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Information exchange under uncertainty: The case of unconventional gas development in the United Kingdom

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ABSTRACT

New techniques of unconventional oil and gas extraction, such as hydraulic fracturing, challenge current political, institutional and administrative practices in how to regulate activities in the underground. Conflicts of interests between economic promotion, landscape and natural resource protection, and new trends on energy markets are further intensified by the fact that techniques of oil and gas extraction come with a considerable amount of uncertainties regarding ecological and health impacts. Information exchange is one important aspect of how political actors try to reduce uncertainties and conflicts. Based on exponential random graph models (ERGM) for network data, we analyze to what degree ideologies, public authority, existing collaboration and scientific expertise drive information exchange in hydraulic fracturing regulation in the United Kingdom. Results show that technical and political information exchange have to be disentangled, and that the former is driven by expertise and existing collaboration, the latter by ideology, public authority and existing collaboration.

1. Introduction

Public policymaking in the field of environmental politics and land use management is increasingly complex, and scientific expertise is often needed to tackle modern policy problems (Lubell, 2013). This is particularly true when new techniques such as hydraulic fracturing for unconventional gas exploitation are discussed and applied, as they challenge current land use practices, environmental protection, property rights distribution and policy regulation about activities in the underground (e.g., Centner and Kostandini, 2015). In such a context, political actors are uncertain about the concrete effects of the new technique (for instance on the environment or human health), about the appropriate policy solution to formulate, and about the reaction and the potentially updated preferences of their peers (Newig et al., 2005). In order to reduce these uncertainties, political actors are expected to choose specific strategies of information exchange, and scientific actors might play an especially important expert role (see also Baird et al., 2016; Papadopoulou et al., 2011).

Besides *technical* information, which involves expert advice about the technology and its potential implications, *political* information is important in helping actors to plan their influence strategies and build coalitions when involved in a policy process. Both technical information on a given problem and political information on strategies of coalition building are important resources for actors seeking to influence a policy process (Heclo, 1978; Leifeld and Schneider, 2012). Furthermore, actors can exchange information for gaining influence over a policy process (Coleman, 1986; Knoke, 1996; Pappi and Henning, 1999; Henning, 2009; Heaney, 2014; Leifeld and Schneider, 2012). Gaining and sharing technical and political information is thus a crucial aspect of actors' strategic behavior in policy processes in general, and even more in the presence of important uncertainties related to potential environmental or health impacts.

Yet, the strategies of information exchange among political actors, and the related differences between scientific and political information, have not been studied extensively. Notable exceptions are Leifeld and Schneider's (2012) study on the domain of toxic chemicals regulations in Germany or the examination of rural development projects by Papadopoulou et al. (2011). More generally, the literature on policy networks suggests that ideological similarity (Sabatier, 1988), social trust (Carpenter et al., 2004), perceived power (Ingold and Fischer, 2014; Fischer and Sciarini, 2016), and functional interdependence (Pfeffer and Salancik, 2003; Leifeld and Schneider, 2012) are important drivers of different types of network relations between actors. In this paper, we rely on various established drivers of network relations and test how they matter for two types of information exchange in the specific setting of land use policy and natural resources management.

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We test our arguments on a policy process related to unconventional gas development. Unconventional gas is extracted using new and controversial technologies of hydraulic fracturing (later: fracking; see Centner and Kostandini, 2015). Fracking allows extracting sizable resources of natural gas from basins that were considered to be difficult or costly to exploit before (IEA, 2012). The successful extraction of unconventional gas can have important consequences for the global energy market and geopolitical world map. However, there are also many environmental risks related to the technology, such as the contamination of surface waters and aquifers, the causation of seismic activity, or the generation of fugitive methane emissions (Stevens, 2010; Jackson et al., 2014). As of today, there is a lack of scientific evidence on the exact economic and environmental impacts of shale gas development (Stevens, 2010; Wagner, 2015). This results in considerable challenges to the promotion or regulation of fracking. The fracking issue therefore represents an ideal case to study information exchange on an issue characterized by scientific uncertainty about its impacts on one side; and uncertainty about how political peers or opponents might react to it on the other (Ingold et al., 2016).

We rely on exponential random graph models (ERGM) for network data to explore which factors account for network relations between actors within the technical and the political information exchange network. New data about the policy process on the regulation of unconventional gas development in the UK between 2007 and 2014 was gathered in the summer of 2014 (Ingold et al., 2016). In the UK, both the energy industry and government identified the high economic potential of unconventional gas development; but environmental risks persist and environmental organizations and the local population oppose fracking sites. Still, the UK is about to develop shale gas in spite of strong public opposition and mobilization (Stevens, 2013).

The remainder of this paper is structured as follows: after discussing the importance of information exchange for political decision-making and for the particular case of policy domains driven by scientific uncertainty and the arrival of a new issue, we deduce several hypotheses from policy process and resource dependence theories. We then briefly present the case, the data and the method. In the next sections, we present and discuss the results from the exponential random graph models. Section six concludes and highlights shortcomings and major findings of this research.

2. Theory

Information exchange among political actors is particularly important in policy domains coming with a high degree of uncertainty about the political problem at stake (Metz and Ingold, 2014) or with conflicts and uncertainties about natural resource use and protection (Berardo, 2014; Coglianese, 1997). For example, uncertainties created by energy shocks have been shown to affect the behavior of actors (Ahrari, 1987; Fischer, 2015; Grossmann, 2012). Uncertainty is defined as actors' limited knowledge about future, past or current events (Walker et al., 2013). In such a situation, actors lack substantive knowledge about a political issue (Newig et al., 2005). They therefore have a harder time defining the seriousness of the problem, recognizing clear policy domain boundaries, anticipating the behavior and beliefs of other actors (Krishnan et al., 2006; Lubell, 2013), "knowing the links or probabilities between actions and consequences" (Weible, 2008), and thus selecting appropriate policy instruments to tackle a problem (Aoki, 2007; Newig et al., 2005; Landry and Varone, 2005). In sum, uncertainty affects political actors' willingness or need to strive for or provide information, as well as their choice regarding which actors they exchange information with.

Information exchange is crucial not only for individual political actors, but also for their joint capacity to successfully address complex policy problems, especially in the domain of environmental policy (Papadopoulou et al., 2011). Schneider et al. (2003) demonstrate the added value of participation in community- and-expertise-based institutions for the resolution of complex problems, while Berardo and Scholz (Berardo, 2014; Berardo and Scholz, 2010 Berardo and Scholz, 2010) underline the importance of bridging and bonding relations between actors, depending on their risk perception. Further, information exchange is an important pre-condition for the establishment of stable network relations and social capital: two important drivers to enhance resilience towards environmental impacts (Ingold et al., 2010).

