Regime Complexity and Overlapping Information: The Case of Energy Projections

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Abstract

International organizations (IOs) provide critical information for policy making and facilitate international cooperation. Their influence creates incentives for IOs to provide information to secure their own reputation while meeting their policy preferences. What affects IO's strategic decisions on which information to provide? I argue that the emergence of competing organizations affects both the quantity and quality of information IOs provide. I theorize that the emergence of a competing IO in the same issue area (e.g. energy policy) can cause existing IOs to release information they would otherwise prefer to withhold about that subject, but only when such information is verifiable, as it leads to the incumbent IO's motivation to maintain their own reputation. However, competition also creates an incentive for IOs to release unverifiable information that corresponds with their own preferences. Using a novel dataset on publications by major energy organizations between 2000-2017, I find that the entry of a competing IO, International Renewable Energy Agency (IRENA), shifted the content of the International Energy Agency's (IEA) publications toward renewable energy despite their longtime expertise for conventional energy sources. Yet, I also find that the creation of IRENA influenced IEA's published unverifiable information, such as energy projections and policy recommendations, towards the preferences of the United States (the IEA's major funder). The findings highlight that while IO competition can incentivize more information provision, it also creates incentives for IOs to move towards funding states to meet their demands.

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1 Introduction

Providing information is one of the crucial functions of international organizations (IO). Many IOs publish a number of news articles, reports, and research across issue areas, such as trade, development, energy, environment, health, and technology. In fact, the IO's discretion over which information to provide constitutes their major source of power, as it affects the subsequent policy debate and outcomes both internationally and domestically. IOs thus face an incentive to use this discretion strategically. They may strategically select which information to provide, following the preferences of major principal states or pressures from interest groups. Yet IOs simultaneously face a need to legitimize themselves as unbiased and reliable sources of information. Both the pressures to cater to member states' interests and to legitimize themselves have seemingly increased under today's so-called regime complexity,[1] in which multiple partially-overlapping institutions operate in the same issue area. This paper asks whether the presence of overlapping institutions affects the quality and quantity of information that IOs provide. More specifically, how does the presence of overlapping institutions create incentives and disincentives for an IO to provide more accurate information, as compared to the case where there is only one dominant IO?

I argue that additional information sources affect the quality and quantity of information provided by existing IOs. In particular, whether overlapping IOs coordinate or compete in providing information is conditional upon the *verifiability* of information they provide and the interest of principal states. Information is *verifiable* if the receiver, such as the public,[2] can easily figure out ex-post whether the IO truthfully reported the information. In this case, IOs avoid telling misinformation because it would be detrimental to their reputation. Yet they still have incentives not to publicize certain information if it is unfavorable to them. In short, IOs can decide which information to publicize and which to be silent about. On the other hand, information is *unverifiable* if it is impossible for the audience to know whether the provider is telling the truth or not. Verifiability can be considered on a continuum, in which some information has smaller chance of getting verified than others (e.g. due to high cost of

[1] In this paper, I use the term "regime complexity" interchangeably with "overlapping institutions."

[2] The "public" here does not necessarily refer to the ordinary citizens, but the attentive public who pay attention to the issue, including NGOs and special interest groups.

verification or information concerning uncertain future). If the information provider cares about their reputation, this chance of verification may deter them from telling false or biased information.[3] In the former case, when the information is verifiable, I argue that an addition of overlapping IO increases the likelihood that the existing IO reveals their information instead of hiding the information. However, in the latter case where the information is less verifiable, additional IOs create room for biased reporting by the existing IO, driven by forum shopping behaviors among domestic actors.

I examine this in the case of energy and environment, one of the issue areas that experienced a rapid increase in the number of institutions over the past few decades (Keohane and Victor 2011; Abbott 2012; Colgan et al. 2012; Graaf and Colgan 2016). While the International Energy Agency (IEA) has been the most acknowledged institution in the field of energy policy, there are now multiple institutions that also provide related information, such as future projections or policy scenarios on energy mix and carbon emissions. Some of them are now widely recognized as major IOs. In particular, International Renewable Energy Agency (IRENA), which was founded in 2009 and came into force in 2010, expanded its membership from 85 countries in 2011 to 167 by 2021[4] and its budget size quickly caught up with that of IEA (Overland and Reischl 2018). These intergovernmental organizations share an overlapping mandate: publishing annual projections and recommendations on energy usage and its consequence. In addition, some individual states as well as private actors, such as business firms, non-governmental organizations (NGOs), and think tanks are also active in publishing energy projections and policy recommendations. These scenarios are used by a wide range of actors, from policymakers to business sectors. For example, companies often use IEA's *"World Energy Outlook"* when they assess climate-related risks.[5]

As an observable implication of my theory, I expect that the IEA starts publishing more information on renewables after IRENA's entry (change in quantity). However, the content of their publications, when they are less verifiable like the long-term energy outlooks or pol-

[3] When it is unverifiable for sure (i.e., zero probability of getting verified), however, there is no reputation cost, and hence the information provider always has an incentive to tell whatever is preferred.

[4] IRENA. "IRENA Membership" (`https://www.irena.org/irenamembership` Accessed January 2022)

[5] International Energy Agency, Dec. 15, 2016. "IEA welcomes Task Force recommendations to disclose climate change risks with scenario analysis"(`https://www.iea.org/news/iea-welcomes-task-force-recommendations-to-disclose-climate-change-risks-with-scenario-analysis`)

icy recommendations, is more likely to become catered to the U.S. interest given the IEA's competition with IRENA (change in quality). To empirically test these implications, I collect data on future energy projections made by the IEA and other institutions between 2000 and 2018, as well as text data of around 900 policy reports published by the IEA, IRENA, and other institutions during the same period. Using designs such as synthetic difference-in-differences (Arkhangelsky et al. 2021), I examine the effect of IRENA's entry on IEA's information. Specifically, I compare the change in IEA's information before and after the entry of IRENA to the change in information by other institutions, which are also in the energy field but not directly competing with IRENA. I find that information on current energy topics, which are *verifiable*, shifted increasingly toward information on renewables after the entry of IRENA compared to information from other institutions. Meanwhile, its projections on future renewable energy usage, which are *unverifiable* in the short term, remained conservative (i.e. much less renewable share projected than those of IRENA and other organizations), even after 2010 when other institutions were adjusting their renewable energy estimates upward. Additionally, in terms of policy recommendations (also *unverifiable*), the text analysis of policy reports indicates that following the entry of IRENA in 2010, the IEA reported more heavily on biofuels relative to solar and wind, which is consistent with the U.S. investment pattern, while the renewable energy topic of other institutions between 2005 and 2018 reflected the global investment pattern (more solar and wind but less biofuel). Finally, to assess the mechanism that these behaviors of IOs are motivated by major financial contributors' demand and support, I look at how the U.S. government actors are using the information published by IEA. A text analysis of the U.S. government publications shows that IEA's information was cited more in the U.S. government for those on conventional energy, especially after the rise of IRENA as an alternative information provider.

Theoretically, this paper contributes to the ongoing debate on whether overlapping international institutions help or impede international cooperation. Some contend that it leads to more cooperative outcomes through flexibility (Keohane and Victor 2011), orchestration (Abbott et al. 2015), hierarchical coordination, or deference and division of labor (Pratt 2018a; Henning and Pratt 2021). Others, in contrast, argue that it causes less cooperative outcomes due to competition and forum shopping (Alter and Meunier 2009). This paper

contributes to the recent development in the literature examining the condition under which institutions can coordinate while in others they instead compete (Pratt 2018b; Clark 2021, 2022). In particular, I look at how the same set of IOs both compete on one front and cooperate on another front, instead of asking which set of IOs compete and which other sets cooperate. Such concurrence of competition and cooperation is observed in many overlapping IOs today. Substantively, this paper examines this consequence of regime complexity on a critical yet understudied function of IOs, which is to provide information. The IO's role as information provider have been theoretically discussed as an important component in international politics (Chapman 2009; Fang and Stone 2012), but with limited empirical test partly due to the difficulties in quantifying information. The data originally collected from the publications of the IEA and other energy institution allows me to systematically test the theoretical expectations.

The next section discusses the contribution to the literature. I then introduce the formalized theory where I discuss how an IO's equilibrium strategies differ when there are multiple IOs compared to the case when there is only a single IO providing the information. The subsequent sections examines the implications of the model and provide empirical tests.

2 Regime Complexity and Information Provision by IOs

2.1 Consequences of Regime Complexity

Do overlapping mandates of IOs encourage them to provide quantitatively and qualitatively better information? The literature on regime complex, defined by Raustiala and Victor (2004) as "an array of partially overlapping and non-hierarchical institutions governing a particular issue-area."(p.279),[6] suggests both the positive and negative effects of overlapping institutions on cooperation among states.[7]

On the one hand, studies have claimed positive impact of regime complexity, as it leads

[6] Pointing out the ambiguity in their definition, Orsini et al. (2013) further defines it as "a network of three or more international regimes that relate to a common subject matter; exhibit overlapping membership; and generate substantive, normative, or operative interactions recognized as potentially problematic whether or not they are managed effectively".

