus followed different logics in the United States and the European Union, with ideas undergirding biofuel policies in the European Union being much more classically 'paradigmatic' than policy ideas in the United States. We argue the source of these differences to be largely institutional. EU emphasis on issues of sustainability appears to be the result of the EU's greater representation of environmental concerns and weaker representation of business interests relative to the

US. The heightened salience of environmental concerns in the EU is also consistent with the EU's normative identity as a global leader on climate change (Parker & Karlsson 2010).

The paper and argument are organized as follows. Section 2 discusses the concept of policy paradigms as developed by Kuhn, his attention to 'anomalies' as a mechanism of paradigm change, and how paradigm change is explained in the literature. We argue accounts that view paradigm change as a function of the commercial viability of alternative technologies fail to appreciate the ways in which calculations of costs and benefits are politically negotiated. This deficiency is corrected in the literature on policy paradigms which recognizes the role of politics in determining how anomalies are handled, sustaining or undermining paradigms in the process. Section 3 elaborates a theory of how politics slow or expedite paradigm change. In contexts where accords must be struck between groups with divergent preferences, the theory posits outcomes of paradigm contests are determined by the extent to which 'entrepreneurial' political actors are able to manipulate the policy discourse so as to marshal support for their policy positions. Institutional contexts with multiple venues are hypothesized to ease this task. Section 4 describes the methods used to test the adequacy of our theory. Section 5 provides the results of our analysis of the role of policy entrepreneurs, their discursive strategies, and political institutions in accounting for the comparative resilience of biofuel policies in the US and the EU. Section 6 concludes.

2. Defining paradigms

The concept of paradigms has been fashionable among academics for over half a century (Merton 1945). A paradigm is a cognitive framework outlining the scope and bounds of appropriate instrumental action (Papineau 1978). Yet, a paradigm must have adherents to be efficacious. A paradigm was thus defined by Kuhn as a 'constellation of beliefs, values, techniques, and so on shared by the members of a given community.' Furthermore, paradigms involve what Kuhn termed 'concrete puzzle-solutions' to common problems, 'employed as models or examples'(Kuhn 1970: 174). The performance of exemplary puzzle solutions sustains or undermines faith in the beliefs and values that support the framework. When a critical mass of community members abandons faith in the belief structures underlying a paradigm, alternative ways of seeing the world gain resonance. Mass defection from old to new ways of seeing and doing is the crux of paradigm change.

Not without controversy, Kuhn was quite literal in his insistence that a paradigm involved a unique way of seeing the world. In Kuhn's eyes, movement from one paradigm to another is akin to a gestalt switch or religious conversion (Kuhn 1962: 93, 149). It is the 'incommensurability' of paradigms that sets them apart. Incommensurability distinguishes incremental improvement upon existing practices from entirely new ways of doing things. If paradigms were commensurable, anomalies —which appear as unexplainable events in the process of puzzle solving— would not be anomalous because they would be explicable according to accepted beliefs. An anomaly is something that cannot be explained given accepted beliefs. Consequently, anomalies fuel paradigm change.

We may define the general paradigm change hypothesis the following way:

anomalies + alternative + mass epistemic defection = paradigm change

Equally important as the presence of anomalies is the existence of an alternative paradigm capable of handling anomalies. It is one thing to know a paradigm is inadequate, it is another to have before oneself a credible alternative. The credibility of the alternative prompts mass migration from one paradigm to another. The unavailability of a full-fledged alternative can draw out the process of paradigm change over many years. While the moment of mass defection appears revolutionary, it is often the case that adherents of one paradigm know there is something better out there, but that it is beyond reach. A paradigm only performs as well as technology permits.

Yet, the advance of technology, too, is governed by paradigms. Complex divisions of labour in modern society mean paradigms operate within and across innumerable spheres. This realization, along with recognition that paradigms in one domain are constrained in some respects by practices prevalent in other communities, has led to the proliferation of the concept to virtually every discipline of social inquiry —from the study of culture writ large, to the study of individual organizations, to the study of the ways in which organizations are studied (Metron 1945; Weaver & Gioia 1994).

Although analytical debates surrounding paradigms and paradigm change subsided in most disciplines by the early 1990s, the concept of paradigms has maintained currency in two literatures under the political economy umbrella. One is the innovation literature, which is home to a theory of stability and change surrounding 'techno-economic paradigms' (Dosi 1982). The other is the public policy literature, which has its own understanding of how 'policy paradigms' are maintained and change (Hall 1993). Neither literature is uncontroversial, and while each has until now kept to itself, it is likely that theoretical advances in one field will inform the other. In particular, it is our contention that scholarly understanding of techno-economic paradigms would be improved by a greater appreciation of the role played by public policy in facilitating or obstructing technological change.

2.1. Technological paradigms

Beginning with the observation that technological innovation is a matter of degree, innovation theorists consider the 'paradigm' to be all-encompassing (Dosi 1982). Consequently, a 'technological revolution' is considered to involve the upheaval of entire systems of economic and social organization.

> A meta-paradigm… is the set of the most successful and profitable practices in terms of choice of inputs, methods and technologies, and in terms of organisational structures, business models and strategies. These mutually compatible practices, which turn into implicit principles and criteria for decision-making, develop in the process of using the new technologies, overcoming obstacles and finding more adequate procedures, routines and structures. The emerging heuristic routines and approaches are gradually internalised by engineers and managers, investors and bankers, sales and advertising people, entrepreneurs and consumers. In time, a shared logic is established; a new 'common sense' is accepted for investment decisions as well as for consumer choice. The old ideas are unlearned and the new ones become 'normal.' (Perez 2010, 194)

Consistent with Kuhn, innovation theorists have found it useful to distinguish between the technical and sociological determinants of technological revolution. On the technical side, two critical conditions stand out: (1) the cost of 'revolutionary' core inputs must decrease relative to the cost of core inputs of established technologies; (2) the infrastructure to deliver the new technology must prove itself technologically and cost feasible (Freeman 1991; Perez 1983). A technological revolution is thus said to proceed in stages. These stages proceed from prototypical and decisive demonstrations in the first and second stages, to 'explosive' yet 'turbulent' diffusion during the third stage, prior to proliferation of the technology in the fourth stage as a new techno-economic system comes to be accepted as 'common sense' (Freeman & Louçã 2001: 146). The process by which a new techno-economic system comes to be accepted is sociological: it involves the conversion process necessary to view established practices as deficient and alternative practices as superior. The conversion process is said to be consolidated in a new 'regime of regulation.'

We may express the techno-economic paradigm change hypothesis the following way:

(*cost of old input > cost of alternative input*) + *viable alternative technology* + *infrastructure* + *regime of regulation* = *paradigm change*

While innovation theorists' engagement with the economics of input cost has been enlightening, a focus on technology and the firms that produce it has limitations. Institutions and culture beyond the firm are, for the most part, treated exogenously, despite recognition that they are important intervening variables in processes of technological change.[1] Chief among the intervening variables is the 'regime of regulation,' which is considered by many innovation theorists to lag behind, and ultimately distort, what otherwise might be a natural trajectory of technological change (Freeman & Louçã 2001: 330; Nelson & Winter 1982: 413). Consequently, adequate explanations for how and when techno-economic paradigms change are not always forthcoming.