2.1. Two types of information exchange

Two types of information relations are important when studying a policy domain under uncertainty (Leifeld and Schneider, 2012): on the one hand, actors exchange technical information in order to enhance their scientific knowledge about the problem as such. For example, Phillipson et al. (2016) demonstrate the importance of professional network relations and the diffusion of expert knowledge under complex and changing land management conditions. On the other hand, political information concerns the strategic exchange of information about similar beliefs, venue shopping and resources. Both types of information can be used to influence a policy process and thereby the policy output, but in different ways. Technical information consists of knowledge about the given problem and enhances substantive knowledge about the issue under uncertainty. It is often generated by scientists in the first place (Leifeld and Schneider, 2012), but can also stem from consultants, policy analysts and government specialists (Weible, 2008). This type of information can be used by actors in order to inform themselves about the substantive issue (the drilling technique, the potential impact on ecosystems, the change in resources allocation or property rights, potential risk for humans or the environment, etc.), or to influence the policy process through knowledge provision to other actors. One specific example would be expert reports prepared for decision-makers.

In contrast, political information is related to the strategic behavior of political actors. It allows actors to coordinate their influence strategies and to organize their work in order to impact policy outputs. According to the Advocacy Coalition Framework, for instance, political actors exchange information within their coalition in order to coordinate their actions (Sabatier and Weible, 2007; Weible, 2008). Political information is used to communicate with peers about strategic actions to influence decision-making. Examples for political influence strategies are the coordination of venue shopping or joint lobbying activities (Leifeld and Schneider, 2012).

2.2. The main drivers of information exchange

Below, we outline four major drivers that are expected to enhance information exchange and discuss their importance in a context of uncertainty. While the first three drivers should be most important for political information exchange, the fourth factor should influence technical information exchange in particular.

2.2.1. Belief similarity

Two actors with similar beliefs on what a policy should look like are likely to exchange information (Weible, 2006; Sabatier and Weible, 2005). Shared values and beliefs are the basis for coalition formation and coordination among actors involved in a policy domain (Sabatier, 1987; Sabatier and Weible, 2007). Generally speaking, we expect actors to rely on belief similarity when choosing their information exchange partners. Applied to land use and natural resources' policies, actors who share similar ideologies regarding the degree of state intervention when regulating activities in the underground are thus expected to get in contact. As illustrated by Pedersen (2010), beliefs are defended in so-called communities and take the form of ecosystem and nature conservation, economic development and the use of resources for human wellbeing, or the development of local business and labor market.

We expect differences between both types of information exchange. First, similar beliefs lead actors to form coalitions with the goal of impacting policy outputs. We thus assume that belief similarity is a stronger predictor for political information exchange, that is, information exchange with respect to influence strategies, than for the exchange of technical information. Second, actors engage in technical information exchange in order to gather substantial information about issues, and to reduce their problem uncertainty (Carpenter et al., 2004; Leifeld and Schneider, 2012). If actors are looking for technical information, they might therefore also reach out to others with which they do not share policy beliefs. Even if no type of information is ideologically "neutral", and actors might also tend to prefer others with similar beliefs to exchange their technical information with, technical information should be less related to actors' policy beliefs than political information. We thus expect a stronger effect of similar beliefs on political information exchange, than on technical information exchange.

Hypothesis 1a. Actors with similar beliefs exchange both political and technical information.

Hypothesis 1b. The influence of similar beliefs on the exchange of political information is stronger than on the exchange of technical information.

2.2.2. Resource dependence

Actors who enjoy important public support or dispose of technical expertise can exchange these resources with actors in charge of the policy process in order to gain influence on the policy process (Pfeffer and Salancik, 2003; Henning, 2009; Leifeld and Schneider, 2012; Baumgartner et al., 2009). Especially in the context of uncertainties and risks related to the impacts of a problem, or of potential policy solutions, as in the case under study, public authorities with formal decision-making power strive for technical information. In exchange, the providers of information get their share of influence on the policy process. Public authorities are thus in a role of an information conduit between other types of actors (May et al., 2016). Therefore, we expect government and administration actors to be especially popular (i.e., have more incoming ties than others) in the technical information network, and especially active (i.e., more outgoing ties than others) in the political information exchange network (see also Ingold and Leifeld, 2016).

Hypothesis 2a. Public authorities have more incoming ties in the technical information exchange network than other actors.

Hypothesis 2b. Public authorities have more outgoing ties in the political information exchange network than other actors.

2.2.3. Existing collaboration

When establishing collaboration, actors can chose from many potential collaboration partners. In order to reduce the diversity of potential collaboration partners, actors might focus on other actors they are already in contact with. Relying on existing contacts should be even more important in a context of uncertainty, as in the policy domain under study. In a situation where actors are unaware of other actors' preferences and behavior, existing relations should be a crucial source of information (Berardo and Scholz, 2010; Fischer, 2015). Existing collaboration relations are typically established during earlier or parallel policy processes in the same or in different, neighboring policy fields. Such existing relations are expected to be important when actors chose with whom they exchange information (Carpenter et al., 2004; Fischer and Sciarini, 2016).

Hypothesis 3a. Actors with existing collaboration exchange both political and technical information.

Hypothesis 3b. The influence of existing collaboration on the exchange of political information is stronger than on the exchange of technical information.

2.2.4. Science and expertise

In modern environmental and technical policy domains, scientific expertise is often needed to tackle modern policy problems (Lubell, 2013). In the struggle against problem uncertainty, actors seek technical information to learn about the substantive issue a policy process is dealing with. Recent studies suggest that the lack of scientific certainty creates a need for knowledge acquisition (Leach et al., 2013). Political actors need knowledge about the policy problem they deal with in order to justify their policy beliefs and to develop influence strategies. Policy learning, awareness-raising, and knowledge improvement are further facilitated where scientific experts interact with political decision-makers (Klein et al., 1999; Schneider et al., 2003). In general, scientists and experts aim for a deep understanding of a particular subject. Because of their expertise, politicians rely on knowledge of scientific actors (Ingold and Gschwend, 2014). Scientific actors are important knowledge providers and are therefore expected to provide other actors with technical information. We have no specific expectations about political information exchange of scientific actors.

Hypothesis 4. In the technical information exchange network, scientific actors have more outgoing ties than other actors.

3. Case, data and methods

3.1. Fracking and uncertainty

Fracking describes the technical process when unconventional shale gas is extracted from shale rocks by hydraulic fracturing. The process allows extracting sizable resources of natural gas from basins that were considered to be difficult or costly to exploit before (IEA, 2012). On the one hand, scholars argue that there is a lack of scientific evidence estimating the exact environmental impacts caused by fracking (Stevens, 2010). On the other hand, and as a consequence, the political and public debate on unconventional gas development is said to lack factual scientific legitimization (Wagner, 2015). Indeed, many aspects of scientific uncertainty influence the debate on fracking regulation, such as the contamination of surface waters and aquifers, the causation of seismic activity, the disposal and recycling of wastewater, the regulation of land use and property rights, or the generation of fugitive methane emissions due to leakages (Stevens, 2010; Jackson et al., 2014). For example, the discussion between Osborn and colleagues (Jackson et al., 2013; Darrah et al., 2014; Osborn et al., 2011) on the one hand and Saba, Orzechowski and Schon (Saba and Orzechowski, 2011; Schon 2011) on the other hand pivoted around whether hydraulic fracturing can be made responsible for methane contamination of drinking water. Further, a lively discussion concerns the greenhouse-gas footprint of shale gas (Howarth et al., 2012; Howarth et al., 2011; O'Sullivan and Paltsev, 2012). Jurisdictional uncertainty with respect to land use and property rights is reported in Holahan and Arnold (2013).