[7] For review on this topic, see Alter and Meunier (2009), Orsini et al. (2013), and Alter and Raustiala (2018).

to flexibility and adaptability (Keohane and Victor 2011), effective governance through orchestration (Abbott et al. 2015), boosted legitimacy (Kelley 2009), or deepened cooperation through deference and division of labor (Pratt 2018a). On the other hand, one of the main concerns is that regime complexity may allow states to forum shop among institutions and consequently triggers a race to the bottom in regulation standards or noncompliance (Alter and Meunier 2009). Others worry about the distributional consequences, as regime complexity may increase the gap between powerful states and others by unevenly serving the interest of the former (Drezner 2009). Moreover, even with such strategic behavior of states aside, regime complexity may incur negative outcomes such as inefficiency due to duplicated efforts and bounded rationality due to complicatedness (Alter and Meunier 2009). Recent studies look further into conditions that mediate the relationship between regime complexity and cooperative outcomes, such as the structure of each complex (Orsini et al. 2013; Eilstrup-Sangiovanni and Westerwinter 2022) or character of issue differentiation (Pratt 2018b).

The regime complexity literature, however, has paid little attention to the informational role of IOs. What is the effect of overlapping IOs on information provision? On the one hand, there has been an increasing pressure for IOs to be transparent for the sake of legitimacy towards the public (Ecker-Ehrhardt 2018). Regime complexity may add to this competition over legitimacy, increasing the cost of appearing to be a biased type. On the other hand, analogous to the forum shopping for regulation, member states may arbitrarily choose information that suits their preferences under regime complexity. This may result in a race to the bottom in information quality among IOs since they want to gain support from certain states. Building on the existing theories of regime complexity, this paper asks when outcomes such as duplicated effort, forum shopping, coordination, or deference, occurs in information provision.

2.2 Information Provision by IOs

Information and Bias of IOs. While this paper focuses on the interaction between multiple IOs with overlapping mandates, most studies on the informational role of IOs theorize the case of a single IO interacting with either single or multiple states and their respective domestic actors. One of the most studied aspects is how IOs could be informative to domes-

tic actors, as they can provide information that domestic governments do not have incentives to disclose (Chapman 2009). International trade institutions, for example, can be used to inform the domestic public about their government's trade policy and practices (Mansfield and Milner 2013; Chaudoin 2014). From the perspective of constructivist theory, IOs are where ideas are disseminated, forming a foundation for epistemic communities (Haas 2008). While many models, including those above, treat IOs as neutral actors, others treat IOs as biased actors and consider conditions under which these biased IOs can still be informative. For example, biased IOs could be informative for a government when domestic experts are even more biased (Fang and Stone 2012) or when two countries under negotiation have power asymmetry (Johns 2007).

Similarly to the latter group, I assume that each IO has its own preferred policy and argue that an entry of a new institution with a different policy preference affects how existing IOs provide information. Regardless of whether its policy preference stems from the bureaucrats' preferences (Johnson 2014) or those of principal member states, especially the large financial contributors, IOs likely have some biases that neither maximize the world's social welfare nor align perfectly with the preference of a single state. In fact, some empirical works suggest that IOs provide systematically biased information. For example, economic forecasts by the IMF may suffer from biases based on political concerns, defensiveness, or its mandate (Dreher et al. 2008a). My argument examines the effect of an entry of new IO on the incumbent IO, each with its own policy preference (bias).

Note that while IOs provide a wide range of information, this paper is specifically interested in those originally produced by IOs. It does not deal with raw information like the GDP of a country, which institutions like OECD or World Bank collect from each government and publish as reported. This is because the data generating process is very different between each type of information, and IOs have more discretion over the former than the latter. Coicaud and Le Blanc (2016) categorize information collected by IOs into five types depending on the means of information gathering: (1) "those collected by IOs based on nationally produced information, with some degree of reprocessing, for the purpose of displaying the information and data"; (2) "original information from multiple sources by IOs", alone or in partnership with outside organizations; (3) "collective production of new information by

members and stakeholders of IOs"; (4) "compilation of inputs from members and stakeholders" and (5) "electronic dialogues, consultations, and forums". This paper addresses the second and the third type, where "IOs take the lead in producing, thereby becoming the de-facto reference source for such data."

IOs Providing Information on Energy. In the case of energy governance, some studies have shown that the IEA's projections of the future energy mix consistently underestimate demands for renewable energy (e.g. solar) compared to projections from other organizations (Carrington and Stephenson 2018; Creutzig et al. 2017). The most common suspect behind this is that IEA is biased toward using conventional energy (coal, oil, and gas), backed up by the interest of the United States and its fossil fuel industries.

The creation of the IRENA was primarily driven by the rising pressure from the German domestic politics demanding an alternative to the IEA for information and policy suggestions on renewables (Van de Graaf and Lesage 2009; Urpelainen and Graaf 2015). The U.S. government was initially opposed to the establishment of IRENA. Likewise, the IEA vocally expressed its opposition (Urpelainen and Van de Graaf 2015). Yet after a concession was made to the U.S. by agreeing to locate IRENA's headquarter to Abu Dhabi, UAE, IRENA's statute was signed in 2009 and entered into force in 2010. It is mostly regarded as an institution to provide information, rather than one for fundraising or specific regulations (Overland and Reischl 2018). Today, IRENA publishes numerous reports and policy advice regarding renewable energy, both at the specific country or regional level and at the global level, ranging from specific issues (e.g. adaptation of hybrid mini-grids)[8] to broader topics such as the estimates of the world renewable energy price in the long term.[9]

Most member states of the IEA, which consist only of OECD members, also hold membership in IRENA. The two institutions cooperate on certain fronts.[10] Yet some anecdotes like the following indicate continuing tensions on other fronts between the two organiza-

[8] IRENA, 2015. *"Renewable Energy in Hybrid Mini-Grids and Isolated Grids: Economic Benefits and Business Cases"*

[9] e.g. IRENA, 2019. *"Global energy transformation: A roadmap to 2050 (2019 edition)"*

[10] For example, they run a joint database, "IEA/IRENA Renewables Policies and Measures Database", which keeps track of renewable energy policies of IEA/IRENA member states.(`https://www.iea.org/policies?source=IEA%2FIRENA%20Renewables%20Policies%20Database`)

tions. In preparation for hosting G20 in 2017, Germany asked both IEA and IRENA to submit a report on their scenarios for decarbonization, resulting in a joint study "*Perspectives for the Energy Transition: Investment Needs for a Low-carbon Energy System*". This was a multiple-chapter study, where "Chapters 1 and 4 reflect the findings of both the IEA and IRENA Secretariats", while "Chapter 2 reflects the IEA's findings only, and Chapter 3 reflects IRENA's findings only".[11] Although they emphasized that they share basic predictions, for example, projecting similar total energy demand, it became apparent that IRENA's projection and scenario in the third chapter relied more on carbon reduction from renewable energy compared to those given by the IEA in the second chapter. These projections are not trivial since they influence the estimated cost of renewable technology and, consequently, the investment decisions on renewable energy by governments and private actors. Most notably, the overestimated costs of solar PV by influential institutions like the IEA may have resulted in its under-investment by public sectors (Carrington and Stephenson 2018).

While reports like above reveal some differences between the projection given by the IEA and IRENA, the question is whether and how the creation of IRENA influenced the IEA's role as an information provider. Interviews with the (former) IEA officials, both by myself[12] and Downie (2020), imply that the IEA was in fact challenged by a series of criticisms and the establishment of IRENA. Given these challenges, they suggest that the IEA (a) opened its door to non-OECD countries as non-member association countries (e.g. China and India) and (b) expanded its issue area focus to climate change and renewable energy. Urpelainen and Graaf (2015) also argues that IEA's increased attention to renewable energy could be the effect of the shadow of IRENA, although it is difficult to differentiate this effect from an alternative explanation that attention to renewable energy would have risen over time even in the absence of IRENA. In this paper, I theorize not only IEA's expanded attention to renewables but also where they differed from IRENA, and empirically test the effect of IRENA's entry by leveraging the publication of other institutions in the energy field, which could be considered as the control group for IEA.

[11] IRENA, 2017. (`https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Mar/Perspectives_for_the_Energy_Transition_2017.pdf`)

[12] Interview A: former Senior Energy Analyst at IEA, conducted in September, 2020.

3 Effect of Overlapping Institutions on Information

I argue that whether a new IO's entry helps or hinders truthful information revelation by an incumbent IO depends on the verifiability of information. Verifiability of information can be defined as the probability that the publisher can be caught in telling false information. Information is more verifiable if it is about facts or about the past, such as the historical mix of electricity usage. Information is less verifiable, on the other hand, when it is about projections or advice for the future, such as future scenarios of energy mix or policy recommendations.