Thus, although it is widely recognized that sociological factors loom large in actors' decisions to adopt a new technology, processes by which attitudes, preferences and regulatory institutions change remains underdeveloped. For instance, while it seems reasonable to treat the relative cost of core inputs as the main explanatory factor, actors' calculus of what constitutes cost is itself variable. The price per ton of coal, for example, has remained relatively low for over a century, yet the perceived cost in terms of negative externalities associated with coal has contributed to the popular perception that coal technology is no longer socially affordable.

We maintain that changes with respect to the popular perception of cost underlie many episodes of paradigm change. Specifically, popular perceptions of cost are a significant factor in establishing regimes of regulation that facilitate technological revolutions. The question is how perceptions of costs and benefits are cultivated, expressed and institutionalized. The answer, we contend, lies in the policy process.

[1] While many case studies delve into the inner workings of the state, public sector determinants are generally viewed as idiosyncratic and therefore resistant to operationalization and generalization (Amsden 1985; Freeman 1987; Mazzucato 2013). Consequently, the task of developing a systematic understanding of how institutions produce outcomes has not occupied innovation theorists to the same extent that it has research on neo-corporatism (see, for example, Iversen 1998).

2.2. Policy paradigms

The concept of policy paradigms comes from a separate literature similarly concerned with issues of cost viability and technical feasibility, not of technologies per se, but of public policies (Hall 1989). In his study of economic policymaking in Britain, Hall (1993) synthesized Kuhn's theory of paradigm change with Bateson's (1972) 'orders of learning,' the latter of which had previously gained currency in organizational theory (for example, Argyris & Schön 1978).

Hall's approach added sophistication to Kuhn's theory of paradigm change by associating orders of learning with orders of policy change. Beginning with the assumption that policymakers, like scientists, are loyal to the prevailing paradigm, Hall hypothesized that, in the face of anomalous developments in the economy, policymakers would first experiment with 'first order' adjustments to policies. These are adjustments to the 'settings' (or 'amount') of a policy with respect to a particular instrument. For example, just as most microscopes have variable magnification, taxes and subsidies have variable rates. If first order adjustments to instrument settings are successful, the paradigm is maintained, albeit in marginally updated form, by a process of first order learning. Having sustained the paradigm, policymakers return to business as usual.

If first order adjustments fail to produce desired results, policymakers experiment with 'second order' policy adjustments. Second order adjustments involve changes to the policy instruments employed by officials. For example, passive manipulation of the interest rate may prove insufficient to stimulate investment, in which case it might be necessary to implement active incentives policies. Similar to first order adjustments, if second order adjustments are successful, the knowledge base is updated, this time by a process of second order learning. In both cases the paradigm is sustained.

Depending on the degree of allegiance among policy actors to the prevailing paradigm, on one hand, and the availability and attractiveness of alternatives, on the other, first and second order learning and experimentation can be drawn out indefinitely (or until all combinations of instruments and settings are exhausted). However, consonant with Kuhn, in the presence of a viable alternative, trial and error with first and second order experimentation gradually erodes faith in the prevailing paradigm. Hall defined 'third order' learning and change as a fundamental rethinking of policymaking. Third order change involves changes not only to the mix of instruments implemented by policymakers but also to the goals policies are intended to achieve. Third order learning is paradigmatic in the sense that it involves abandoning previous understandings of how the world works in exchange for a new way of seeing.

In Hall's (1993) study, Keynesian economists in the late 1970s could not make sense of simultaneously high inflation and unemployment: an anomaly according to the Keynesian paradigm, which sought full employment as its primary goal. Monetarist economists, however, had an explanation for simultaneously high inflation and unemployment that hinged on distortions in the labour market and mismanagement of the money supply. As Keynesian instruments persistently failed to allay problems they purported to solve, the economics profession underwent a paradigmatic crisis. This crisis prompted mass defection of professional economists from Keynesianism to monetarism. Yet, it was only with the election of Margaret Thatcher in 1979 that the economic policy paradigm shifted decisively away from the Keynesian goal of full employment to the monetarist goal of inflation management.

We may express the policy paradigm change hypothesis the following way:

anomalies + alternative + mass epistemic defection
+ authoritative champion = paradigm change

The key insight gleaned from Hall's study is that the critical variable is political: politics can either slow or expedite the process of policy change. But politics are not exogenous to the rest of the process. Anomalies erode public confidence in politicians, as well. That is, even if politicians represent constituencies allied to an established paradigm, failing policies cannot be sustained forever when there exists a viable alternative. The real, hitherto unresolved, question is whether and how politics and policies inhibit or facilitate the recognition of alternative paradigms. Acknowledging that policy paradigms may regulate technical domains that inform policymaking, we have before us an explanation for how and why the regime of regulation may help or hinder techno-economic revolutions. The next section elaborates a theory of how policy paradigms are discursively sustained or subverted throughout ongoing processes of policymaking.

3. A revised theory of paradigm stability and change

The question of how epistemic defection translates to policy change has recently given rise to a revisionist literature on policy paradigms (Daigneault 2013; Hogan & Howlett 2015). Yet, despite many insights, the revisionist literature has not put forward an alternative theory of paradigm change (Baumgartner 2014; Princen & 't Hart 2014). Rather, most work in this vein is framed as critique. Carstensen (2011), for example, problematizes the notion that policy making is paradigmatic, contending instead that policy actors are more often 'bricoleurs' than they are strict adherents of standalone paradigms (see also Campbell 1997). Borrowing the concept of bricolage from Lévi-Strauss (1966), this perspective sees public policy as relying primarily upon crude science wherein the process of problem solving is pragmatic and incremental.

Arguments of this sort have had resonance among policy scholars since Lindblom's (1959) famous description of day-to-day policymaking as 'muddling through.' Kay (2007), for example, argues the Australian health insurance system was established through a process of 'patching' as a compromise between what could be considered two distinct approaches to health insurance. More recently, Princen and Van Esch (2016) found that the EU Stability and Growth Pact is premised on a hybrid of neoliberal and ordoliberal principles. Others have identified resistance to mandated policy reforms among administrators as a source of paradigmatic ambiguity (Capano 2003).

Although critique and empirical observation are useful and illuminating, few have isolated precisely what is deficient about Hall's theory of paradigm change. Proponents of Hall's three order approach are, of course, always free to argue that policy ideas are sometimes paradigmatic, and that findings to the contrary are symptomatic of the fact that the policies in question are ill-suited to the paradigm label (Baumgartner 2014). As Zittoun (2015: 125) points out, however, Hall's study was really about paradigm change in the science of economics. It was incidental that the institutions of British government allowed a single authoritative political actor —Prime Minister Thatcher— to bring about a change in the policy paradigm uncontested. From this point of view, Hall's approach is adequate for

explaining situations in which policy change can be brought about with an executive order. But most of the time it cannot. Accords must be struck between groups with divergent preferences. A polity is not a tight community whose members hold shared beliefs, values and techniques.