3.2. Fracking policy in the United Kingdom

Our analysis deals with the policy process on the regulation of fracking in the United Kingdom (UK). In the UK as well as in many other countries, the energy domain has to cope with conflicting goals related to energy security and economic interest for cheap energy, on the one hand, and climate change policies, on the other. This constant challenge explains the interest of political actors for new sources of energy in general (Goldthau, 2013), and unconventional gas exploitation in particular (Weible et al., 2016). No one single event, but rather several different developments can be regarded as triggers for creating political and public attention for the issue of fracking in the UK (Cairney et al., 2016a; Bomberg, 2015). First, drilling techniques were improved over time and now include horizontal drilling or seismic techniques, which made the extraction of shale gas economically profitable. Second, and as a consequence of technological advances, the success of the United States in shale gas production opened up the discussion around developing fracking also in the UK.

In the period between 2007 and 2014, the UK government attempted to attract investors, increase public acceptance, and provide the necessary regulation for fracking activities. The British Geological Survey started to review the potential for unconventional gas extraction in the UK in 2008 and identified a relevant production potential (Selley, 2005). Subsequently, the House of Commons and the House of Lords organized consultations and evidence sessions and mandated reports about the impacts of shale gas on energy markets, energy security, water supply or the economy in general.[1] After a suspension of test drillings as a consequence of two minor earthquakes and local protests, the State Secretary for Energy and the Department of Energy and Climate Change announced new regulatory requirements and a package of commitments towards communities hosting fracking activities. Finally, in order to attract investors, the UK government proposed a new tax regime for companies active in the domain of shale gas extraction. This new regulation was included in the Finance Bill of 2014. Until now, the most important outcomes of the policy process on the regulation of unconventional gas development in the UK have been the establishment of a new administrative office, the Office of Unconventional Gas and Oil (OUGO); the inclusion of unconventional gas sources into the Gas Generation Strategy, and the publication of supporting details ("Developing shale gas and oil in the UK") to the government policy "Providing regulation and licensing of energy industries and infrastructure".

3.3. Data

Data on all relevant variables was gathered through an online survey in the summer of 2014 (Ingold et al., 2016). For our survey, we took into account collective actors such as political parties, interest groups, NGOs, administrative agencies or scientific institutions. In line with Knoke et al. (1996: 7), collective actors rather than individuals stand in the foreground of today's politics. Policies and policy documents are drafted and decided upon by collective actors, and if individuals intervene, they do so as representatives of these collective actors. We relied on the classical combination of decisional, positional, and reputational approaches to identify the relevant actors in this policy process (Knoke, 1993). The combination of three approaches makes sure no important actor is missing. It is rooted in early elite studies (French, 1969) and has been successfully applied in many studies on policy processes and networks (for example Ingold and Fischer, 2014; Kriesi and Jegen, 2000, 2001; Kriesi and Jegen, 2001; Knoke et al., 1996; Laumann and Knoke, 1987). First, following the decisional approach, we identified actors participating in the different venues of the UK national-level policy process on fracking (Magill and Clark, 1975). Based on documentary analysis, we identified 17 relevant venues (see examples above, and list of venues in Appendix B) of the national-level policy process between 2007 and 2014. Actors participating therein are identified via an in-depth analysis of secondary sources such as lists of participants in official meetings, information from official administrative websites, or reports of think tanks, energy companies, and other organizations. Second, according to the positional approach, we completed the first list of actors with organizations holding an overall strategic position or important formal competences in the UK political system, such as governmental offices or parties in Parliament. This resulted in a list of 40 actors to whom we sent the survey. Following the reputational approach, all survey participants were asked to indicate the most important actors. Actors could further indicate any important actor which was missing on the actors list, according to their view. This would have allowed to identify actors not appearing in documents related to fracking in the UK, but which still were influential on the issue. Yet, no additional actor was mentioned more than once by the survey respondents, and we thus concluded that no important actor was missing from our list.[2] Furthermore, we could reduce our list to 34 relevant actors, as six organizations were evaluated as not important, or as not enough involved in the respective process (see Appendix A for full actors' list). This actor list includes 10 scientific actors, 5 environmental non-governmental organizations (NGOs), 9 industry representatives and 10 political actors in the narrow sense (i.e. political parties or government administration). The response rate to our online survey corresponds to 56%.[3] For our analyses, we still include all 34 actors in the network. We thereby take advantage of the fact that in network surveys, respondents also deliver partial information on (their relations to) all other actors. We have thus only missing information on the network relations from non-respondents to other actors, but not from respondents to non-respondents.

We analyze two distinct network relations: technical and political information exchange. Given that the distinction between two types of information exchange might not be easy to understand for survey partners, we made sure to include a precise definition of both types of information, as well as examples in the written questionnaire. In order to gather data on the technical information exchange network, we first provided the survey partners with the following definition: *Technical information is information on the technical aspects of unconventional gas development, as well as scientific information on potential implications for the environment and neighboring population. Examples are given by information on the requirements for the well construction to access unconventional gas or on the estimation on fugitive methane emissions generated by unconventional gas operations.* We then provided them with the list of actors active in the domain of shale gas extraction in the UK between 2007 and 2014. Based on the above definition of technical information and the list of actors, we asked survey partners to indicate a) from which organizations they regularly obtain technical information related to fracking, and b) which organizations they regularly provide with technical information related to fracking. We took both pieces of information into account to create a network of technical information exchange ties between actors. Whenever either actor *a* indicated providing technical information to actor *b*, or actor *b* indicated receiving technical information from actor *a*, we include a directed network tie from actor *a* to actor *b* in the network.

Political information exchange was defined in the survey as follows: *Political information is information related to political affairs, i.e. information that allows your organization to organize during the policy process. Examples are information on the preferences of other actors or on the agenda for the next meeting with coalition partners to discuss the influence strategy on the policy process.* Again, based on the same list of actors that are active in the domain of shale gas extraction in the UK between 2007 and 2014, survey partners were then asked to indicate a) from which organizations they regularly obtain political information related to

[1] The UK Parliament Website 2014. Available at: http://www.parliament.uk. [Accessed 4 March 2014].

[2] Actors which were added to the list once are Greenpeace, the Institute of Directors, Her Majesty's Treasury, the National Trust, the Royal Society for the Protection of Birds, the Department for Communities and Local Governments, Deutsche Bank, Bloomberg News Energy Finance, and the All Party Parliamentary Group on Unconventional Oil and Gas.

[3] Whereas similarly low response rates are quite common in policy network studies (Ingold, 2014; Lubell and Fulton, 2007), we acknowledge that this might be problematic, especially because data points in a network are dependent on each other. While missing data might affect endogenous network parameters, it has probably less an effect on the assessment of exogenous parameters. This is even more true given that on average, non-respondents did not systematically differ from respondents in terms of actor type (response rates per type: scientific 50%, NGO 80%, industry 44%, political 50%), power (as perceived by respondents, who were asked about the power of all 34 actors: average power of respondents: 0.42, average power of non-respondents: 0.45), or belief similarity (as perceived by respondents, who were asked about the belief similarity (value between −1 and 1) with all 34 actors: average belief similarity with respondents: 0.0, average belief similarity with non-respondents: 0.1). A model based on respondents only (network with 19 actors) yields the same result, with the exception of public authorities, who have a significantly positive activity parameter in the technical information exchange model.

fracking, and b) which organizations they regularly provide with political information related to fracking. Based on the answers to these questions, a network of political information exchange was created as described above.