The theory relies on a key assumption about IO's incentive: IOs are concerned with both (a) their public reputation for providing correct information and (b) the credit they get from their principal states (i.e. major funders) for providing information that aligns with their government's preference. In fact, former IEA staffs told in interviews that the IEA cares about its publicity — the IEA and its Executive Director care about how well the World Energy Outlook sells, who uses their analyses, and how they get used.[13] Measures like website access and download counts of their publications are internally used as important indices to assess their impact.

Under this trade-off between achieving (a) and (b), I argue that the presence of an additional IO makes the existing IO weakly more likely to reveal verifiable type of information. Analogous to a persuasion game with reputation cost, in which decision-makers (policymakers) consult biased experts (IOs) (Bourjade and Jullien 2011, etc.), IOs are more likely to publish their information when there are multiple IOs compared to the case where only one IO exists. However, when the information is unverifiable or only verifiable by a slight chance, IOs have incentives not to report the information truthfully. Analogous to the credit rating agency game (Camanho et al. 2009; Bolton et al. 2012; Mariano 2012; Bae et al. 2017), an IO under the presence of overlapping IOs has incentives to ignore the received signal as they compete for the credit they get from domestic government or experts who can shop for IO reports that make median voter/congress choose a certain policy. I describe the mechanism and derived hypotheses from the theory below.

[13] Interview A; Interview B: former Senior Energy Analyst at IEA, conducted in May, 2021

3.1 Verifiable Information: Quantity of Information

Consider the case where an IO, an expert on the topic, is concerned about its reputation as a competitive information provider, but also has its own policy bias to align themselves with main contributor's preference. The median voter makes a policy decision (e.g. the final vote on a bill by the U.S. congress) based on the received report from IOs. For verifiable type of information, IOs do not have incentive to tell false information since it would be detrimental to their reputation. Instead, IO who is biased toward the status quo face both an incentive to *conceal* the information and make the median voter choose the status quo, as well as an incentive to *disclose* it and be regarded as a competent type (for the sake of reputation cost). Whereas the expert in the canonical model of reputation by Morris (2001) is concerned about the reputation cost for being regarded as a biased agent, I assume IO to be an expert who cares about the reputation cost for not providing the correct information as in Bourjade and Jullien (2011)'s model. While reputational concerns in the former case create an incentive for an unbiased expert to lie so as to avoid being regarded as a biased type, those in the latter case motivate a biased expert to report truthfully. Experts are hesitant to hide information because they worry about losing their reputation as being the competent type who receives the correct signal.

How does an incumbent IO's strategy change when a new IO emerges, compared to the case where only the incumbent IO exists to provide information? If the bias is different between IOs (but still similar against the status quo), both IOs are more likely to report a received signal than the counterfactual case where only single IO exists. This is because the benefit of not providing the information decreases as the other IO might reveal it anyway, and the relative weight of the reputation cost becomes higher. For example, the IEA may want to start revealing more about renewable energy if IRENA starts publishing about renewables. When an IO decides on whether or not to reveal verifiable types of information, the presence of overlapping IOs may help increase the likelihood of its information provision. Empirically, this applies to a situation where IOs choose whether to discuss a certain topic or not. It is not about which exact values to report (e.g. choosing between 10% or 15% as the estimated value), but whether to spare attention to that topic and reveal some information that is

likely to be provided by the competing IO. This leads to the following hypothesis.

Hypothesis 1. *For verifiable types of information, entry of a new IO makes the incumbent IO more likely to provide the information that the new entrant IO provides.*

I empirically test this using the case of IEA's agenda upon the creation of IRENA. I look at the change in the quantity of information about renewable energy provided by the IEA following the competitor IO's entry (i.e. the establishment of IRENA). I compare this change to the contemporary changes in the published content from other energy organizations, which share overlapping mandate to publish energy information but are not under direct competition with IRENA. This alleviates the concern that the changes in IEA's published information was driven by confounders such as international oil demand, trends in renewable energy market, or public pressure to address climate change.

3.2 Unverifiable Information: Quality of Information

Next, suppose each IO receives partially verifiable signal and chooses either to incorporate that signal in the information they publish. The lack of verifiability could be leveraged by IOs, as they now have an incentive to tell information that aligns with their policy bias while pretending to be a competent type who receives the correct signal. For example, some IOs annually publish certain projection figures, but they may publish a figure that contradicts the information they obtained without being caught as providing false information.

When there are multiple IOs, states can select from multiple reports to fund and refer to. Under each IO's incentive to maintain reputation as an expert and to meet the preferences of funders, the weight of the latter increases under competition. Analogous to credit rating agency (CRA) models, the entry of a competitor IO makes the incumbent IO less likely to incorporate the signal and instead pretend to be the competent type when information is less verifiable. This theory on verifiability and information provision aligns with the empirical finding of Dreher et al. (2008b), which argues that IMF forecasts in the long term are more prone to discretionary forecasting than the forecast in the short time horizon. While Dreher et al. (2008b) addresses the case of one dominant IO (IMF), I consider the case where

competition among IOs exist.

Empirically, this suggests that when information is less verifiable, such as projections on further future or advice on uncertain issues, the presence of competing IOs makes it more likely for the incumbent IO to ignore a new signal and report information that aligns with their policy preferences.

Hypothesis 2. *For unverifiable types of information, the incumbent IO's information becomes more biased toward its preferred policy upon the entry of a new IO.*

To examine such cases of less verifiable information, I look at future energy projections and policy recommendations published by overlapping energy institutions. The idea is to compare IEA's future projections and recommended policy tools with those from institutions that are not directly competing with IRENA and examine how the IEA's information differed from other similar organizations after IRENA's entry.

Note that the current theory does not treat the entry of new IO as endogenous. In reality, the entry is likely endogenous. The dissatisfaction with existing IOs, interacting with the competitive environment, influences how an existing IO adapts and whether new IOs enter (Lipscy 2015). In fact, the case of IRENA illustrates how the status quo information environment (dominance of IEA) caused the entry of a new IO (IRENA). Yet the focus of this paper is the effect of regime complexity on information provision by the existing IOs, given that a new IO entered. This focus on the effect of regime complexity is compatible with many studies in the literature. In the empirical section, I focus on the behavior of existing IOs, instead of that of the new ones. This alleviates empirical concerns for endogeneity, as I am primarily interested in what happens to the incumbent *after* the entry of new IO.

3.3 Domestic Demand for IO's Information

Furthermore, I empirically examine one of the key assumptions behind the theory on IO's utility. The theory assumes that IOs want to cater to the demands of their top financial contributors to a certain extent, and that this incentive increases when there is a competing IO. While it is not straightforward to empirically identify top contributors' interest

regarding IO's published information, this demand could be indirectly probed through how the domestic governments are using IO's published information. If influential contributors, most notably the U.S. government in IEA's case, keep citing information that aligns with their preferred policy (i.e. conventional energy) or even increasingly so compared to other institution's publications, it should send a signal to the incumbent IO that there is high demand for their information on that issue. This leads to the following hypothesis regarding the major contributor government's demand.

Hypothesis 3. *After the entry of a new IO, the main supporting government of the incumbent IO is more likely to use the incumbent IO's information on those particularly aligned to their preference than those that are now also provided by the new IO.*

I examine this in the context of the U.S. government, which has been the IEA's top financial contributor (Appendix Table 3, Figure 6). Given the U.S. government's initial opposition against IRENA, the hypothesis above predicts that the U.S. government cites IEA's information more for those on conventional energy than those on renewables. I test whether the context in which the IEA's information is used among the U.S. domestic government changes over time, before and after the entry of IRENA. While the overall distribution of agenda in IEA's publication shifted toward renewable energy (as in Hypothesis 1), a finding that the U.S. government cited IEA's information more in the context of conventional energy would imply a strong signal that the U.S. government's demand for IEA's information is centered on those on conventional energy.

4 Data and Empirical Strategy

To evaluate Hypothesis 1 and 2, I use data collected from energy outlook publications and other policy reports published across multiple institutions for each available year (Table 1). I consider IEA's publications, such as its annual *"World Energy Outlook,"* as the cases treated with competition after the entry of IRENA, whose major function is to provide information to facilitate policy discussion. Energy outlook publications are also published by other intergovernmental organizations, such as *"Energy Outlook for Asia and the Pacific"* by the

Asian Development Bank or *"World Oil Outlook"* by OPEC.[14] In contrast to IEA, however, these IOs are unlikely under direct pressure to compete with IRENA. Although their energy reports overlap with those of IRENA in terms of giving projections and policy suggestions, their main mandate is not providing information on energy issues. In addition to intergovernmental organizations, some individual states provide international projections, such as the US Energy Information Administration (EIA)'s annual publication of *"International Energy Outlook"*. There are similar publications by private actors as well, such as business firms (e.g. Shell,[15] ExxonMobil,[16] Bloomberg[17]), non-governmental organizations (NGOs, e.g. World Wildlife Fund, Greenpeace), and think tanks (e.g. World Energy Council). These individual states and private actors, although some of them share the main mandate of providing information on energy governance, are unlikely competing with IRENA either. They differ from IRENA or IEA in terms of their main source of financial contribution and toward whom they hold accountability.