The question is how 'bricolaged' or otherwise negotiated solutions emerge from situations in which parties to negotiations possess discrete, incommensurable, and paradigmatic preferences. The fact that multi-modal or *n*-peaked preferences cannot be resolved by bargaining has led many to conclude policymaking is monopolistic. Baumgartner and Jones (1993: 83), for example, explain that 'policy image monopolies' follow from institutions that limit the debate to a tractable number of dimensions —what is known as 'structure-induced equilibrium' (Shepsle & Weingast 1981). Similarly, those working within the advocacy coalition framework surmise there will often be an institutionally-privileged dominant coalition held together by shared normative and instrumental beliefs (Jenkins-Smith et al. 2014). From the advocacy coalition perspective, bargaining and brokerage take place principally with respect to 'secondary' or instrumental aspects of coalitions belief systems (Sabatier 1988: 148). Still, the question remains: what happens when policy ideas are paradigmatic and institutional conditions do not lend themselves to monopolistic outcomes?

For their part, scholars in the field of comparative political economy have relied less on structure induced equilibrium to explain policy stability, favouring instead explanation that privileges power resources and the strategic navigation of institutional rules (Esping-Andersen 1990; Katzenstein 1985; Knoke et al. 1996; Scharpf 1997). When coalition resources are evenly matched, change is theorized to take place through the accumulation of marginal defections (Ostrom 1990). These defections are theorized by many to follow from shifts in the policy discourse brought about by skillful 'policy entrepreneurs' (Hall & Thelen 2009; Schmidt 2008).

The fact that the policy entrepreneur is well-established as an agent of change in both the comparative political economy and public policy literatures suggests that public policies, and the process by which they are made, are important units of analysis in social science research (Baumgartner & Jones 1993; Kingdon 1984; Schneider, Teske & Mintrom 1995; Streeck & Thelen 2005). Yet, the policy entrepreneur, along with scholars' understanding of what constitutes entrepreneurialism, has been ill-defined in much past research (Mintrom & Norman 2009). For a theory to be adequate, it needs to have a causal mechanism: it needs to be able to answer questions related to 'who' and 'how.' In other words, adequate theory must plausibly account for how agents effect change, constrained or facilitated as they are by institutions.

3.1. Agents of change

The policy entrepreneur mobilizes bias by identifying unmet needs, whether apparent or latent, and proposing alternatives by which needs may be satisfied. From some perspectives, mobilization of bias results in a 'bandwagon' or 'cascade': terms evocative of mass defection of the sort associated with paradigm change (Baumgartner 2013). From other perspectives, the entrepreneur is a master of coalition-building (Mintrom & Norman 2009). In either case, the techniques at the disposal of the policy entrepreneur are rhetorical and, in some cases, heresthetic (Baumgartner & Jones 1993: 29-30). For clarity,

rhetoric implies persuasion, whereas heresthetics involve the manipulation of the decision situation such that one's preferred alternative wins out over others (Riker 1986).

Taking seriously the question of how policy entrepreneurs use rhetoric and heresthetics to mobilize coalitions or instigate mass defection, Schneider, Teske and Mintrom (1995) borrow from Austrian economics to establish the link between the communication of ideas (rhetoric) and preference formation (persuasion). Invoking Kirzner's (1973) concept of entrepreneurial 'arbitrage,' Schneider and colleagues posit that policy entrepreneurship is not always merely about getting actors to see things in a new light, but rather getting actors to see what were once thought to be discrete alternatives as somehow synergistic (what Kingdon [1984] calls 'recombination'). In other words, arbiters are sometimes capable of breaking down the walls of incommensurability by getting actors to perceive the choice situation differently (Casson 1982). Arbitrage effectively creates a compromise preference point where there previously was none (Schneider et al. 1995: 49).

Of course, arbitrage is not always possible. Moreover, when preferences are discrete and incommensurable, stakeholders will often prefer their opponent's alternative, as a 'second best' option, over some muddled compromise (Egan 2014). Yet, as acknowledged by Lindblom (1959) and many researchers since, 'muddling' seems to be the rule rather than the exception. Thus, where Kirzner's arbiter fails, Levi-Strauss' bricoleur may succeed.[2] The differences between bricolage and arbitrage are subtle. An arbitrage solution can be demonstrated *ex ante*, for example, with thought exercises or logical proofs. In this way, we might say arbitrage is rational: its logic is deductively derived. Consequently, although arbitrage involves creating something from what was already there, arbitrage solutions are paradigmatic in the sense that they encompass clear frameworks outlining the scope and bounds of appropriate instrumental action. Bricolage, by contrast, is knowledge in the making: it is experimental and, thus, 'pre-paradigmatic.' Just as anomalies erode a paradigm, anomalies may erode a bricolage solution. Otherwise, a paradigm may emerge from a bricolage solution. The logic of the paradigm, in this case, is inductively derived after the facts of experience present themselves. The arbitrage and bricolage routes to paradigm change highlight the fact that incommensurability is a matter of perception.

3.2. Institutions

The policy discourse, and the acts of rhetoric and persuasion therein, are not free flowing. Rather, discourse is situated within and regulated by institutional contexts, which vary by case and over time. Usually, the process of policymaking plays out in successive, nested games (Scharpf 1997; Tsebelis 1990). Moreover, discursive battles often unfold within a complex 'ecology of games' (Long 1958). As Baumgartner and Jones (1993) point out, as debate on issues moves from one policymaking venue to another, opportunities arise to reframe issues so as to sustain or subvert the status quo.

[2] On this point, it is crucial to note that when alternatives are perceived to be incommensurable, bricolage is necessarily experimental. Indeed, according to Levi-Strauss (1966), bricolage is emblematic of crude science and is often based on superstition, hunch, theism and mysticism. This is not to say that bricolage cannot lead to scientific discoveries. On the contrary, many established practices, ranging from food preparation to medicine, were first discovered by a process of bricolage, many generations before modern science caught up.

Venue shopping tactics reveal a paradox of pluralism in the sense that it is often not necessary for policy entrepreneurs to convince a majority of stakeholders that a particular alternative is superior to others. Rather, entrepreneurs may use heresthetic strategies, according to which only a select number of authoritative decisionmakers need to be persuaded. Ironically, the division of labour among specialized committees in many political systems means the argumentative logic surrounding a particular alternative does not need to be consistent from one venue to another. This is particularly true in presidential systems where the agenda is set by multi-partisan legislatures with lax party discipline (Tsebelis 2002). Consequently, depending on the situation, entrepreneurs do not need to be very entrepreneurial at all. Instead, advocates of a particular alternative may appeal to multiple logics in different policymaking forums in defense of their position. This is likely to occur in cases where special interest constituencies enjoy privileged access to policymaking forums and strong political representation.

In sum, institutions facilitate or obstruct what might be considered the natural progression of the discourse by structuring debate on how anomalies and alternatives ought to be perceived by stakeholders and decision makers. Analytical engagement with institutions brings clarity to the critical political variable thus far underdeveloped in existing theories of paradigm change. Taking both discourse and institutions seriously, we arrive at the following argument.

