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A possible integration of multiple paradigms used in integrated assessment modelling of climate change

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Abstract: Most of the models used to analyze international climate policy treat the problem as if it operates on only a single level. This is the result of a reliance on integrated assessment models (IAMs) that, for reasons of analytical tractability, typically employ assumptions that allow the economy to be modeled as if it is managed by a single, utility-maximizing central planner without regard to the influence of either lower-level actors or international pressures. While game theoretic models have been used to study international negotiations, they generally do not consider feedback from domestic actors who have heterogeneous beliefs and vulnerability to climate change. In this paper, we provide an overview of a preliminary policy modeling framework, called ENGAGE, styled after the Putnam two-level game in which interactions among negotiators at the international level are linked with the preferences of constituents at the domestic level. Domestic constituents in our model include firms and households who function as agents within an evolutionary representation of economic growth, energy technology, and climate change, resulting in a two-way dynamic feedback between international agreements and domestic policy outcomes. We present the basic elements of the two levels of the model and discuss plans for future model development.

Keywords: integrated assessment model; climate policy; agent-based model; scenario discovery; Putnam two-level game

1 INTRODUCTION

The development of climate policy represents a global, collective decision-making problem unprecedented in scale and complexity. In order to inform stakeholders in the policy process, scientists have spent the last 30 years developing integrated assessment models (IAMs) that combine the salient features of natural and social scientific theory into linked representations of economic, societal, and environmental systems. While there is no doubt that IAMs have provided key insights into climate change dynamics and impacts, they often fall short in supporting the formation of real-world policy (Schneider and Lane, 2005; Weyant, 2009).

A primary reason for this shortcoming is that, for the sake of analytical tractability, most IAMs adopt a deterministic, aggregated approach to modelling that largely ignores the interplay between complexity and the deep uncertainty of key model structures and parameters (Ackerman et al., 2009; DeCanio et al., 2000). In the standard IAM, it is assumed that a reasonable approximation of economic and social systems can be realized by assuming that the economy is composed of households and firms that have perfect information, have infinite cognitive ability, and are perfectly rational. By invoking this assumption, the economy can be modelled as if it is managed by an omniscient central planner who makes investment and policy choices to maximize expected global or regional welfare. Conditional on a set of model parameter point estimates or distributions, the inferred optimal climate policy provides a narrative of how society should respond to the threat of climate change given rational human behaviour.

In reality, the problem of climate policy formation and implementation requires satisfying interests at multiple levels. Policy-makers are subject to international influence at the regional and global levels, as well as pressures and constraints applied by constituents at the domestic level. Game theory has been used extensively to analyse international negotiation (see Forgo et al., 2005) but has tended to neglect the role of lower-level stakeholders in influencing such agreements.

Formally analysing the role of a non-trivial number of domestic stakeholders in shaping international climate policy has been elusive because the resulting heterogeneity precludes tractable analysis by traditional game theoretic models (Earnest, 2008). An alternative is to follow a recent trend in economics towards computational approaches, notably agent-based models (ABMs) and evolutionary game theory (EGT). ABMs represent the world as made up of heterogeneous, boundedly-rational agents who act in their own interests and yet engage in substantive communication. In this way, ABMs are uniquely suited to address the question of how microscale interactions can generate emergent behaviour that influences outcomes at a higher level (Miller and Page, 2007). EGT focuses on the strategic interaction among agents in a population over time in an environment in which payoffs change and agents are able to switch strategies (Friedman, 1998) (Friedman, 1998). Clearly, ABM and EGT share many features and have been increasingly linked in the literature (Bousquet et al., 2001). Although ABM and EGT have both advanced significantly in recent years, developments in the context of climate change policy have been surprisingly limited (Moss et al., 2001).

We outline the framework of a multi-level, agent-based model that integrates the ABM and EGT paradigms in order to simulate both international negotiation and the domestic dynamics of the economy, energy, and climate change. Specifically, we propose integration of an evolutionary model of economic growth within the framework of an evolutionary two-level negotiation game. As applied to international policy negotiation, the model can be used to link the preferences and strategies of negotiators to the evolution of domestic constituent beliefs and policy preferences. We see this approach as combining the most constructive features of two promising approaches.

2 MODEL DESCRIPTION

The extant ABM energy and climate change literature can be classified into four groups, which are distinguished by techno-economic and geopolitical level. The lowest *Level 4* ABMs focus on either the diffusion of one or more technologies in a single market with little or no feedback to the broader economy (De Haan et al., 2009; Eppstein et al., 2011; Faber et al., 2010; Mueller and de Haan, 2009; Schwoon, 2006; Sopha et al., 2011; van Vliet et al., 2010), or on local adaptation to climate change (Acosta-Michlik and Espaldon, 2008; Berman et al., 2004). *Level 3* ABMs have a broader focus on the electricity market or overall energy use with little or no macro-economic feedback (Batten and Grovez, 2006; Conzelmann et al., 2005; Wittmann, 2008; Xu et al., 2008). At *Level 2*, system boundaries include the entire macro-economy of a country, region, or the world, but typically sacrifice technological detail and resolution of household decisions (Beckenbach and Briegel, 2010; Janssen and de Vries, 1998; Nannen and van den Bergh, 2010; Robalino and Lempert, 2000). Analysis at *Level 1* entails interactions among countries or regions, with little or no feedback between underlying domestic actors and international decisions and policy (Voudouris et al., 2011). Thus, at the level necessary for global scenario generation, the extant ABM literature does not provide much improvement over traditional techniques.