For Hypothesis 1 (verifiable information), I scanned these publications with OCR and obtained text data to examine the change in topics that were discussed in these major energy report publications over time. I employ keyword assisted topic model (`keyATM`) by Eshima et al. (2020) to estimate the topic proportion of each publication. This method allows us to label topics over certain set of keywords before fitting the model. The energy issue topics and keywords for each are constructed from the labels and terms that appear in IEA's "*Energy Technology RD&D Budget Database*". This provides key terms for each type of energy source. I manually collapsed a few similar topics and deleted keywords that appear in more than five categories (e.g. "technology"), resulting in twelve topics. The pre-labeled topics and keywords can be found in Appendix Table 4. To account for each organization's unobserved characteristics, I use covariate model of `keyATM` and incorporate publisher organization (e.g. IEA, EIA, etc.) as a covariate. Using the estimated topic proportion of renewable energy topics, I examine whether IEA's agenda on current energy

[14] Although the main focus of "World Oil Outlook" by OPEC is oil-related issues, it provides overall energy information including those on renewables.

[15] *Shell Scenarios.* (`https://www.shell.com/energy-and-innovation/the-energy-future/scenarios/new-lenses-on-the-future/earlier-scenarios.html`)

[16] *Outlook for Energy.* (`https://corporate.exxonmobil.com/Energy-and-innovation/Outlook-for-Energy`)

[17] *New Energy Outlook.* (`https://about.bnef.com/new-energy-outlook/`)

issues shifted more toward renewables after the entry of IRENA around 2010, compared to changes in topic proprotion observed in other organizations that were unlikely under competition with IRENA.

For Hypothesis 2 (unverifiable information), I use the values of projected energy usage for 2030 documented in each scenario from energy outlook publications available between 2007 and 2017.[18] These long-term energy projections are difficult to verify for anyone in the foreseeable future. Although researchers at the IEA may care whether they got the numbers right thirty years after the publication (Kurozumi 2015), these scenarios mostly serve as policy guidance toward the future rather than as predictions. In fact, the IEA often emphasizes that "the World Energy Outlook does not forecast what will happen, but it explores different possible futures."[19] The IEA is hence sometimes criticized as presenting numbers too optimistic in favor of conventional energy and downplaying the future for renewables,[20] while others criticize IEA's recently increasing engagement with renewable energy issues as an overstretch, "becoming too much like IRENA."[21] Based on each value manually extracted from each publication, I specifically calculate the predicted renewable energy share (in percentage)[22] to compare how the projection for 2030 changed between 2007 and 2017 across each scenario, before and after IRENA's entry. In addition to assuring comparability across institutions, renewable energy share fits the purpose of this analysis since it is a substantively important figure for energy organizations that are often mentioned in media reports or cited in subsequent policy reports by energy organizations. To estimate the effect of IRENA's entry on IEA's scenarios, I use synthetic difference in differences (SDID) estimator (Arkhangelsky et al. 2021) and construct synthetic controls for IEA's projections from organizations not directly competing with IRENA (Table 1).

To test Hypothesis 3 (domestic mechanism), I use text data of documents published

[18] The year range used is based on availability of IEA's projections specifically for 2030.

[19] International Energy Agency. Dec. 4th, 2019. *"Introducing the Sustainable Development Scenario"* (`https://www.iea.org/events/introducing-the-sustainable-development-scenario`)

[20] "IEA accused of undermining global shift from fossil fuels" *The Guardian*. April 5th, 2018. (`https://www.theguardian.com/environment/2018/apr/05/iea-accused-of-undermining-global-shift-from-fossil-fuels`)

[21] Arima, Jun. 2020. "IEA Should Deliver Messages Reflecting Energy Realities" *International Environment and Economy Institute.* (`http://ieei.or.jp/wp-content/uploads/2020/05/IEA-Should-Deliver-Messages-Reflecting-Energy-Realities.pdf`)

[22] Calculated as of renewable energy Total Primary Energy Demand (TPED).

Institution	Type	Frequency	Years of Publication
Treatment (IRENA) and Treated (IEA)			
IRENA	IGO	Irregular	2010-18
IEA	IGO	Annual	2000-2004, 05-11, 12-18
Control group			
OPEC	IGO	Annual	2007-2017
World Energy Council	INGO	Irregular	2007, 13, 17, 19
EIA (USA)	Domestic	Annual	1985-2018
IEEJ (Japan)	Domestic	Irregular/Annual	2006, 2014-2019
EU	Regional	Irregular	2003, 05, 07, 09, 13, 16
Shell	Firm	Every 3 years	2001-2016
Equinor	Firm	Annual	2011-2018
Exxon Mobil	Firm	Annual	2005-2018
British Petrolium	Firm	Annual	2011-2018
Bloomberg	Firm	Annual	2015-2018

Table 1: **List of Energy Outlook Publications**. Each publishing organization has regular publication series that discuss the projected energy mix and energy policy both at the global and regional level. The ones in bold text are incorporated in the empirical analyses presented in the main text.

by the U.S. government and examine how information from the IEA is cited. As noted earlier, interviews with former IEA staffs suggest that the IEA cares about their publicity and measures the impact of their publications based on the amount of their usage and the actors using them. I therefore expect that how the U.S. government actors are using the IEA's information affects the subsequent works and agenda of the IEA. I use the set of U.S. governmental documents collected by `VoxGov` between 2003 and 2020. This includes texts from official statements and SNS, including press releases, speeches, statements, and blogs from Senate/House legislators, Senate/House floor and committee (e.g. Senate Committee on Finance), departments and agencies (e.g. U.S. Department of Energy), President and the President's Executive Office.[23] Among these, there are 2,642 documents that refer to the IEA and 195 that refer to IRENA. To focus on the context in which IEA is cited, I extract 100 words[24] before and after the term "IEA" or "International Energy Agency" appears in each document and estimate the topic proportion with the structural topic model (Roberts et al. 2014) to test whether the context in which IEA is cited by the U.S. government changed

[23] See Graewingholt (2020) for further discussion on the quality of the data.

[24] This threshold is manually selected for substantive interpretation based on a reading of randomized sample of texts.

Source for Press Releases, etc.	Renewables	IEA	IRENA
Departments and Related Agencies	22453	632	44
House	8915	75	4
Senate	7307	127	0
Independent Agencies and Gov. Corporations	3460	105	12
House Committees	1175	47	2
Senate Committees	895	77	1
President	439	29	8
Senate Leadership	321	1	0
House Leadership	285	5	0
Executive Office of the President	240	10	0

Table 2: **Number of U.S. governmental documents containing each relevant keyword (renewables, IEA, and IRENA), by source of the document.** The set of documents consist of those collected by `VoxGov` between 2003 and 2020.

before and after the entry of IRENA. One concern for this approach is that a referral to IEA does not necessarily indicate that the document is citing IEA's information, let alone whether they are expressing agreement or disagreement with the information. By reading one hundred sample of randomly drawn documents, 52% were citing information of IEA in order to make the document author's point, 38% were on discussion or reference to IEA as an international organization (e.g. report of conferences where IEA was in the list of participants), and 10% were on regular discussion of U.S. and foreign oil reserves determined by IEA. The majority of the cases were citations of IEA's information, and none of these cases were citing to express disagreement or question the information. For example, Figure 3 displays an excerpt from a document with a high topic proportion in "Oil/Gas." As in this case, the IEA's projections over the U.S. fossil fuel sector, such as future LNG export or oil production, are often used in speeches advocating for investments or regulations benefiting the fossil fuel industry. To test Hypothesis 3, I use a binary treatment indicator of IRENA's existence (i.e. dummy variable indicating years after 2010) as the key independent variable in the covariate when estimating the topic model, along with other covariates consisting of the document source (congress, committee, press releases, etc.) and year of publication.

Timing and Endogeneity of IRENA's Entry. While I use 2010 as the year IRENA emerges, the timing of its entry is a matter of discussion. Although an idea of IRENA was brought up at Bonn International Renewable Energy Conference in 2004, its first prepara-

tory conference only began in 2008. In 2009, the IRENA Statute was signed, which took effect in 2010. However, its preparatory conference continued into 2011, when the first policy report was published. To account for the uncertainty that existed prior to 2010 in how much financial support IRENA gets from each member and where its headquarter is located, I here employ 2010 as the year IRENA actually came into effect. In addition, as noted in the previous section, IRENA's entry itself is not exogenous to some domestic government's preferences or other international factors that affect IEA's publications. This concern is alleviated by comparing information published by IEA with those published by other institutions that were also likely susceptible to these confounding factors.