> Hypothesis: *policy change in democratic systems is an ongoing discursive battle. The more pluralistic the attendant institutions, the less stable and coherent policy outcomes will be. Still, we should expect dominant and subordinate paradigms at work, as determined by the relative influence of agents espousing particular alternatives. Alternatives are made commensurable by way of entrepreneurial ingenuity, expressed in rhetoric.*

4. Research methods

We use multiple methods to test the adequacy of our revised theory of paradigm change. One method is process tracing of policy developments through a qualitative textual analyses of government documents and media accounts. The documents examined extend beyond those that form the basis of our statistical assessment to include documents produced by regulatory bodies and, in the case of the EU, those produced by the institution responsible for initiating legislation, the European Commission.

The methodology of process tracing extends to the second source of information for our analyses: interviews with representatives of organized interests and political institutions in a position either to act as policy entrepreneurs or to reflect on the discourses and strategies of those who assumed entrepreneurial roles. Together, document analysis and interviews allow us to identify the causal mechanisms and processes that explain the sequence of policy events, from agenda setting through to policy implementation.

Our third method, structural topic modelling, provides a statistical basis for drawing the inferences about the ways in which the policy discourse has unfolded in each jurisdiction over time. Structural topic modelling employs a method of unsupervised machine learning known as latent dirichlet allocation to derive latent variables representative of topical content from text (for a full description of the mechanics

of latent dirichlet allocation, see Blei, Ng & Jordan 2003). A major advantage of unsupervised machine learning is reduced bias. Researchers do not define topics *ex ante*: rather, topics are derived computationally, as probabilities, from distributions of co-occurring words in the sample text.[3] The purchase of structural topic modelling lies in its ability to estimate topic covariation among metadata variables that accompany text, such as information about its source (Roberts et al. 2014). Our statistical sample consists of 187 legislative committee documents from the US Congress and European Parliament related to biofuels.[4]

5. The emergence, contestation, and resilience of the biofuel policy paradigm in the United States and the European Union

5.1. The emergence of biofuels: Multiple discourses

Over the past four decades, the United States has used an array of fiscal and regulatory supply- and demand-side policy instruments to promote a domestic biofuels industry. Fiscal instruments are extensive; they include most prominently grants, loan guarantees, subsidies, and tax credits to support the whole supply chain of biofuels from research, feedstock production, demonstration projects, conversion technology, infrastructure development, and consumption incentives. These fiscal tools are appropriated not only in energy bills but also in farm bills passed by Congress. On the demand side, a major policy instrument since 2005 has been volumetric mandates requiring biofuels to be blended with petroleum products. First set at 7.5 billion gallons by 2012 in the 2005 Energy Policy Act, the Renewable Fuel Standard (RFS) was increased almost five-fold in the 2007 Energy Independence and Security Act (EISA), to 36 billion gallons by 2022.

In contrast, although individual member states have used fiscal policy instruments to support domestic biofuels production, the European Union has relied on its regulatory powers to support renewable fuels. It first established voluntary blending requirements in the 2003 Biofuels Directive, with mandatory blending requirements coming four years later than in the US, in the 2009 Renewable Energy Directive (RED) (Skogstad 2017).

In the US, although goals of energy security stemming from dependence on imported oil amidst the oil crises of the early 1970s were an early rationale for fiscal support for US biofuels production, the 2005 legislation that created a market demand (volumetric requirements) for biofuels added goals of environmental protection and rural development to those of energy security. Ethanol emerged as a replacement for methyl tert-butyl ether (MTBE), the oxygenating agent mixed with gasoline to reduce air

[3] While researchers can bias results by arbitrarily selecting the number of topics (denoted as *k*), or by abusing thresholds and stopword filters, a standard procedure is to select *k* based on the size of the residual (Taddy 2012). As for thresholds and stopword filters, a good rule of thumb is to use them sparingly.

[4] To the extent that the European Parliament is considered to be the EU institution most likely to favour stringent environmental and sustainability policies (Burns 2013), the analysis of documents produced by the European Parliament may unduly emphasise sustainability topics and not be fully reflective of the plurality of topics considered in other EU institutions. We intend to conduct a structural topic model analysis of European Commission documents to see if there is such a bias. In this paper, we use our qualitative analysis of European Commission documents to mitigate the likelihood of the EP's sustainability bias.

pollution in certain geographic areas, when MTBE was associated with underground water contamination, recognized as a carcinogen, and banned in several states. The 2005 Energy Policy Act was passed by Congress at a time of high gasoline prices and reduced national processing capacity as a result of Hurricane Katrina, and depressed corn market prices. An ethanol blending requirement would provide an alternative market for corn, allowing farmers to extract higher prices from the market rather than have to rely on government support payments. At 7.5 billion gallons, the mandate was set low enough not to threaten the oil companies whose fuels were being displaced, but high enough to make ethanol profitable and to drive up ethanol production to exceed the mandate target.

Three rationales —energy security via reduced dependence on imported petroleum, economic development and higher incomes for rural America, and environment protection via reduced consumption of greenhouse gas emitting fossil fuels— were articulated and nurtured by a broad coalition comprised of the renewable fuel industry, farm organizations, and some environmental organizations to result in an increase in the RFS and other biofuel support measures in the 2007 Energy Independence and Security Act (Mondou, Skogstad & Houle 2014). The congressional debates that led up to EISA described ethanol as 'a transformative technology: it would make the country largely independent of foreign (especially Middle Eastern) oil, would be home-grown, would employ many thousands of Americans, would reduce energy costs in the long run, and would be environmentally superior to fossil fuels.' The capacity of this coalition to prevail against an anti-biofuel coalition of oil, livestock and food manufacturing industries, and some environmental organizations can be attributed not only to contextual factors —high oil prices— but also 'stuff in EISA for everybody' (Confidential Interview with official in the Bush Administration , Washington, October 11, 2011). The result was 'a renewable energy bandwagon' that enjoyed bipartisan support (Confidential Interview with EPA official, Washington, October 11, 2011).

As in the US, from the late 1990s through to 2008, biofuels were presented in the EU as a solution to multiple problems: energy security; environmental protection, and specifically, reduced greenhouse gas emissions (GHGs) and climate change mitigation; and agricultural/rural development. These multiple problem-solving rationales were repeatedly made by the European Commission, the EU institution with the exclusive right to propose legislation (Commission of the European Communities 1997; 2000; 2003; 2007; 2009). Multiple rationales gave incentives to a coalition of farm organizations and biofuel producers to rally behind EU legislation to encourage biofuels, and facilitated similar inter-party and inter-governmental coalitions in the European Parliament and Council of Ministers. Member States could highlight their own preferred goal to justify supporting the 2009 legislation that established mandatory blending requirements (Skogstad 2017).