ENGAGE is a flexible multi-module modeling framework designed to simulate the interaction among international climate treaty negotiation (*Level 1*) and national policy formation (*Level 2*) based on the dynamics of regional economic and technological systems. Conceptually, it is a probabilistic, multi-agent, evolutionary economic model (c.f. Safarzyska and van den Bergh, 2010) in which the feedback between international negotiation and regional dynamics is structured after the Putnam two-level game (Putnam, 1988). In ENGAGE, a diverse set of agents (negotiators, firms, and consumers) engages in purposeful behavior by observing and interacting with their surrounding environment and other agents. Their choices exhibit bounded rationality in the sense that the agents have limited cognitive abilities and incomplete information (Simon, 1955). They rely on decision heuristics that are based on theoretical and empirical findings from the literature (e.g., Thaler (1985), Heath and Soll (1996), Bettman et al. (1998), and Gigerenzer and Brighton (2009) for consumers, Dosi et al. (2010) for firms, and Lai and Sycara (2009) for negotiators). Regional economy-energy dynamics are based on the evolutionary macro-economic model of Dosi et al. (2010).

ENGAGE is designed to serve robust decision-making in two capacities. The first is as a *policy discovery* tool. In this mode, policy formation is endogenous to the model and allows for the investigation of scenarios where policy formation and system structure co-evolve (Faber and Frenken, 2009) This mode is especially useful for testing robustness to structural uncertainties, such as the heuristics used in specifying agent decision rules and representation of the innovation process. The second capacity is as a *scenario discovery* tool, as outlined by Robalino and Lempert (2000). This mode allows one to engage in a participatory, computer-based approach that achieves fully integrated scenario creation for exogenously supplied policies. A particularly useful aspect of the scenario discovery mode is that policy solutions from other modeling frameworks can be used as an input into ENGAGE, allowing for testing of policy robustness to imperfect information and agent bounded rationality.

2.1 Putnam Two-Level Game

In ENGAGE, the conceptual link between the international *Level 1* and the domestic lower *Level 2* is based on the Putnam two-level game (Figure 1). The theory of two-level games has had a profound influence on thinking about the way states behave in international negotiations. According to the metaphorical frame put forth by Putnam (1988), international negotiations take place at two levels. At the international level (Level 1), negotiators bargain for a tentative agreement. Each negotiator is assumed to have “no independent policy preferences, but seeks simply to achieve an agreement that will be attractive to his constituents” (Putnam 1988:435-6). At the domestic level (Level 2), there are separate discussions among constituents within each nation about whether to ratify the agreement. Hence, the negotiators face a dual task. First, they must try to negotiate an agreement that they expect to pass the Level 2 ratification requirement in all (significant) nations. And second, given that a particular agreement has been reached at Level 1, they must seek to persuade their own constituents to accept and to ratify this agreement.

2.2. Level 1: International Negotiations

We represent the Level 1 negotiation process through a modified version of the model described in Lai and Sycara (2009). In this model, negotiators do not possess perfect information or foresight, but have knowledge of their constituents' preferences, which conform with an underlying multi-attribute utility function. This utility function delineates preferences over multiple key aspects of climate policy being negotiated and determines the players' proposals and responses, however the mathematical form of the function is not known in its entirety to any of the negotiators.

The negotiator's win-set is defined by linking the parameters of the utility function to prevailing preferences at Level 2, where the preferences of domestic agents, such as households and firms, are defined and aggregated based on observations reported in the literature (e.g., Bang, 2010; Fisher, 2004). These domestic preferences are dynamic and are tied to agent beliefs and economic conditions. Because economic conditions are probabilistic in our model and are linked to negotiation at Level 1, ENGAGE has the ability to generate scenarios of international climate policy that are directly linked to micro-level assumptions about agent beliefs and decision rules and the economic system in which agents operate.