Also several independent variables were operationalized via network relations gathered through our survey. First, we asked actors to indicate with which organization from the same actors' list they *agree*, and with which they *disagree* about policy measures to be taken for the regulation of unconventional gas development in the UK. This information serves as a proxy for the similarity of actors' policy beliefs (Ingold, 2011). It captures agreement and disagreement with respect to the degree and type of state intervention, and thus the policy design (Howlett, 2014), including policy measures (such as concessions, moratorium or bans related to unconventional gas extraction) and goals (such as defined shares in the energy mix or landscape protection objectives). It was used to create a network of agreement and disagreement relations between actors, with values of −1 representing disagreement between two actors, 1 representing agreement, and 0 representing a neutral relation. Overall, there is slightly more agreement on beliefs than disagreement in the network, as the average value of all ties is positive (density of 0.04). Second, in order to assess the power of actors, we rely on the measure of reputational power (e.g., Knoke et al., 1996). About half, i.e. 18 out of 34 actors were mentioned as being powerful with respect to fracking issues by at least 50% of the other actors. Third, drawing on the same list of actors, we asked survey partners to indicate with whom they strongly collaborated in other policy processes on energy and environmental issues during the last ten years. This allows us to create a network of actors where a tie (1) represents existing collaboration in earlier or parallel processes, whereas the absence of a tie (0) represents no collaboration in earlier or parallel policy processes.[4] The density of the network of existing collaboration amounts to 0.14. Finally, we coded each actor according to its organizational type, i.e. as a public authority (public administration and government agencies, including government parties, that is, the Conservative Party and the Liberal Democrats[5]), an industry or private interest group, a green NGO, or a scientific research institute.

3.4. Network approach and exponential random graph models (ERGM)

Creating and sustaining policy networks is a strategy for political actors to exchange resources and information and try to influence policy decisions (Baumgartner et al., 2009; Baumgartner and Leech, 2001; Atkinson and Coleman, 1989; Pappi and Henning, 1999; Leifeld and Schneider, 2012; Bouwen, 2004).

Adopting a network approach, we test the impact of the different factors laid out in the theoretical section on the networks of political and technical information exchange by estimating Exponential Random Graph Models (ERGM, Robins et al., 2007; Lusher et al., 2013). ERGMs allow for statistical inference on network data, which by definition are non-independent (for applications in political science, see, e.g., Cranmer and Desmarais, 2011; Leifeld and Schneider, 2012; Gerber et al., 2013; Ringe et al., 2013). Non-independency among observations in network data means that the probability of a tie of information exchange between two actors might depend upon the structural properties of the network in which the two actors are embedded. Standard regression models are unable to take this dependency into account and would erroneously attribute explanatory power to exogenous variables (Cranmer and Desmarais, 2011; Lusher et al., 2013). Given the dependency among observations, error terms would be correlated across observations, standard errors would be too small, and p-values for exogenous variables too optimistic (Leifeld and Schneider, 2012).

In order to avoid the assumption of relational independence, ERGMs model the probability of observing a given configuration of the network, as compared to all other possible network configurations with the same number of nodes and network density (Cranmer and Desmarais, 2011). The structure of the network is modeled based on actor-level variables (node covariates), dyadic variables (edge covariates), and endogenous network structures. The latter refer to effects of network structures on the network itself, such as actors' tendency to reciprocate ties or close triangles (i.e. to collaborate with an actor to which one is already indirectly connected). The relation between the probability of a network m and the network statistics in Γ can be expressed by the following formula, where Θ is the vector of k parameters that describe the dependence of $P(Ym)$ on the network statistics in Γ (Cranmer and Desmarais, 2011; Hunter et al., 2008b):

$$P(Y_m) = \frac{\exp\left(-\sum_{j=1}^{k} \Gamma_{mj}\Theta_j\right)}{\sum_{m=1}^{k} \exp\left(-\sum_{j=1}^{k} \Gamma_{mj}\Theta_j\right)}$$

As represented in this formula, ERGMs calculate the probability of observing the given network configuration, as compared to all other network configurations that could potentially have been observed given the network size and density. ERGMs integrate an exponential family form log-likelihood function. Due to the very high number of possible network configurations, computing the exact maximum likelihood is however computationally too demanding (Cranmer and Desmarais, 2011; Lusher et al., 2013). Therefore, we estimate ERGMs using Markov Chain Monte Carlo Maximum Likelihood (MCMC-MLE), which approximates the exact likelihood by relying on a sample from the range of possible networks to estimate the parameters (Cranmer and Desmarais, 2011). In a given step, MCMC-MLE proceeds by approximating the sum in the denominator of the likelihood function based on a series of networks sampled from the distribution parameterized with those parameters that maximized the likelihood using the previous sample of networks. This iterative optimization proceeds until the value of the approximate likelihood function no longer changes, that is, when the differences between the sufficient statistics of the observed network and the average of the sufficient statistics in the sample of simulated networks are no longer significant (p greater than 0.05) (Cranmer and Desmarais, 2011).

4. Analysis

For our empirical analysis, we tested the same model for both networks, that is, technical and political information exchange. Both networks include 34 nodes (collective actors involved in UK fracking politics). While both networks are rather sparse, the network of technical information exchange has clearly a higher density (0.18, meaning that 18% of all possible ties in the network do exist in reality) than the network of political information exchange (0.08). This important difference indicates that our survey partners were indeed able to distinguish between both types of information exchange. More substantively, the fact that the technical information exchange network is denser than the political information exchange network tends to confirm our basic assumption that we are dealing with an important amount of uncertainty in this policy domain. Under uncertainty – and in an early stage of political decision-making – actors mainly need to gather information on the issue itself, and focus less on forming coalitions or discussing influence strategies. The summary statistics are presented in Table 1.

Table 2 presents descriptive results with respect to both types of information exchange between types of actors. It distinguishes between state authorities, private interests, NGOs and scientific actors, as explained in the description of the data. Actor groups in the rows are the

[4] We are aware that gathering data on several processes within the same survey is not ideal. Ideally, data on collaboration in earlier or parallel processes should be gathered in separate surveys to avoid priming of respondents.

[5] The Labour Party and the Green Party, as opposition parties during the time of our study, are coded as a separate, residential category.

Table 1
Network descriptives.

Network	Number of actors (nodes) in network	Density of network	Number of edges in network	Average number of ties per actor	Percentage of reciprocated ties/all ties
Technical Information Exchange	34	0.18	204	6.00	42%
Political Information Exchange	34	0.08	97	2.85	55%

Table 2
Densities across actor types.