5.2. Contestation and comparative resilience

From early 2005 onward, the environmental impacts of biofuels, have been a continuing concern for several EU stakeholders (Kavalov & Peteves 2005). Environmental groups have highlighted anomalies of biofuel mandates in terms of goals of reducing GHG emissions and protecting biodiversity. With allies across the EU's plural legislative institutions (the European Commission, the European Parliament, the Council of Ministers), they have been able to keep the issue of the environmental sustainability of biofuels

on the policy agenda. Both the 2003 Biofuels Directive and the 2009 Renewable Energy Directive required the European Commission to issue reports on the potentially negative environmental effects of biofuel mandates.[5] The Commission's 2007 Progress Report, which followed a public consultation, stated it was essential that biofuel policies be designed to meet sustainability criteria, including by discouraging the cultivation of biofuels feedstock from lands with high biodiversity (Commission of the European Communities 2007).

New scientific analyses further undermined the framing of biofuels as environmentally friendly (Searchinger et al. 2008), questioning biofuels GHG savings once indirect land use changes (ILUC) were taken into account. ILUC refers to the conversion of land not previously used to produce food into agricultural production in order to replace the land diverted to biofuels feedstock production. Other studies linked biofuels mandates to high food costs —most especially, of corn and vegetable oils, feedstocks for ethanol and biodiesel respectively— and raised concerns about the social costs of biofuels. Although these reports failed to derail EU biofuels,[6] they did result in legislative provisions in RED that highlighted sustainability concerns. Biofuels were required to meet specified environmental sustainability criteria with respect to GHG savings and direct land use in order to count toward national renewable targets and receive national support schemes. The Commission was also required to review and report on the potential impact of GHGs from ILUC effects of biofuels (Commission of the European Communities 2007: 11). The European Commission's Report, issued in late 2010, acknowledged that indirect land use change from biofuel mandates could have an impact on GHG savings associated with biofuels (European Commission 2010: 14).

The overwhelming focus on biofuels' negative environmental (and social) effects splintered the coalition of earlier supporters of biofuel mandates. Environmental groups who had earlier supported RED peeled off from farm organizations and biofuel producers, joining the anti-biofuel coalition of oil industry companies and development organizations mobilized by concerns about biofuels' impacts on food costs and land use in countries like Indonesia and Malaysia, the source of imported vegetable oils used in biodiesel production. These shifting political dynamics and the heightened attention to the suspect environmental effects of conventional biofuels led member states that had earlier supported conventional biofuels to change their minds and to now agree to limit biofuel mandates. The result was an amendment to RED in 2015 to cap conventional biofuels' contribution to 7% of vehicle transport fuels, below the 2009 10% target. Since then, as the European Commission has proposed legislation that would further reduce the biofuels' cap to 3.8% in 2030, biofuel proponents have sought to salvage conventional biofuels by emphasizing their contribution to rural development, and, to a lesser extent, energy security.

In the US, environmental effects of biofuels have not been as salient, despite early concerns of government regulators and scientists about the potential negative environmental effects (US General Accounting Office 1980) and doubts that corn ethanol could reduce GHGs (US General Accounting Office

[5] The 2003 Directive required the report to examine the sustainability of the crops used to produce biofuels (including on land use), and the effects of biofuels and other renewable fuels on climate change and CO2 emissions (Commission of the European Communities 2003: Article 4, clause 2).

[6] The Renewable Energy Directive was part of a climate change package, that the European Commission and the French President of the Council of Ministers were determined to finalize in order to shore up the EU's credibility as a leader on climate change in the run-up to the Copenhagen climate change negotiations in late 2016 (Parker & Karlsson 2010: 935).

1997; Wang et al. 1997). These environmental concerns did not result in binding sustainability criteria in the 2005 RFS, but the Environmental Protection Agency (EPA) highlighted the potential for international land use changes to negate biofuels' GHG reduction benefits (US Environmental Protection Agency 2007). Although divided on the desirability of biofuels,[7] environmental groups who mobilized around the 2007 EISA secured provisions that promoted sustainable (advanced) biofuels, required conventional biofuels (corn ethanol) to meet sustainability standards, and limited the contribution of corn ethanol to no more than 15 billion gallons of the 36 billion gallon mandate through to 2022. EISA also required both direct and indirect land use change effects to be taken into account when determining biofuels' GHG emissions over their life cycle. With considerable input from the biofuels industry, the model developed by the Environmental Protection Agency, responsible for implementing the RFS, showed that GHG emissions from domestically produced corn ethanol and biodiesel, as well as imported sugar cane ethanol, fell within the EISA-specified GHG emission savings.

Rather than issues of environmental sustainability, criticisms have centered on the economic costs of biofuels, and the infeasibility of the RFS itself.[8] Economic self-interest (rising costs and/or lost profits) united a coalition of associations representing the petroleum, livestock, and food manufacturing sectors to press elected politicians, as well as the EPA, to amend, waive, and/or repeal the RFS. Petitioned by governors of ten states in the summer of August 2012 to use its waiver authority to reduce the RFS on grounds of economic harm to the livestock sector, the EPA declined to do so. Nor did reformers prevail with congressional lobbying. The pro-biofuels coalition (of several organizations representing conventional and advanced biofuels producers) remained sufficiently cohesive to ward off the threat of legislative initiatives to reform the RFS. Among the arguments for the status quo was that RFS policy stability was needed to secure the capital investments to bring new technologies to commercialization, and to protect jobs from existing investments (Michael McAdams, Advanced Biofuels, testimony to the US Committee on Energy and Commerce, June 26, 2013).

A more significant challenge has been the failure of cellulosic fuel to make the technological breakthrough to the commercial scale anticipated by RFS statutory requirements. A specific and rising mandate for cellulosic ethanol (which does not pose the food versus fuel tradeoff alleged of corn ethanol) was a condition for environmental organizations' support for EISA (besides a cap on the corn ethanol mandate). The US, however, did not produce cellulosic ethanol in 2007 when the mandate was established. Since then, cellulosic production has continued to lag well behind cellulosic statutory limits. The EPA sets volumes of renewable fuels on an annual basis, and has waiver authority to reduce the total volumes of renewable and advanced fuels to address any shortfall in available volumes of cellulosic fuel as

[7] US environmental groups have been divided on the issue of renewable fuels. The Natural Resources Defense Council (NRDC) supported the RFS, while Friends of the Earth supported biofuels only if were sustainability criteria were included in EISA. The Environmental Defense Fund was not actively engaged. Environmental groups have also divided on the promise and environmental benefits of cellulosic biofuels, some skeptical they will be produced commercially

[8] A further implementation issue concerns difficulties in ensuring compliance with RFS obligations. Refiners, blenders, and importers of fuel are required to demonstrate they possess credits in the form of RINs (the unique renewable identification number for every gallon of renewable fuel produced), purchased either from the fuel producer or on the spot market, that equal their annual volumetric obligation. Evidence of speculation in RINs and RIN fraud have been fodder for critics and raised allegations of the inability of the EPA to oversee renewable fuels' markets.

compared to statutory levels.[9] Its determination that volumes of cellulosic fuel have been far below statutory limits, and unable to be made up by sufficient volumes of advanced and total renewable fuel has resulted in the EPA using its waiver authority to reduce annual volumetric requirement for cellulosic/advanced biofuel volumes substantially downward to the gallons actually being produced.[10]

The EPA's use of its waiver authority, and its delay in establishing volumetric requirements, has been a source of legal challenges from both the biofuels industry and petroleum companies/refiners. The former has attempted to limit the EPA's use of its waiver, arguing it violates congressional intent to develop the biofuels market and has deterred the necessary investment in renewable fuels, especially in the most costly to produce advanced biofuels. The latter have sought waivers to volumetric requirements on grounds of both economic cost and practicality. To date, the EPA's adjustment of the settings of biofuel mandates has kept the policy instrument intact.