5 Empirical Findings

5.1 IEA's Information

5.1.1 Verifiable Information: Agenda in Energy Outlook

First, I look at the content of energy outlook publications for available years (Table 1) and examine how the agenda of IEA's general energy reports changed after the entry of IRENA in 2010, compared to the change in reports by other institutions that are not likely under direct competition with IRENA over their functions or funding (H1). Figure 1 plots the topic proportion for each annual energy outlook by the IEA and the U.S. Energy Information Administration (EIA, a U.S. agency), on solar and wind energy topic (left panel) as well as oil, coal and gas topic (right panel) estimated with keyword assisted topic model (`keyATM`). It shows that the energy outlook publication by the IEA, "*World Energy Outlook*"(WEO), experienced a significant increase in the proportion of solar and wind energy topic around 2008-10, when IRENA's first preparatory conference started (2008), the Statute was signed by its original members (2009) and took effect (2010), compared to its U.S. domestic counterpart, "*International Energy Outlook*"(IEO) published by EIA. While this trend is generally noticeable in topics on renewables (besides biofuels), the clearest effect is seen in the solar

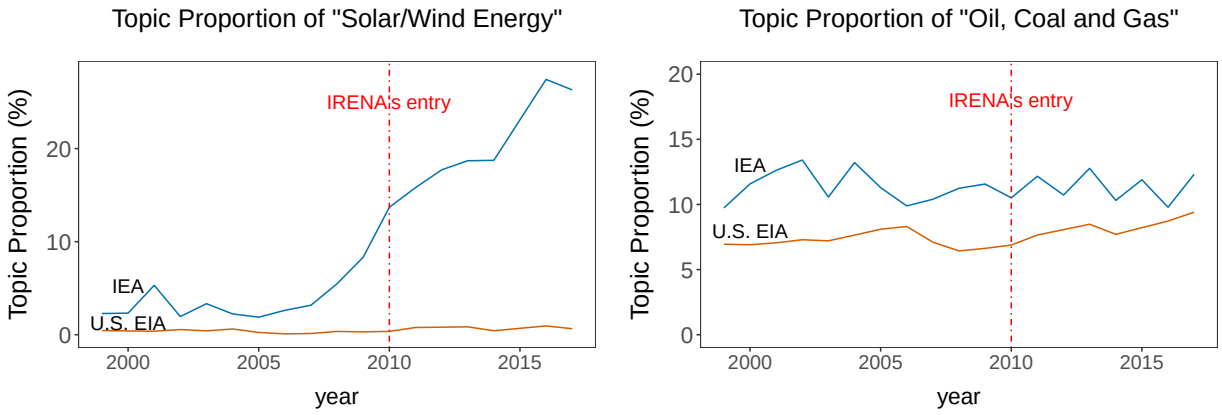

Figure 1: **Topic Proportion of World Energy Outlook (by IEA) and International Energy Outlook (by U.S. EIA), for "Solar/Wind Energy" Topic (left) and "Oil, Coal and Gas" Topic (right):** The left panel shows that IEA's topic proportion in its World Energy Outlook increased around 2010 (when IRENA was established) while those of EIA's topic in International Energy Outlook remained low. As a comparison, the right panel shows that for topic on oil, coal and gas, both IEA and EIA had similar trends in topic proportion both before and after 2010.

photovoltaics, and this matches the topic heavily covered in IRENA's working papers.[25]

EIA's publication as a control alleviates the concern for a confounding effect of general policy attention, in which both the creation of IRENA and the shift in IEA's policy changes are driven by overall shift in policy attention toward green growth and renewable energy in multiple countries[26] for many reasons (e.g. cut in oil export, recession, etc.) (Meckling and Allan 2020). While Overland and Reischl (2018) addresses the difficulty in claiming the effect of IRENA on IEA's increasing focus on renewables, this design supports Urpelainen and Graaf (2015)'s argument by comparing IEA's information to those of domestic agents (e.g. EIA) that were less pressured by the competition with an entry of new IO (e.g. IRENA).

5.1.2 Less Verifiable Information: Energy Projections

Next, to examine the effect of IRENA's entry on the IEA's publication of less verifiable types of information (H2), I look at the long-term energy projections, which is difficult to verify for anyone in the foreseeable future. Figure 2 plots the effect of IRENA's entry in

[25] Comparing the relative topic distribution of all the working papers published by IRENA between 2010-2018 and all the IEA publications on renewables between 2000-2018 (excluding WEO), the most substantive difference in topic distribution within the renewables, between IEA and IRENA, lie in the solar energy topic (Appendix Figure 8). I used keyword-assisted topic model (`keyATM`).

[26] Besides the US, as evidenced by EIA's non-response.

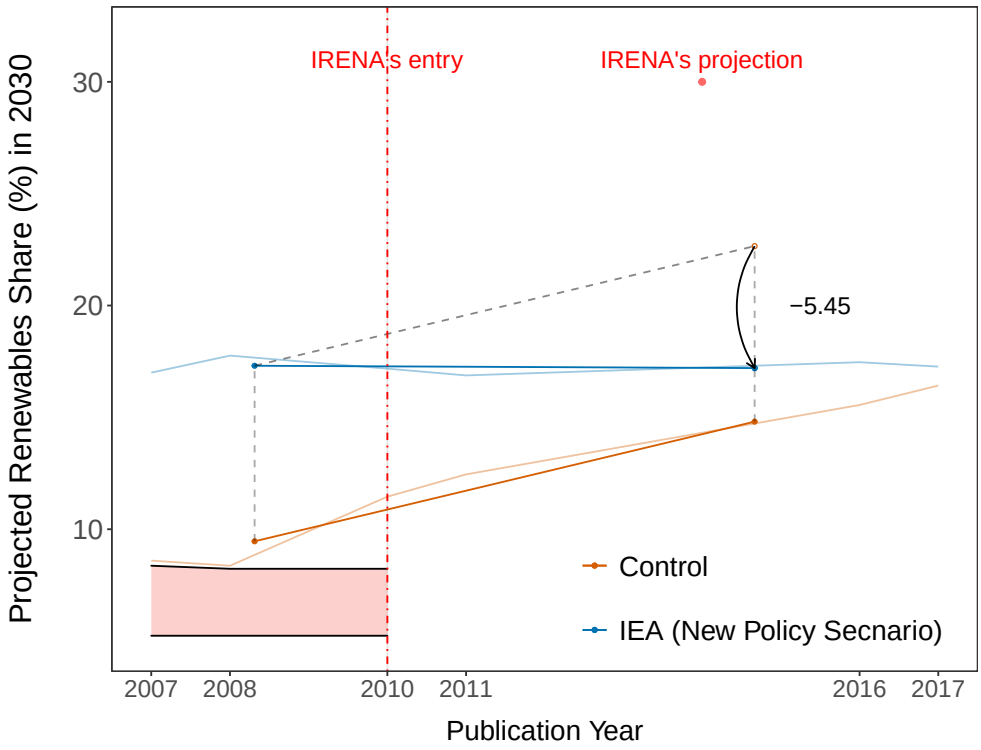

Figure 2: **Estimated Effect of IRENA's Entry on IEA's New Policy Scenario.** Based on the comparison with synthetic control group that consists from weighted average of the projections from the U.S. EIA and OPEC, the estimated effect of IRENA's entry in 2010 on IEA's projection of renewable energy share in 2030 was 5.45 percentage point lower than the counterfactual by 2015.

2010 on IEA's projected value of renewable energy share for 2030,[27] estimated with synthetic difference in differences (`synthdid`). The synthetic control consists of projections for 2030 made in scenario series provided by OPEC and U.S. EIA from mid-2000s to 2010. These are both institutions traditionally focused on fossil fuels, which I expect to be less likely to adjust their renewable share projections upward compared to pro-renewable organizationsm, and in particular not in response to the entry of IRENA. However, these organizations were shifting their estimates upward, which is not surprising given that the renewable energy sector was growing rapidly over this period. Compared to the counterfactual projection for the IEA constructed from scenarios by these instituions, IEA's renewable share projection for 2030 was 5.45 percentage point lower than the counterfactual by 2015. In fact, while the

[27] The share among the world's total primary energy demand, projected in IEA's New Policy Scenario between 2007 and 2017.

non-IEA scenarios (including those made by oil companies like Statoil[28]) were adjusting the renewable share estimates upward, all of IEA's scenarios (Current Policy,[29] New Policy,[30] and 450 Scenario[31]) kept their projections almost constant across these years (Appendix Figure 7). One caveat is that the IEA had higher estimates to begin with in the mid-2000s compared to these oil-focused organizations in the control group. However, by 2015, the predicted renewable energy share by all IEA scenarios was surpassed by Statoil's estimates (Appendix Figure 7). Even the reference scenarios by the EIA and OPEC, which used to be much more conservative in the renewable estimates in the 2000s, almost reached the projection by IEA's reference scenario (Current Policy Scenario) by 2010 and even surpassed it after 2015. These findings, together with those in the section above, imply that while the IEA quantitatively increased the amount of information provision on renewables, its stance on the renewable energy potential qualitatively became relatively conservative compared to other energy institutions that were not directly competing with IRENA.