	Publ. auth.	Private actors	NGO	Science
Technical Info				
Publ. auth.	**0.31**	**0.21**	**0.28**	0.18
Private actors	**0.35**	**0.25**	0.11	0.12
NGO	**0.23**	0.07	**0.20**	0.04
Science	**0.25**	**0.19**	**0.24**	0.10
Political Info				
Publ. auth.	0.06	**0.19**	**0.15**	**0.18**
Private actors	**0.19**	**0.12**	0.07	0.06
NGO	0.05	0.04	**0.08**	0.02
Science	0.03	0.02	0.02	0.03

ones sending information, actor groups in the columns receive information. For example, the density of information exchange between state actors and private interests in the technical information exchange network is 0.21. Bold values indicate that the density of information exchange between the two categories of actors is above the density of the whole network.

Three main findings appear from the above-average values between actor types in the technical information exchange network. First, public authorities receive technical information from all other types of actors, which is a first indication in favor of our hypothesis 1 on resource dependency. Second, public authorities also send technical information to other types of actors. This corresponds to the idea that public authorities act as an information conduit between other actors (May et al., 2016). Third, and in line with our hypothesis 4, scientific actors also send technical information to all other actor types. Descriptive results based on above-average values in the political information exchange network mainly show that public authorities grant political information to all other types of actors, which again supports our hypothesis 1 on resource dependency.

ERGM results appear in Table 3.[6] Bold values indicate a significant effect at the conventional level of $p \leq 0.05$. Goodness-of-fit statistics appear in Appendix C and indicate an overall good model fit.[7]

First, belief similarity has a positive influence on actors' tendency to provide others with technical as well as political information. Still, the size of these effects varies depending on the type of information. Coefficients are 0.35 in the technical information exchange model and 0.98 in the political exchange model, respectively. The size of effects, that is, the odds of observing a tie if the independent variable increases by one unit, can be obtained by calculating the exponential function of effects.[8] While the probability that two actors exchange technical information is only about 40% higher ($e^{0.35} - 1 = 0.42$) if they have similar beliefs, the odds that they exchange political information is more than twice as high ($e^{0.98} - 1 = 1.66$) if their beliefs are similar. Second, there is no significant effect for public authorities to send or receive technical information. This means that public authorities are no different than other actors in terms of sending or receiving technical information. However, public authorities have a strong tendency to provide others with political information (see again Table 2). Being a public authority increases the odds of providing other actors with political information by a factor of about 6 ($e^{1.98} - 1 = 6.02$). The chances of receiving political actors, by contrast, are more than 7 times lower ($e^{1.12} - 1 = 7.33$) for public authorities than for other actors.

Third, existing collaboration in earlier or parallel processes has a significant and positive effect in the technical information exchange network, but not in the political information exchange network. Fourth and finally, the model shows that scientific actors have a negative tendency to receive technical information, and a positive tendency to send technical information. By contrast, while scientific actors are no different than other actors with respect to receiving political

Table 3
ERGM Results.

	Techn. info	Polit. info
H1: Belief similarity	**0.35**	**0.98**
	(0.17)	**(0.25)**
H2: Publ. authority incoming	−0.07	**−2.12**
	(0.22)	**(0.57)**
H2: Publ. authority outgoing	0.42	**1.96**
	(0.25)	**(0.55)**
H3: Existing collab.	**0.70**	0.42
	(0.19)	(0.28)
H4: Science incoming	**−0.82**	0.39
	(0.24)	(0.45)
H4: Science outgoing	**0.91**	**−1.41**
	(0.26)	**(0.60)**
Controls		
Edges	**−3.30**	**−4.87**
	(0.36)	**(0.42)**
Reciprocity	**2.49**	**5.80**
	(0.29)	**(0.76)**
GWESP(0.1)	**1.06**	0.02
	(0.23)	(0.13)
GWDSP(0.1)	**−0.20**	**0.10**
	(0.03)	**(0.02)**
Private actors incoming	**−0.55**	**−1.11**
	(0.23)	**(0.54)**
Private actors outgoing	**0.74**	0.94
	(0.26)	(0.54)
Other type of info	**0.76**	**0.67**
	(0.22)	**(0.23)**

Bold entries point to significant effects at the conventional level of p-values of 0.05 or lower.

[6] Additional exogenous (reputational power) or endogenous (geometrically weighted outdegree distribution, cyclic triples) control variables do not affect our substantive findings, nor strongly influence model fit (AIC and BIC can be used to compare model fit for the same network). Dropping actor type sending and receiving variables or the variable for earlier or parallel collaboration variable does not substantially influence results either.

[7] The assessment of goodness-of-fit is based on a set of network statistics not included in the model: p-values are used to check whether given statistics on the observed network (in-degree distribution, out-degree distribution, etc., see Appendix 3) are not significantly different from the average statistics in a set of networks simulated based on the model parameters. A common threshold used for assessing model fit is a p-value greater than 0.05 (Hunter et al., 2008a). The plots indicate that our models provide an overall good fit to the data, i.e. the dark lines (observed values) lie within the boxplot area (simulated values) for almost all configurations. The model for technical information exchange tends to slightly overestimate the number of edges with 2 shared partners, and slightly underestimate the number of edges with 9 or more shared partners. The model for political information exchange slightly underestimates the number of nodes with in- or out-degree of 0.

[8] The size of effects can only be interpreted assuming that all other covariate values are the same, that is, that the rest of the network is fixed. For more detailed explanations, see Hunter et al. (2008b) and Goodreau et al. (2008).

information, they provide others significantly less with political information, as compared to other types of actors. These results suggest that scientific actors play a role of scientific information provider, and no role of political advocacy, also in a policy domain with high scientific uncertainty.

The remaining effects are controls. First, an "edges" parameter controls for the number of ties in a network. Its negative values, as observed in both models, correspond to the network densities lower than 0.5 (see Table 1), and express that the chances of observing a tie are below 50 per cent. Second, we control for reciprocity: this parameter is positive in both models, indicating that actors tend to reciprocate ties of information exchange. If actor a sends information to actor b, then actor b tends to send information to actor a, too. Yet, the effect is stronger for political (5.80) than for technical (2.49) information exchange. Again, we can calculate the size of effects. Thus, the probability of a tie from a to b is 329 (e5.80 − 1 = 329.30) times higher if there is also a tie from b to a in the political information exchange network, but only about 11 (e2.49 − 1 = 11.06) times higher in the technical information exchange network.

Third, we control for an endogenous network effect of triangular structures which appears in many social networks. More specifically, we control for the fact that actors link to others they are already indirectly connected with, i.e. through a third actor.[9] The respective GWESP (geometrically weighted edgewise shared partner) and GWDSP (geometrically weighted dyadwise shared partner) parameters should be interpreted together (Hunter, 2007). The GWDSP captures the tendency of a dyad (i.e. of a pair of actors that are related or not) to have one or more shared partners. It is a baseline effect that controls whether any two actors in the network tend to have shared partners. Once dyadwise shared partners have been controlled for, the GWESP measures whether two actors that exchange information are more likely than pure chance to have shared partners (Leifeld and Schneider, 2012). The model on technical information exchange exhibits triadic closure, meaning that actors with shared partners tend to exchange information. A negative GWDSP parameter means that any two actors have a negative tendency to have shared partners. On top of that, the positive GWESP parameter indicates that whenever two actors are related by a tie of information exchange, they tend to have shared partners. Contrary to technical information exchange, there is no evidence in the political information exchange network that actors collaborate with those with whom they have already shared partners.[10] Fourth, industry actors have a negative tendency to receive any type of information, but they do provide others with technical information. Finally, we control the other type of information, respectively, in the models. Results show that both types of information are related, that is, that the presence of a political information exchange tie increases the odds of observing a tie of technical information exchange, and vice versa.