5.3. A structural topic model of the biofuels discourse

To assess the extent to which our qualitative findings are sustained quantitatively, we first constructed a dataset from 187 legislative committee documents from the US Congress and European Parliament spanning the period from 1992 to 2017. Next, employing Taddy's (2012) procedure for selecting the number of topics *k*, we estimated the residuals of six structural topic models ranging from *k* = 15 to *k* = 40. Observing that a twenty-five topic model returns the smallest residual (1.50), we fit a semi-parametric structural topic model of the form:

$$\widehat{Pr}(\beta_k, \theta_i, y_{ij} | \boldsymbol{X}_i) = \beta_1 x_1 + m_1(x_2)$$

where $\widehat{Pr}(\beta_k, \theta_i, y_{ij} | \boldsymbol{X}_i)$ is the estimated probability that a document belongs to a topic *k* given observed words $\boldsymbol{X}_i$; β_1 is the binary regression coefficient for the geographic variable x_1 (US or EU); and m_1 is the partial regression function of the time variable x_2 (operationalized quarterly).[11]

To ensure reproducibility and meaningful topics, following Roberts, Stewart and Tingley (2016) and Eisenstein, Ahmed and Xing (2011), we employed spectral initialization and fit a sparse additive generative model (SAGE). We limited stopwords to six frequently used words with little semantic

[9] Volumetric limits are established for four different renewable fuels: conventional biofuels, advanced biofuels, biodiesel, and cellulosic fuels. Cellulosic and biodiesel volumes can meet advanced biofuel volume requirements, and all three can meet total renewable fuel requirements. Conventional (corn ethanol) fuel volumes remain constant from 2015 to 2022, while those in the other three categories continue to increase.

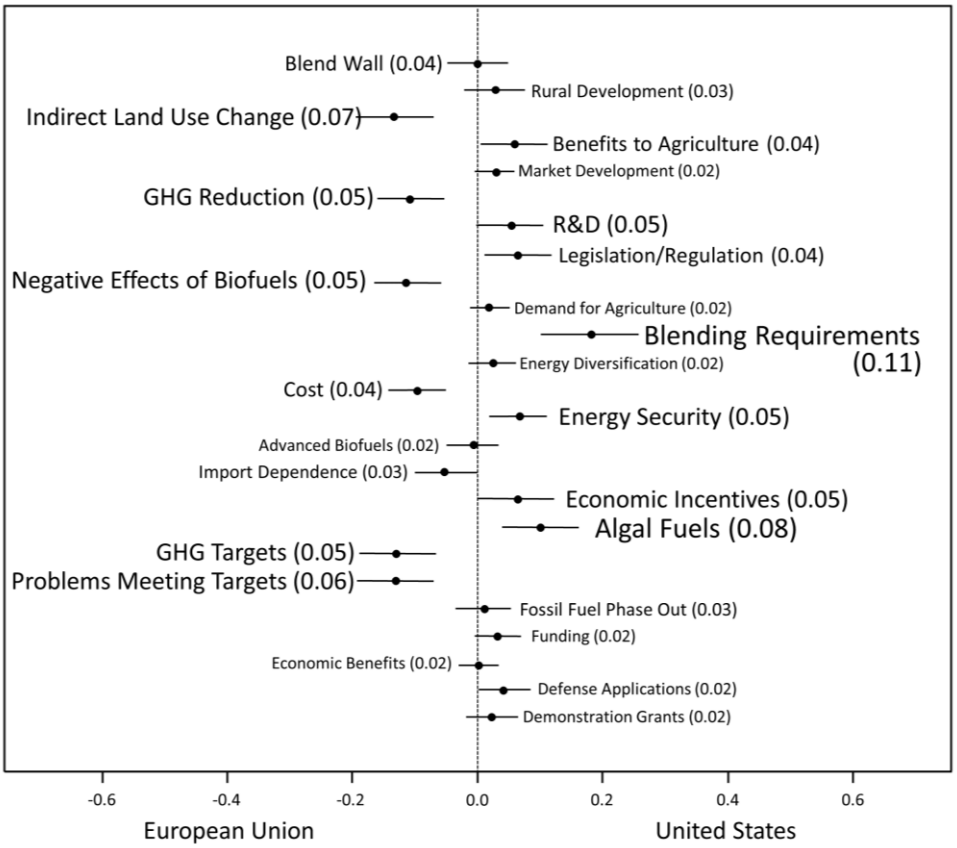
[10] The EPA has generally refrained from using conventional corn ethanol to fill the gap, owing to the limits of so-called `blend wall': that is, auto manufacturers have stated that blending ethanol in amounts greater than the predominantly current 10% will harm most engines and void their warranty.

[11] More precisely, $\beta_k \sim$ Dirichlet (η) and $\theta_i \sim$ Dirichlet (α), where η and α are deep parameters that define word distributions by topic. β_k is the probability of observing each word *j* in a vocabulary (*v*) given topic *k* (where $\beta_{k1} + \ldots + \beta_{kv} = 1$). θ_i is the probability that a document *i* is about a topic *k* (where $\theta_{i1} + \ldots + \theta_{ik} = 1$). For each position *ij* in a document, the topic for that word y_{ij} is drawn as the multinomial distribution of θ_i (i.e., $\prod_{K=1}^{K} \theta_{ik}^{1(y_{ij}=k)}$) and the word itself is drawn as the multinomial distribution of β_k.

meaning (‘chairman,’ ‘committee,’ ‘secretariat,’ ‘secretary’, ‘etc,’ ‘commission’). We did not impose any lower threshold on word frequency.