5.2 Domestic Mechanism: U.S. government's demand

To investigate the domestic mechanism behind the model (H3), I look at whether and how the way influential member states use the information published by the IEA changed after the entry of IRENA. I examine the case of the U.S. government, which is the IEA's top financial contributor. Figure 4 shows the topic proportion estimated with structural topic model (`STM`) across all the documents in this dataset, using 100 words before and after each occurrence of "IEA" or "International Energy Agency".[32] The number of topics is set to seven for substantive interpretability and the labels are assigned by the author.[33]

Figure 5 shows how the topic proportion has changed before and after the establishment of IRENA in 2010. Controlling for a set of confounders (year, year squared, party of the

[28] Statoil was a private oil company based in Norway. The company name changed to Equinor ASA in 2018.
[29] The scenario that assumes that only the policies currently in effect will be in place in the future.
[30] The scenario that assumes that only the policies that are either currently in effect or currently already announced to be implemented will be in place in the future.
[31] The scenario that assumes new policies will be announced and implemented in the future.
[32] Since some documents, such as Congressional floor speeches, are long and consist of multiple issues, I use this threshold to focus on the context in which the IEA's information was referred to.
[33] The covariates included for the estimation are fixed effects for year and document source.

Exports are producing good paying jobs and investments at home and environmental benefits abroad," said Center for LNG Executive Director Charlie Riedl. "We commend EXIM for hosting today's discussion and look forward to working others to ensure clean, affordable, and reliable US natural gas is available to the global market." "I congratulate and thank Chairman Reed for her leadership in focusing EXIM on increasing US natural gas exports, an incredibly important emerging issue that benefits our economy as well as our geopolitical interests," said Christopher Guith, Acting President of the Global Energy Institute at the US Chamber of Commerce. **The International Energy Agency forecasts that the US will account for one-third of global natural gas production and two-thirds of anticipated LNG export growth by 2025.** Under President Trump, the United States has become a net natural gas exporter for the first time since 1957. About EXIM bank: EXIM is an independent federal agency that promotes and supports american jobs by providing competitive and necessary export credit to overseas purchasers of US goods and services. A robust EXIM can level the global playing field for US exporters when they compete against foreign companies that receive support from their governments. EXIM also contributes to US..." (*Export-Import Bank of the United States, 2019*)

Figure 3: **Example text of the US governmental documents citing the IEA.** "Chairman Reed and Liquefied Natural Gas Industry Discuss How Ex-Im Can Assist U.S. LNG Exporting", Press Release from the Export-Import Bank of the United States (Ex-Im Bank). Aug.22, 2019 (`https://www.exim.gov/news/chairman-reed-and-liquefied-natural-gas-industry-discuss-how-exim-can-assist-lng-exporting`)

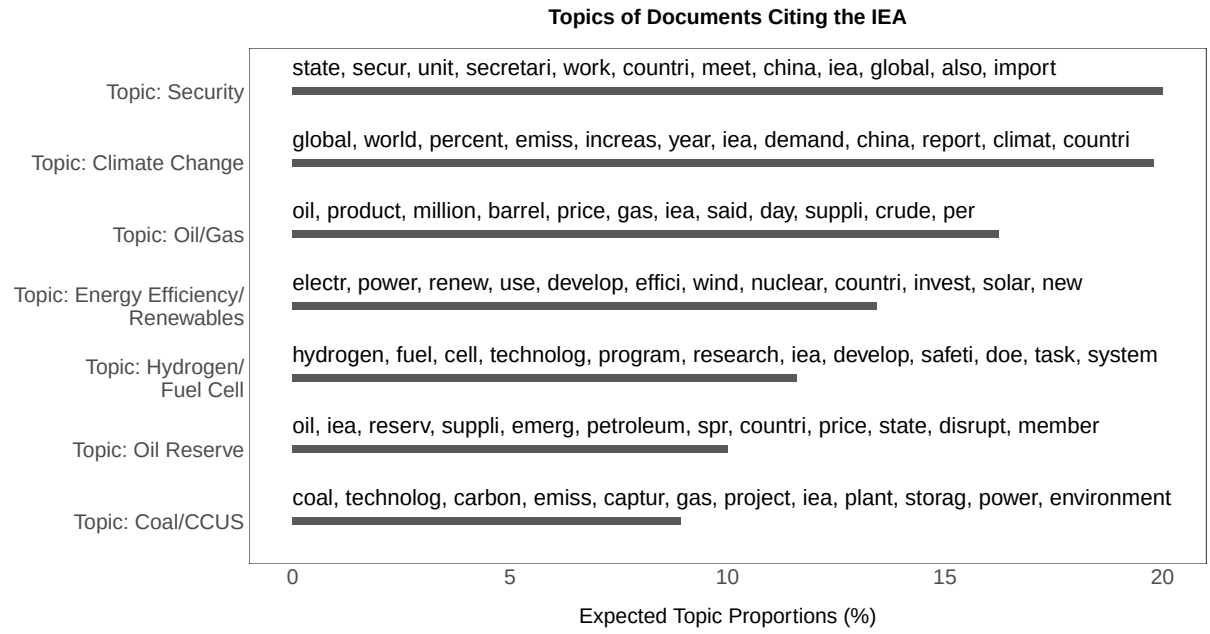

Figure 4: **Expected topic proportion of US Congressional/Executive Documents citing the IEA, 2003-2020.** The x-axis shows, for each of the topics listed on the y-axis, the expected topic proportion of each U.S. governmental document containing the keyword "International Energy Agency", extracting 100 words before and after all occurrences of "IEA" or "International Energy Agency". Topic proportions are estimated using `STM` package. The number of topics is set to $K = 7$ for best interpretability. Each topic is labeled by the author.

President, source and content type of the document), topics such as oil/gas, oil reserve, and hydrogen/fuel cell appear more when citing the IEA in or after 2010 than before 2010. For example, the oil/ gas topic increases by about 6 percentage points in U.S. governmental documents citing the IEA in or after 2010 compared to those published before. In contrast, topics such as climate change and coal/CCUS (carbon capture, utilization, and storage) technology decreased for documents citing the IEA since 2010. Coal/CCUS and hydrogen/fuel cell, in particular, are difficult to interpret from these results since they can be referred to both in the context of promoting green sector (e.g. that investments should be made more in reducing carbon emissions, including CCUS) and in promoting fossil fuel/automotive industry (e.g. that investment should go to CCUS technology while keeping fossil fuel investments instead of pivoting to investment in renewables). Yet the results, in general, suggest that the IEA's information regarding fossil fuels was referred to more in the U.S. government since 2010, the year IRENA was established, compared to before. [34]

In addition to this demand from public sector, private sectors also hold interests in information published by these IOs. For example, a lobbying record of ExxonMobil suggests that in 2008, they lobbied on a House of Representatives bill to establish IRENA (most likely against its passage).[35] On the IO's side, the IEA also has an interest in building connections with the private sectors. Although the IEA does not disclose its funding source to the public, they acknowledge that part of its funding comes from the private sector. Moreover, in addition to the Coal Industry Advisory Board, an advisory group consisting of coal-related industrial enterprises that has existed since 1979, the Energy Business Council (EBC) was established in 2009 under the direction of the IEA's Executive Director Fatih Birol.[36] While this council is by invitation only and operates under the Chatham House Rule, the list of

[34] To account for the concern that this time period overlaps with increasing attention by the U.S. government on shale gas and fracking, a preliminary analysis with `keyATM` estimation incorporates this as an independent topic into estimation and find the similar (yet weaker) pattern in the oil and gas topic as well as climate change topic.

[35] H.R.5529 - International Renewable Energy Agency (IRENA) Act of 2008. Based on LobbyView Data (Kim 2018). Although the lobbying record does not reveal whether they supported or opposed the proposed bill, other lobbying records of ExxonMobil suggest that they lobbied against establishing IRENA.