[9] Having common acquaintances contributes to the establishment of information exchange between actors. On the one hand, a joint contact helps actors to reduce the uncertainty about the quality of the alter and to know which other actors to trust (Leifeld and Schneider, 2012). On the other hand, being already indirectly connected to another actor allows actors to have some social control over an information exchange contact (Burt, 2005). Yet, whether trust or social control is the real driver behind this mechanism is hard to establish (Shrestha and Feiock, 2009).

[10] These effects of triadic closure take a transitive and not a cyclical form. An additional control variable (cyclic triples, see footnote 4), which represents triads in which information flows in a circle, is non-significant in both models. This means that either a) actors provide other actors, to which they are already indirectly providing information, with information, or b) actors receive information from actors from which they already indirectly receive information, or c) actors provide information to actors which also receive information from the same third actor. However, actors do not provide other actors, from which they indirectly receive information, with information.

5. Discussion

Relying on established arguments mainly borrowed from policy studies and the policy network literature, we expected that belief similarity, authority, existing contacts and scientific expertise have a positive impact on the creation of ties among actors in both types of information networks. We further had more detailed expectations on the differences between political and scientific information exchange. In accordance with hypothesis 1a, we can confirm that actors who perceive each other as allies and share policy beliefs related to the regulation of unconventional gas development have a positive tendency to exchange information among each other. In the same vein, results from our models also lend support to hypothesis 1b: having similar policy beliefs has a stronger positive effect on the exchange of political information than on the exchange of technical information among actors. In agreement with Leifeld and Schneider (2012), this result indicates the importance of differentiating between information that concerns the technical nature of the policy problem, and information on political aspects such as venue shopping or coalition formation strategies. Related to different types of uncertainties, our results suggest that both types of information exchange serve different purposes. Whereas the first appears to be more politically neutral and delivers actors with knowledge about the risks and effects of the problem at stake (e.g., when applying hydraulic fracturing techniques), the latter clearly depends more on belief similarity among actors and potentially reduced uncertainties concerning strategic behavior of ideological peers and opponents. Indeed, it comes closer to what is defined as coordination patterns among like-minded peers or coalition members (Weible, 2006; Sabatier, 1988).

Results with respect to resource dependencies and the role of public authorities give partial support to our second set of hypotheses. There is no support for our hypothesis 2a, as public authorities do not receive more technical information than others. The statistical model (Table 3) does not confirm descriptive results (Table 2), which suggested that public authorities receive an above-average share of technical information. By contrast, we can confirm hypothesis 2b: public authorities tend to provide other actors with more political information, as compared to other types of actors. Furthermore, and again in line with our resource dependency argument, public authorities receive considerably less political information than other actors (Phillipson et al., 2016). Results derived from the statistical model thus suggests that public authorities are less popular, but more active. A first explanation for this finding might be the issue-related context: hydraulic fracturing and the extraction of unconventional gas is a very technical and new topic. As a consequence, decision-makers and authorities are strongly dependent on knowledge that can be provided by other types of actors; but are themselves not (yet) a reliable or appropriate source of information and knowledge. Nevertheless, and as shown in the descriptive statistics as well as suggested by the study of Baird et al. (2016), actors who are linked to public authorities and governments might still benefit from this link as public (and political) information received from state actors might still pay off in terms of policy impact and success. Second, in the UK and at the time of our study, hydraulic fracturing regulation was not yet finalized. Some of the action did not take place at the national level, but in the regions (such as Scotland): thus again, non-state actors might have reached out for information provided by public authorities, but not at the national level as investigated here. This is also in line with Phillipson et al. (2016), who found that in complex land use decision-making, expertise is not performed by single monopolies anymore, but that professional interactions characterize practices and decision-making.

Empirical results also support our third hypothesis on existing collaboration. There is partial evidence for hypothesis 3a, which suggests that if two actors have collaborated in earlier or parallel processes, they are likely to exchange political and technical information with respect to hydraulic fracturing. Results show that this is true for technical information only. This is not in line with hypothesis 3b where we expected these effects to be stronger for the exchange of political information than for the exchange of technical information. Additionally to earlier or parallel collaboration, our models also controlled for reciprocity: Both networks exhibit strong tendencies of reciprocity, but the effect of reciprocity is clearly stronger in the political information exchange network than in the network of technical information exchange. Reciprocity in the very same network might be more of an immediate sign of trust-dependent behavior, and thus be more important for political information exchange. This is important insight for the future design of so-called collaborative governance mechanisms where a variety of public and private actors concerned with natural resource or land use management are affected (Berardo and Scholz, 2010; Berardo and Lubell, 2016; Angst and Hirschi, 2016). It is not only the mere participation that impacts structures of collaboration, but rather the fact that actors know each other from other policy processes.

Finally, we can corroborate the hypothesized role of science in policymaking under uncertainty (H4): Scientific actors strongly provide other actors with technical information on the issue, and thus play their classical role of passive information providers. By contrast, they do not receive any technical information, which again is not a surprising finding. Scientific actors certainly need technical information for their research and other activities, but they receive this information from peers in the scientific domain rather than from any other type of actors involved in policy processes. This also suggests that scientific actors have a classical view of scientists as observers of reality, also called pure scientists or science arbiters (Pielke 2007) and not as active actors in transdisciplinary knowledge exchange with stakeholders from politics and practice (e.g., Hadorn et al., 2008). Furthermore, as suggested by their negative tendency to send political information, the role of scientific actors in a policy process is one of knowledge provision rather than lobbying or participating in formal decision-making. This goes hand in hand with arguments in research on dynamics and directions of evidence provision (Giebels et al., 2015): our results suggest that scientific actors do not actively "push" into the political sphere, and that knowledge is rather transferred "on demand from decision-making" (also known as "pull from politics").

It thus seems that even in environmental policy domains with high levels of uncertainty, scientific actors do not play a policy role. Recent literature on knowledge transfer and brokerage however emphasizes that the interface between science and policy should be strengthened, and this particularly in policy fields that deal with increasingly intractable societal or environmental problems (Rockström et al., 2009). Results from this analysis suggest that giving incentives to both, science and politics, might be necessary in order to increase interactions (Hering, 2016). This needs new types of venues, such as bridging organizations (Crona and Parker, 2012) or forums (Fischer and Leifeld, 2015), as well as actors acting as brokers to facilitate network interactions (Christopoulos and Ingold, 2015; Pielke 2007). Results here show that the empirical separation between scientific and political information allows for a more nuanced assessment of the different roles scientific actors play in policymaking.