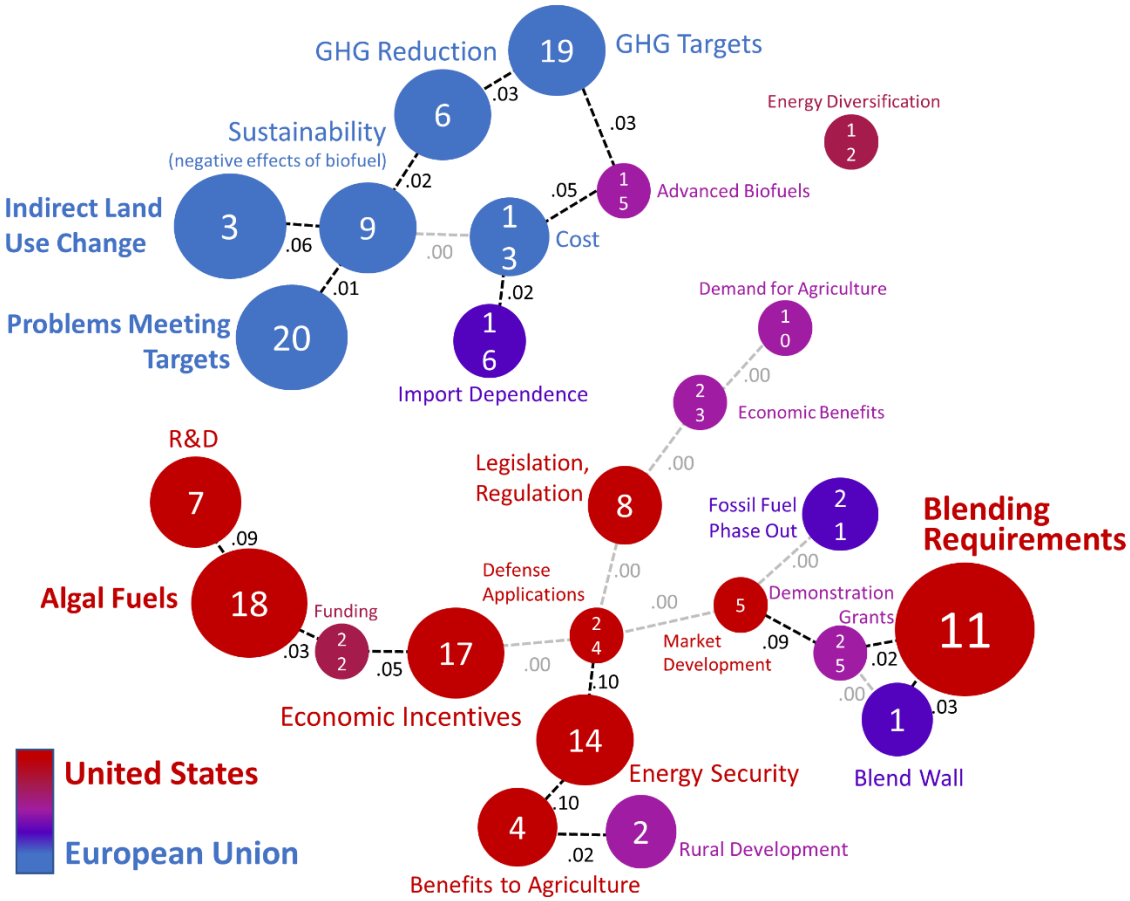
Figure 1 is generated using the ‘stm’ R package by Roberts, Stewart and Tingley (forthcoming). It displays the distribution of topics, along with topic descriptions and 95% confidence intervals, across our cases. Topic proportions are reported in parentheses.

Figure 1: Topic proportions by geography



From the distribution of topic proportions we may infer a number of things. To begin with, all topics having to do with climate change mitigation are biased toward the European Union, while all topics having to do with economic benefits of biofuels are biased toward the United States. Similarly, energy security seems to be strongly biased toward the United States, notwithstanding the stand-alone topic ‘import dependence,’ which is biased toward the EU. Clearly, there are important differences with respect to the logic of biofuel policies between the two cases. These differences are elucidated by the graphical representation of topic correlations in Figure 2.

Figure 2: Topic correlations



Size is indicative of topic proportion. Correlations are noted numerically. The United States discourse is more varied, with tightly clustered themes only tenuously related to one other. The discourse in the European Union, by contrast, is tightly integrated (linked by positive correlations) around the dominant theme of climate change mitigation

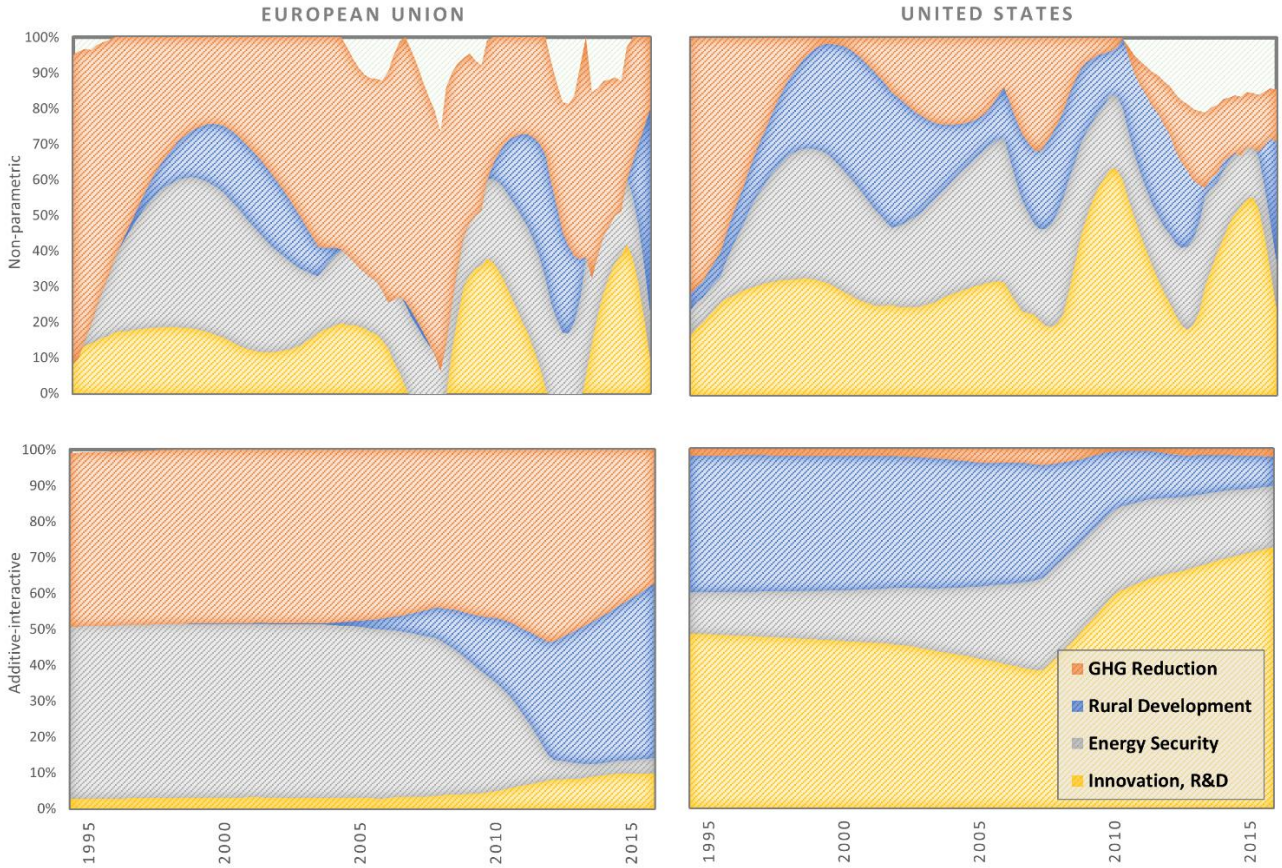
The pattern of topic correlations represented in Figure 2 supports our hypothesis and earlier findings that the policy discourse in the United States and European Union have followed distinct logics. Whereas the EU discourse is tightly integrated around the theme of climate change mitigation, the American discourse shows a clear bias toward economic benefits and concerns about energy security. Note, however, that themes in the US discourse are tenuously linked, as evidenced by weak topic correlations tying together three topic clusters (the exception is the strong correlation between energy security and benefits to agriculture/rural development). In the EU, although matters of rural development and economic benefits are salient, they are not integrated into what we might call the EU paradigm, which is dominated by environmental concerns.