[36] "IEA celebrates the 10th anniversary of the Energy Business Council with its largest gathering ever in Paris" the International Energy Agency, April 2019. (`https://www.iea.org/news/iea-celebrates-the-10th-anniversary-of-the-energy-business-council-with-its-largest-gathering-ever-in-paris`)

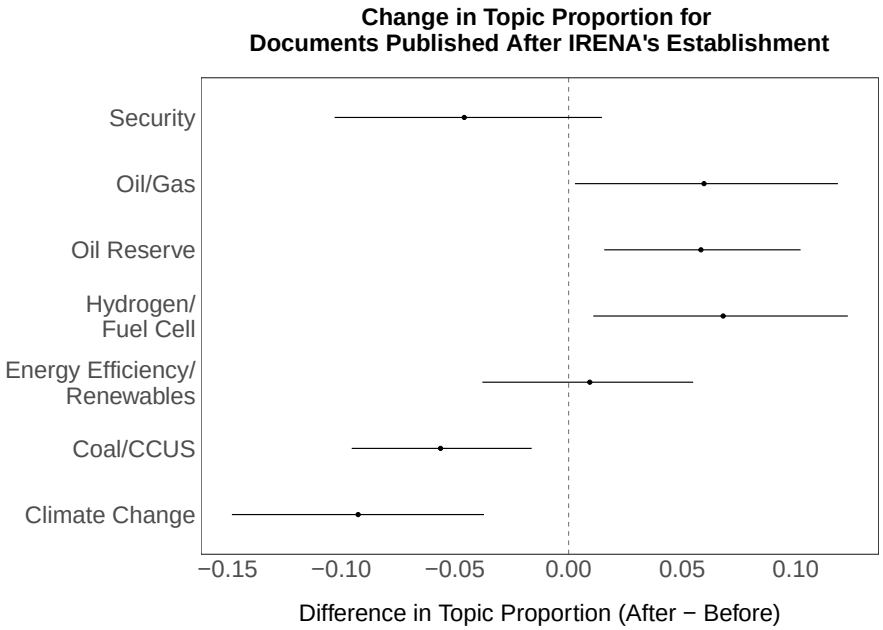

Figure 5: **Effect of Post-IRENA Dummy on Topic Proportion** This plot shows that the information from IEA is mentioned more in the context of topics like oil/gas, oil reserve, and hydrogen/fuel cell and less so for topics like climate change and CCUS after 2009 (when IRENA was established), controlling for other covariates including year, source of the document (Senate, House, legislator press releases, President, departments and related agencies, etc.), and party of the President.

the past participants suggest that they mostly consist of firms in the fossil fuel sectors and heavy industry.[37]

6 Discussion

An increasing number of public and private organizations today are providing information to inform both domestic and international policy-making on the same issue areas, sometimes very similar in content yet at other times with substantive differences across organizations. This paper asks how the quality and quantity of information published by IOs may be affected by an entry of a new overlapping institution. Based on the trade-off IOs face between preserving their reputation as a competent expert and catering to their main funders to secure its authority over competitor, I theorize that upon the entry of a new IO, existing

[37] For example, 30 companies invited to the IEA EBC meeting were either in fossil fuel industries, electricity, heavy industries, or finance. (IEA News, March 16th, 2017. "Expanding ties with the energy industry" (`https://www.iea.org/news/expanding-ties-with-the-energy-industry`))

IOs are weakly more likely to report a verifiable type of information, while they may be motivated to provide more biased information for unverifiable type. To empirically test this, I looked at the information on energy issues, where the IEA, the incumbent IO, faced the entry of IRENA in 2010. This paper makes the following contributions.

First, it contributes to the debate on whether overlapping institutions promote or impede cooperation among states. Instead of asking whether or not they promote cooperation, this paper argues how the same set of IOs both compete to undermine interstate cooperation on one front and deepens cooperation on another depending on the type of information. Along with the recent literature that investigates the conditions under which overlapping institutions fuel cooperation, this highlights the importance to granularly theorize the effect of overlapping institutions based on each type of IO activities.

Second, this paper brings the regime complexity debate to a critical yet understudied function of IOs: providing information to guide policy-making both domestically and internationally. As exemplified by recent discussions on the politics of scientific information in areas such as climate change or the global pandemic, the source of information affects how people perceive the information. Different institutions often provide different information, which ignites political debates. This paper asks how the fact that overlapping institutions exist affects the information that the incumbent IO strategically provide. While IO's role as information providers has been central to the IO literature and discussion of IO's functions, empirical test has been limited partly due to the difficulties in quantifying information provision. This paper addresses this by utilizing texts and collecting figures from IO's publications.

More broadly, this paper speaks to the debate over how IOs operate and what role they play as a consequence. It highlights the trade-off that IOs face between its incentive to maintain reputation as a neutral expert and its incentive to cater to major donors to secure their survival and authority. Consistent with the view that IOs operate under bureaucratic autonomy (Barnett and Finnemore 2004), IOs strategically behave and provide information to maximize their payoffs. Given such an incentive structure, competition among IOs may foster more information provision in some cases but may encourage biased information provision in others. Future research could further analyze the overall social welfare implications

of introducing competitions among IOs.

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7 Appendix

7.1 Empirical supplements

Financial Contributions

	Voluntary		Assessed	
	IEA	IRENA	IEA	IRENA
1	Sweden (27%)	Germany (41%)	US (25%)	US (22%)
2	Denmark (16%)	UAE (39%)	Japan (23%)	Japan (11%)
3	Japan (15%)	Norway (9%)	Germany (10%)	China (9%)
4	Germany (10%)	Belgium (6%)	UK (7%)	Germany (7%)
5	Switzerland (5%)	Japan (3%)	France (7%)	France (6%)

Table 3: **Top five financial contributors for IEA and IRENA in 2017.**

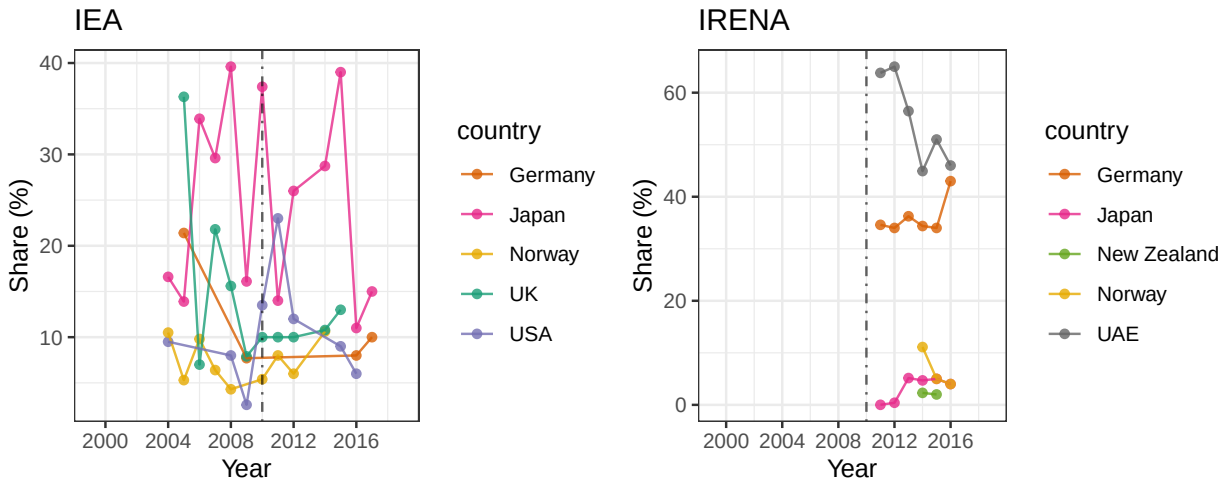

Figure 6: **Share of top voluntary contributors to IEA (left) and IRENA (right) across years.** Only countries that appear in top 5 for more than twice (for IRENA) or three times (for IEA) after 2000 are displayed. Data is collected by the author based on "Report on Financial Contributions to International Organizations", *Ministry of Foreign Affairs of Japan* (`https://www.mofa.go.jp/mofaj/gaiko/oda/shiryo/sonota.html`).

Topic	Keywords
Energy Efficiency	equipment, buildings, appliances, industry, industrial, techniques, processes, design, envelope, operation, efficient, ict, management, lighting, control, heating, cooling, ventilation, operations, batteries, portable, devices, residential, commercial, bldings, transport, on-road, vehicle, batteries, storage, advd, motors, ev, hev, fcv, sys, combustion, engines, electric, infrastructure, materials, off-road, efficiency, waste, recovery, utilisation, communities, agriculture, forestry, pumps, chillers
Oil, coal and gas	fossil, coal, igcc, oil, liquid, gas, refining, transport, storage, non-conventional, combustion, conversion, refinement, iron, steel
CO2 capture and storage	co2, carbon, capture, utilisation, storage, separation, transport, emission, ccus, pipeline, underground, geological, ship, removal
Solar and Wind	solar, heating, cooling, photovoltaics, thermal, high-temprature, pv, sunlight, module, modular, csp, ste, concentrating, sun, sundown, wind, onshore, technologies, offshore, techs, speed, speeds, turbine, turbines, hub, rotor, diameter, sea, land, shore
Biofuels (including liquids, solids and biogases)	biofuels, biomass, liquids, solids, biogases, liquid, gasoline, ethanol, diesel, kerosene, jet, algal, solid, thermochemical, biochemical, anaerobic, digestion, heating, bioenergy
Geothermal, ocean	geothermal, hydrothermal, hot, dry, rock, drilling, exploration, aquifer, pool, ocean, tidal, wave, salinity, gradient
Hydroelectricity	hydroelectricity, hydropower, pump, pumped, river, run, flow, pondage, reservoir, water, flood, irrigation, turbine
Other renewable energy sources	renewable, sources
Nuclear fission and fusion	nuclear, fission, fusion, magnetic, confinement, inertial, light, water, reactors, lwrs, converter, heavy, hwrs, cycle, fissile, material, recycling, reprocessing, waste, plant, safety, integrity, protection, decommissioning, breeder
Hydrogen and fuel cells	hydrogen, infrastructure, cells, stationary, mobile, chemical, electrolyser
Electric power conversion, transmission, distribution and storage	electric, conversion, generation, technologies, electricity, transmission, distribution, technologies, cables, conductors, ac, dc, power, techs, smart, grid, control, integration, load, management, monitoring, standards, interoper, cyber, security, storage, electrical, batteries, electrochemical, electromagnetic, mechanical, storage
Other basic energy research	research, development