6. Conclusions

Information exchange is a crucial aspect of political actors' strategic behavior in policy processes, an important pre-condition for political decision-making and, as a consequence, has important impacts on policy outputs. We argue that this holds particularly true for policy domains dealing with scientifically uncertain phenomena. Under scientific uncertainty, political actors are keen to exchange information with others in order to increase their ability to form opinions and justify decisions (Kenny, 1992). In such situations, we expected actors to particularly rely on information from ideological peers, from other actors they perceive as powerful, from actors they already know, and from scientists.

To test these assumptions, we analyzed the policy process on unconventional gas development in the UK between 2007 and 2012. Fracking policy provides an ideal example for a policy domain influenced by uncertainty, as unconventional gas exploitation and the method of fracking still come with several uncertainties related to their impact on the economy and environment (IEA, 2012; Stevens 2010, 2013; Jackson et al., 2014). Based on survey data on actors participating in the UK fracking policy domain, we ran exponential random graph models for network data. Results from these models allowed us to answer the question of what drivers lead actors to exchange technical and political information in the context of uncertainty.

First, based on existing literature, we claimed that there is a crucial difference between political and technical information exchange among actors involved in policymaking. Technical information allows actors to gather scientific expertise about the phenomenon under discussion, whereas political information is exchanged to coordinate actions and strategies within the policy process. Results reported in this paper confirm this assumption: the density of technical information exchange is clearly higher than the density of political information exchange. We conclude that in a policy process dealing with a new issue and coming with a non-trivial amount of scientific uncertainty, technical information, and thus the gathering of knowledge about the issue at stake, is more important than political information exchange in order for actors to conceive political influence strategies (Ingold et al., 2016).

Second, we expected to observe differences also with respect to drivers of technical as compared to political information exchange. Results indeed point to different underlying factors with respect to one or the other type of information exchange: Among the variables included in our analysis, only existing collaboration, reciprocity and belief similarity are drivers of both political and technical information exchange. However, reciprocity and similar beliefs on how to regulate unconventional gas development are much more relevant for *political information exchange*. This finding is clearly in line with the basic assumption of the Advocacy Coalition Framework (Sabatier, 1987), which claims that actors form coalitions with like-minded others in order to influence policy processes (Leifeld and Schneider, 2012; Ingold and Fischer, 2014). A second important driver of political information exchange is public authority. Government and administration actors provide others with political and technical information, but receive only technical information from other actors. This finding largely confirms expectations derived from resource dependency theories, as well as recent findings on the nature of public administration as an information conduit. Besides authority, we identified another main driver for *technical information exchange* among actors. In domains under uncertainty, scientific actors provide others with expertise. Yet, as compared to earlier studies in environmental politics and high-risk domains such as biotechnology (Ingold and Gschwend, 2014; Montpetit, 2011; Schneider et al., 2003), where scientific actors played a key role in policy processes, scientists in the UK hydraulic fracturing domain do not play the policy role of so-called issue advocates (Pielke 2007), given their passive role in the political information exchange network.

There is one obvious limitation to this research that future work may try to overcome: we argue that both types of information exchange are particularly relevant to actors in policy domains dealing with a social or environmental problem that is very complex and uncertain. Examining only the case of hydraulic fracturing politics in the UK, we are of course unable to assess whether the factors related to information exchange are different when studying a policy domain with less uncertainty. To test this implicit assumption, comparative research involving policy processes or actors with different degrees of scientific uncertainty is needed (Weible et al., 2016). Furthermore, scientific uncertainty is obviously not the only characteristic at the level of policy processes which might influence actor behavior in there. To take into account other characteristics, such as for example issue salience or political institutions, a comparative design would again be appropriate (Cairney et al., 2016b).

Appendix A. : Actors' list

Actor Acronym	Full actor name	Category 1 = Public; 2 = Industry; 3 = NGO; 4 = Science; 5 = Political parties
BGS	British Geological Survey	4
CABINET	*Cabinet*	*1*
CAMPAIGNRE	Campaign to protect Rural England	3
CENTRICA	*Centrica*	*2*
CHATHAM	*Chatham House*	*4*
CIA	*Chemical Industries Association (CIA)*	*2*
CNG	CNG Services Ltd.	4
CONSERV	Conservative party	1
CUADRILLA	Cuadrilla Resources Holding Ltd	2
DECC	Department of Energy and Climate Change (DECC)	1
ECCCOMMITTEE	Energy and Climate Change Committee of House of Commons	1
ENVAGENCY	*Environment Agency*	*1*
FRACKOFF	*Frack off*	*3*
FRIENDS	Friends of the Earth	3
GEOLSOCIETY	*Geological Society*	*4*
GFRAC	*Gfrac technologies*	*4*
GREEN	Green party	5
HSE	*Health and Safety Executive*	*1*
IGAS	IGas Energy	2
LABOUR	*Labour party*	*5*
LIBERAL	*Liberal Democrats*	*1*
NATIONAL	National Grid	2
NO HOT AIR	No Hot Air	3
OUGO	Office of Unconventional Gas and Oil (OUGO)	1
OILGASUK	*Oil & Gas UK*	*2*
POLICY	Policy Exchange	4
SHELL	Shell international Ltd.	2
ROYALACADEMY	*The Royal Academy of Engineering*	*4*
ROYAL SOCIETY	*The Royal Society*	*4*
TOTAL	*TOTAL*	*2*
TYNDALL	Tyndall Centre Manchester	4
UKERC	UK Energy Research Centre (UKERC)	4
UKOOG	*United Kingdom Onshore Operators Group (UKOOG)*	*2*
WWF	WWF UK	3

Note: Actors in italic did not respond to the survey.