To capture the temporal dimension, Figure 3 compares output from two models suitable for generating topic proportions over time. One is the semi-parametric model outlined earlier. The other is an interactive model designed to capture the interaction effect between geography and time variables. It is of the form:

$$\widehat{Pr}(\beta_k, \theta_i, y_{ij} | \boldsymbol{X}_i) = \beta_1 x_1 \cdot \beta_2 x_2$$

In order to capture the interaction between geography and time, parameterization is necessary. This means fitting an additive model that cannot produce the nuance afforded by partial regression splines. The inverse tradeoff is that semi-parametric regression does not fully capture geographic effects in its estimation of topic proportions. In other words, the top panels of Figure 3 better capture the effect of the time variable; the bottom panels better capture the effect of geography.

Figure 3: Estimated topic proportions, semi-parametric and additive-interactive models



Calculated by combining topics 'GHG Reduction' and 'GHG Targets' ('GHG Reduction'), 'Rural Development' and 'Benefits to Agriculture' ('Rural Development'), 'Energy Security' and 'Import Dependence' ('Energy Security'), and 'Economic Incentives' and 'R&D' ('Innovation, R&D'). Top panels are calculated using semi-parametric regression (smoothing splines on the time variable). Bottom panels are calculated using additive regression with an interaction term between geographic and time variables. Semi-parametric analysis reveals nuance not captured by additive models; however, results are not fully interactive. Additive regression is fully interactive, but parameterization obscures some nuances in the data.

Figure 3 reveals several additional differences between the cases. First, the issue of energy security drops off rapidly around 2008 in the European Union but is sustained in the United States. The disappearance of the energy security dimension in the EU can be explained by the theory of technological innovation outlined earlier, which hypothesizes that the relative price of core inputs determines the growth trajectory of new technologies. From this perspective, it seems plausible that the drop in world oil prices following the 2008 recession meant that import dependence was no longer a problem. Yet, policies in support of biofuels were abandoned in neither the European Union nor the United States. Moreover, the concern over energy security was sustained in the US despite a drop in energy prices.

Taking a perspective that sees cost as more than the price commanded for inputs, the perseverance of biofuel policies after 2008 is not surprising: on both continents, an original impetus for pursuing biofuels was environmental. That said, it is clearly evident that other concerns —particularly rural economic development— came to occupy the American discourse early on. In contrast to the EU, environmental concerns occupy a very small proportion of the biofuels discourse in the US. Somewhat surprising is the salience of innovation and R&D in the US. Yet, attention to innovation and R&D in the US (most recently as it relates to developing 'third generation' algal biofuels) is consistent with our theory that American institutions grant greater access and voice to industrial interests than do the institutions of the European Union.

5.4. *Discussion*

As conveyed by the case analysis, political processes factor large in determining whether and how alternative technologies are brought to fruition and sustained in the face of anomalies. While mechanistic theories of paradigm change may explain some of the variance we observe, differences between the cases cannot be understood without an appreciation of how institutions structure constraints and opportunities for entrepreneurial agents to affect the policy discourse.

In both the US and EU, 'second order learning' and has prompted efforts to reorient biofuels production toward sustainable 'advanced' cellulosic and algal biofuels. Yet, while efforts to bring advanced biofuels to commercial scale have been wrought with challenges in both jurisdictions, there is a clear disparity between the cases with respect to policymakers' sense of urgency to ensure biofuels are sustainable. This disparity appears to stem from differences in how anomalies have been interpreted in each jurisdiction. In particular, the negative environmental effects of land use change have been much more salient in the EU than they have in the US, affecting the calculus of costs and benefits associated with biofuels in different ways in each case.

In the US, the tendency for political institutions to grant access and voice to industrial interests has given rise to a biofuels discourse dominated by economic concerns. This has allowed policy entrepreneurs to craft rhetorical strategies that highlight economic and other benefits of biofuel policies while discounting environmental costs. Although business is by far the best represented interest group at the EU level (Wonka et al. 2010), the considerable influence of environmental groups, especially in the European Parliament, has led to the opposite outcome. Although pro-biofuels entrepreneurs in the EU may be successful in promoting sustainable biofuels, constrained by a dominant epistemology that takes seriously

the negative environmental effects of land use change, entrepreneurs are prevented from discounting environmental concerns. Seen in this light, the EU biofuels discourse is much more classically paradigmatic than is its US counterpart. Whereas policy entrepreneurs in the US have considerable room to act as 'arbitres' and 'bricoleurs,' in the EU, economic and environmental rationales for pursuing biofuels have become incommensurable. For this reason, it is unlikely the EU will implement new directives related to biofuels, notwithstanding breakthroughs in the production of advanced biofuels.

6. Conclusion

This paper has sought to advance scholarly understanding of paradigm change by outlining and testing a revised theory centred on the politics of epistemic defection. Focusing on the rhetorical and heresthetic strategies of change agents, on one hand, and the institutional contexts in which they operate, on the other, our explanation fills two important gaps in the literature by bringing greater clarity to hitherto underdeveloped political variables. First, appreciation of institutional constraints imposed on the policy discourse sheds light on the ways in which the regime of regulation facilitates or impedes what might otherwise be a natural path of progression. Second, thorough conceptualization of the rhetorical and heresthetic strategies at the disposal of entrepreneurial change agents reveals how and why certain trajectories may be sustained despite persistent anomalies.

Our hypothesis that institutions can be discursively navigated to maintain or subvert the status quo is affirmed by our analysis and comparison of biofuels policies in the United States and European Union. In contrast to the European Union, where the discourse has been dominated by questions of sustainability, policy debates in the United States shifted focus toward the economic benefits of a domestic biofuels industry. We argue these differences stem from institutional differences across the two cases. American institutions have granted economic interests greater opportunity (and environmental groups lesser opportunity) to influence the policy discourse than have the institutions of the EU. The result has been a change of emphasis regarding policy goals from environmental to economic concerns. On the other side of the Atlantic, access afforded by EU institutions to environmental advocates has necessitated commensurability between renewable energy and environmental discourses, which has not been sustained over time. Rather, the biofuels paradigm in the EU has been undermined by anomalies, particularly as they relate to the negative environmental effects of land use change.

The findings suggest that, while the concept of paradigms may not always be appropriate to describe the state of the world, paradigms are a useful benchmark for assessing and understanding the logic of policy inputs and outputs. Methodological advances allowing the policy discourse to be traced across cases and over time provide researchers with tools to assess the bias of policy, multifaceted as it may be, as the policymaking process unfolds (Princen & van Esch 2016). Moreover, structural topic modeling and similar methods provide a means to systematically analyze and explain how politics intervene to produce what might otherwise be considered unexpected results.

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