Table 4: **Keywords used in keyword assisted topic model.**

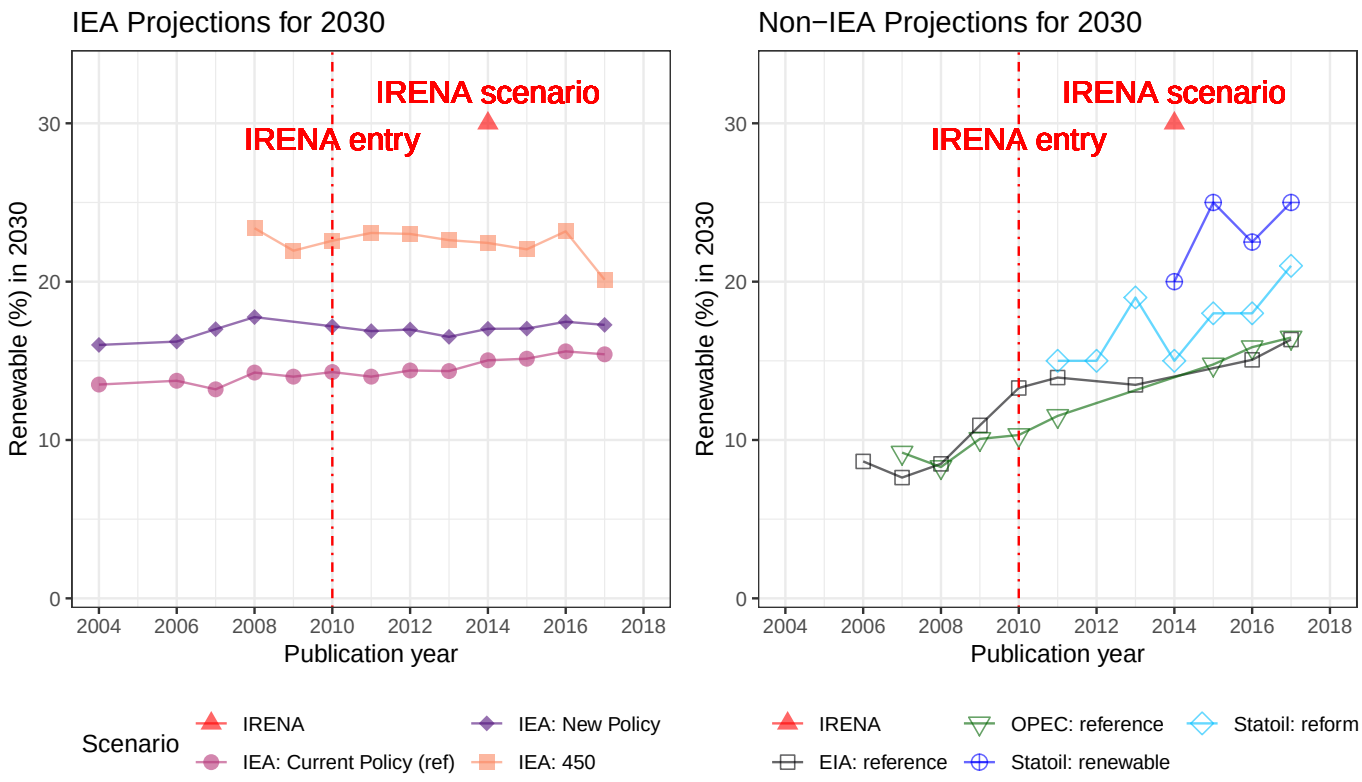

Figure 7: **Predicted share of renewables energy in 2030, by IEA (left) and other organizations (right)**: Each point shows estimated renewable energy share (x-axis) for each energy outlook scenario published in each year (y-axis). IEA's projection for the share of renewable energy consumption in 2030 did not change much from the mid-2000s to the late 2010s in any of the scenarios (Current Policy, New Policy, and 450 Scenario), while other institutions such as OPEC, US EIA, and Statoil (private company) were adjusting their scenarios upward throughout this period.

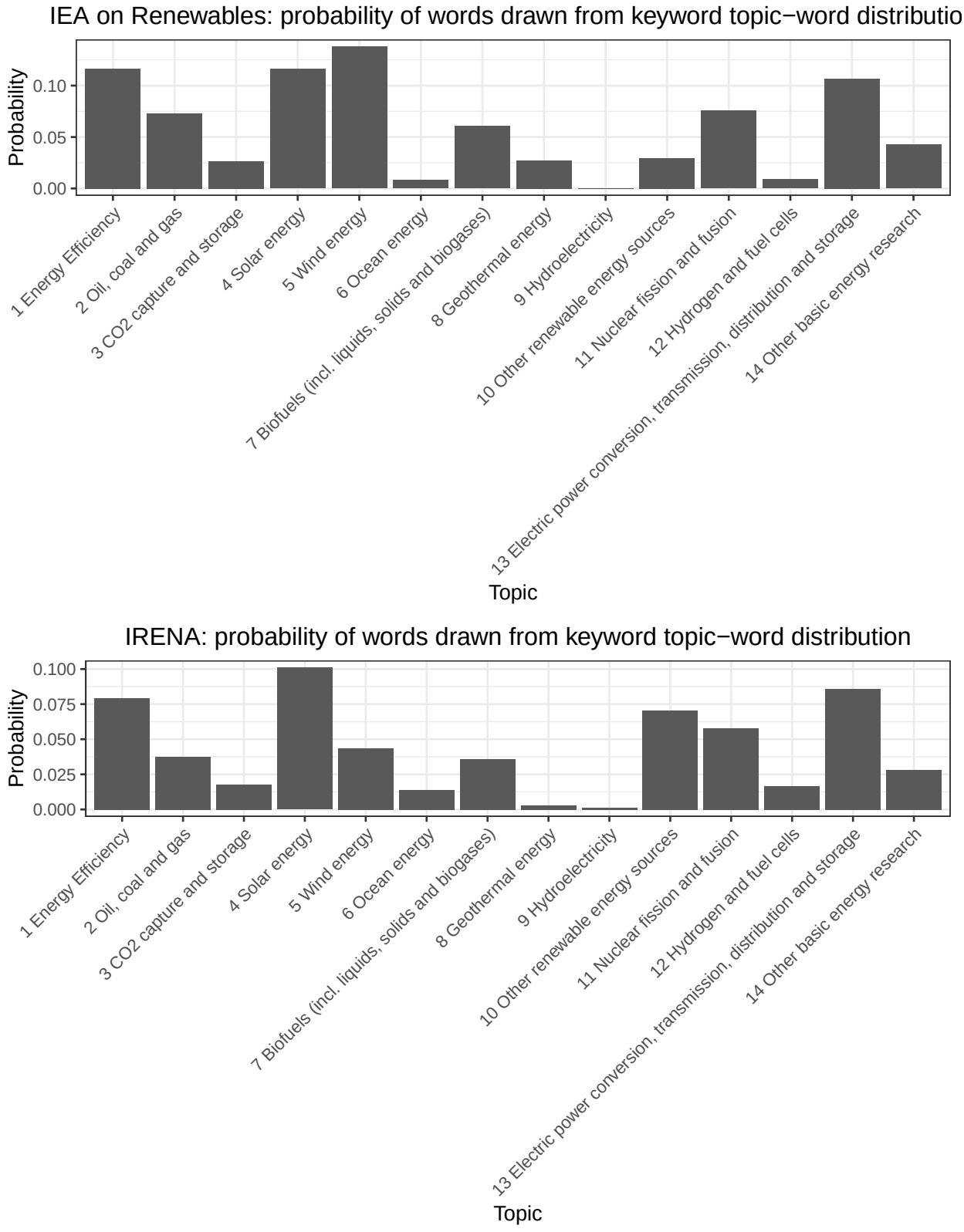

Figure 8: **Topic distribution of IEA's publications on renewables (top) and IRENA (bottom) based on keyword-assisted topic model.** Keywords for each category are constructed based on the labels and terms that appear in IEA's "Energy Technology RD&D Budget Database". Probabilities are estimated using `keyATM` (Eshima et al. 2020).