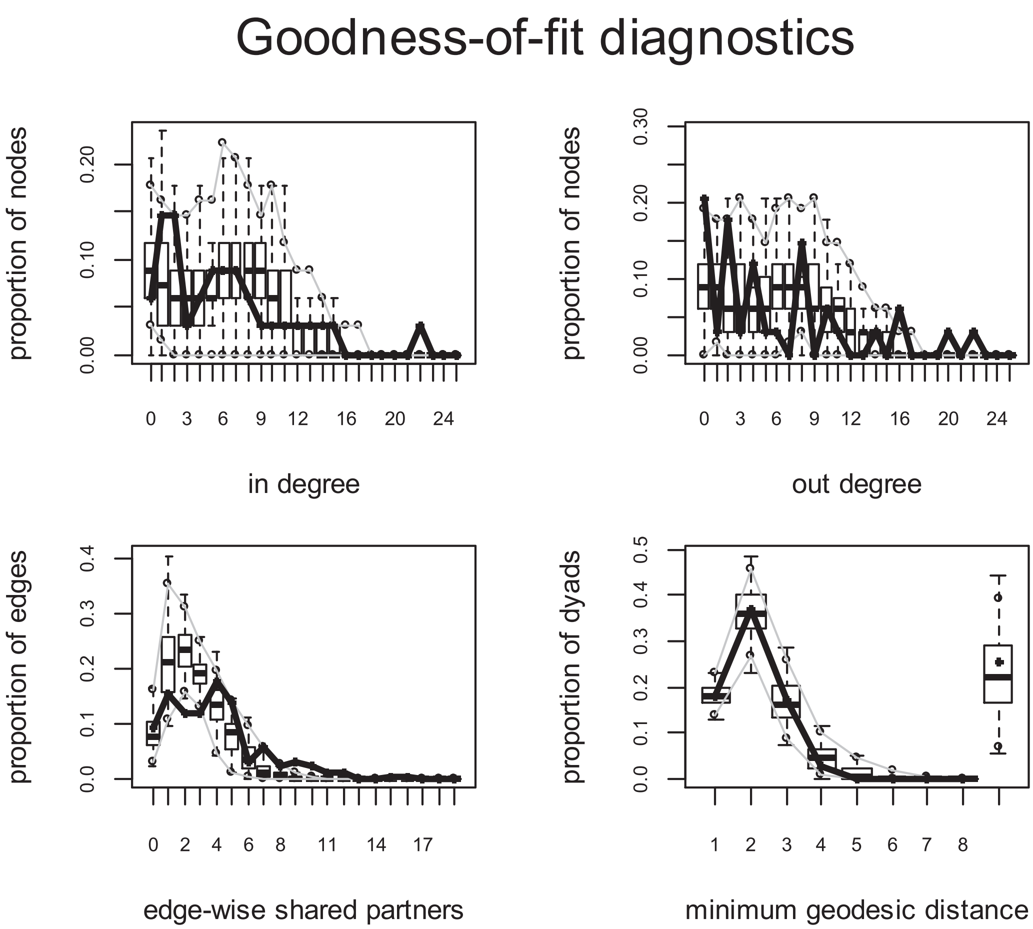
Appendix B: List of venues

Date	Venue
November 2007–February 2008	13th Onshore Licensing Round (UK Petroleum Exploration and Development License (PEDL)).
November 2010–March 2011	Written evidence session and hearings for the forthcoming report on shale gas (organised by the Energy and Climate Change Committee of the House of Commons).
May–July 2011	5th Report "Shale gas" published by the Energy and Climate Change Committee of the House of Commons *and* Government response.
April 2012	Publication of expert report "Shale Gas Fracturing: Review and Recommendations for Induced Seismic Mitigation" *and* invitation for public comments by the DECC.
June–December 2013	Publication of report "Shale gas extraction in the UK: a review of hydraulic fracturing" by the Royal Society and Royal Academy of Engineering *and* Government Response.
July 2012–January 2013	Written evidence session and hearings for the forthcoming report "The Impact of Shale Gas on Energy Markets" (organised by the Energy and Climate Change Committee of the House of Commons).
December 2012	Publication of the Gas Generation Strategy by the DECC.
December 2012	Permission for shale gas extraction after the suspension caused by two earthquakes and announcement of new regulatory requirements by the Secretary of State for Energy and DECC.
December 2012	Establishment of the Office of Unconventional Gas and Development (OUGO).
April–July 2013	7th Report "The Impact of Shale Gas on Energy Markets" by the Energy and Climate Change Committee of the House

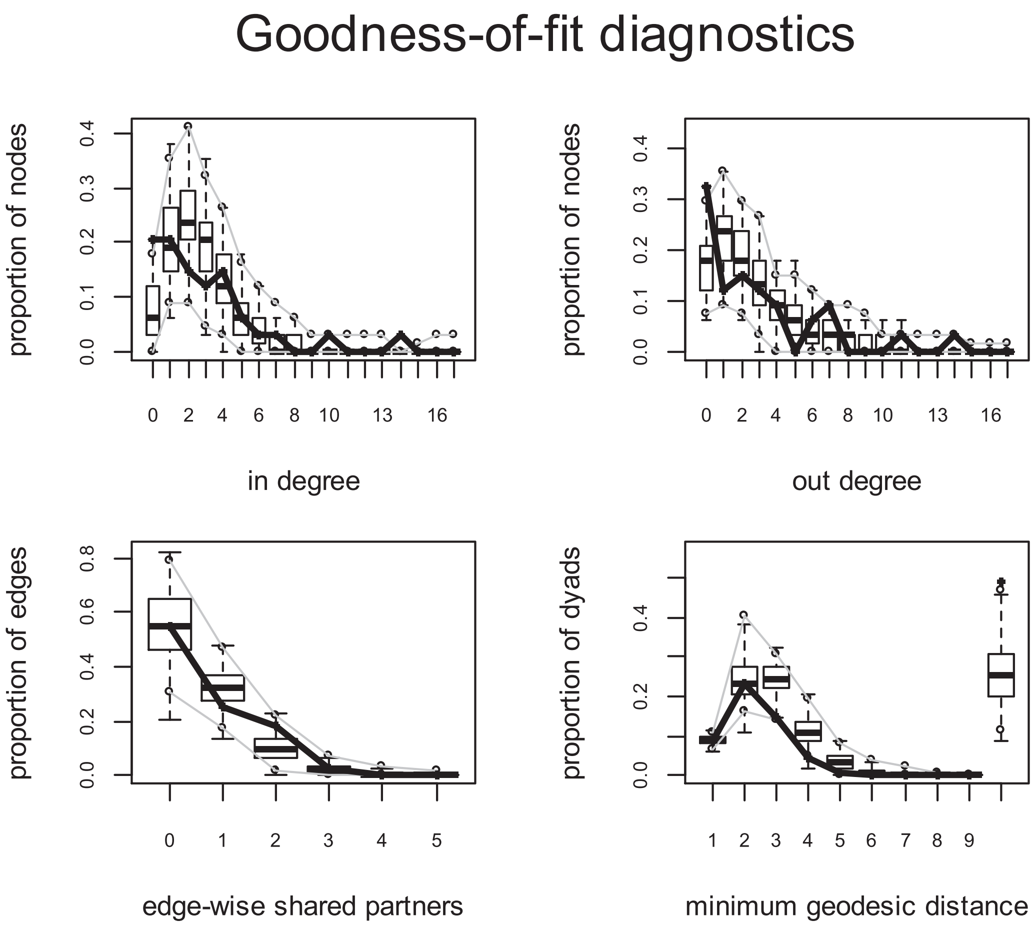
	of Commons *and* Government response.
June 2013	Announcement that the shale gas industry has committed to a package for communities that host shale gas development.
July 2013	Updating of the government policy "Providing regulation and licensing of energy industries and infrastructure" with a Supporting Detail on Shale Gas Development.
July 2013	Publication of "Planning Practice Guidance for Onshore Oil and Gas" by the Department for Communities and Local Government.
July–September 2013	Oral and written evidence session on the Economic Impact on UK Energy Policy of Shale Gas and Oil (organised by the Committee of Economic Affairs of the House of Lords).
July–December 2013	Proposal of UK Government of a new tax regime for shale gas *and* consultation.
August 2013	Technical Guidance "Onshore oil and gas exploratory operations" published by the Environmental Agency
September 2013	Report "Potential greenhouse gas emissions associated with shale gas production and use" published by DECC.

Appendix C. : Goodness-of-fit diagnostics

a) Goodness-of-fit plots for technical information exchange model



b) Goodness-of-fit plots for political information exchange model



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