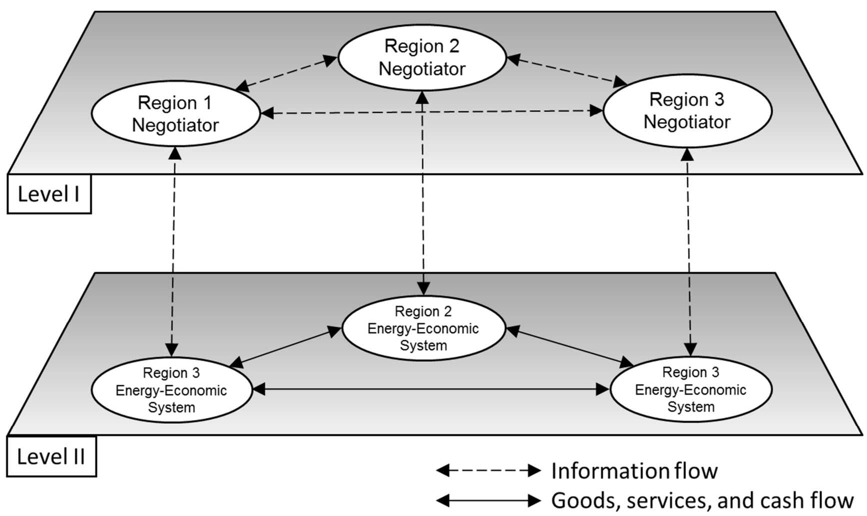

Figure 1. Schematic of the two-level structure of ENGAGE

2.3 Level 2: Domestic Energy-Economy Module

Our domestic model is based on the ABM of endogenous growth and business cycles introduced by Dosi et al. (2010), which we refer to as the DFR model. Our model significantly expands on the DFR model by adding energy as an input and cost factor in the production and use of goods and machines. We also add a simplified energy system, including energy technology and production firms.

In the DFR model, the economy is composed of two types of agents, firms and workers, which observe their environment and make boundedly-rational decisions. Firms are divided into two types, capital-good and consumer-good. Capital-good firms produce machines that are sold to consumer-good firms, which use machines to produce homogenous consumer goods. Workers sell their labor to firms in exchange for the market wage and use all of their income to buy consumer goods. The public sector taxes wages and firm profits and uses the revenue to provide income to unemployed workers. Details of the model's structure are described in (Gerst et al., 2012).

Although our current proof-of-concept model is relatively simple, it allows for the production of scenarios in which prices, wages, energy use, and technological change are determined endogenously. This makes the model responsive to policy details, such as revenue recycling, that are not able to be addressed by many aggregated neoclassical economic models (Figure 2). For example, shifting R&D spending to renewables is predicted to delay the market penetration of low carbon fuels relative to BAU, increasing medium-term energy prices and speeding up the eventual introduction of renewables. Implementing only a carbon tax moves up the penetration of low carbon and renewable sources. However, compared to *R&D shift*, the *Tax* scenario yields much higher energy prices. As shown by the Tax and R&D scenario, the entry of renewables into the market improves considerably when revenue raised from a carbon tax is recycled to renewable R&D. This points to the importance of having a model that can assess the coupled effects of increased R&D spending and a carbon tax. Details of the application of our model to policy analysis are described in (Gerst et al., 2012).

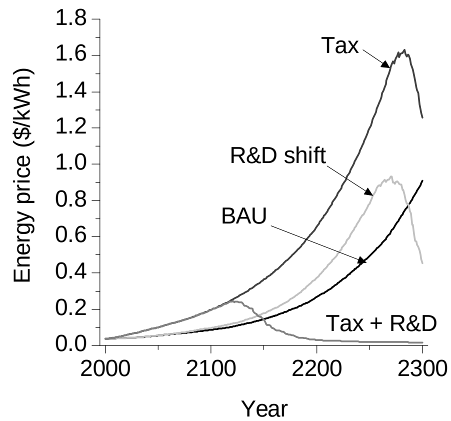

Figure 2. Example results of domestic ABM showing median energy price for business-as-usual (*BAU)* and policy scenarios.

Similar to the two-level model presented by Earnest (2008), we abstract away from voting, lobbying, political parties, and governmental structure by defining a single government agent for each nation whose preferences and beliefs regarding climate change are a function of the beliefs of its constituent agents. Consequently, the government's decision rules are dependent on a weighted function of the aggregate beliefs of the other agents as well as its own beliefs. The weights given to each group are representative of that group's power to influence the government's domestic and international behavior. With this setup, heterogeneous power among agent classes can be specified. The details of this weighting method are still being worked out.

3 SUMMARY OF MODEL PARADIGMS BEING INTEGRATED

In the spirit of this conference session focused on characterizing environmental modeling paradigms, we provide a summary comparison in of the two model approaches that we are integrating for the purpose of climate policy assessment (Table 1).

Table 1: Comparison of model paradigms as employed in ENGAGE

Approach	**Application**	**Types of Data**	**Treatment of Space**	**Treatment of Time**	**Treatment of Uncertainty in Inputs/ Parameters**	**Treatment of Uncertainty in Model Structure**	**Optimization or Scenario-Based**
Agent-Based Models	Representation of domestic system dynamics System experimentation & scenario analysis	Quantitative and Qualitative	None	Annual time steps	Stochastic model runs	Explored with sensitivity Analysis	Scenario-based and heuristic search
Evolutionary Game Theory	Negotiations between multiple boundedly-rational players	Qualitative	Lumped national or regional	Sequential process, with conceding strategies as a function of time.	Explored with sensitivity analysis	Explored with sensitivity analysis	Heuristic search

DISCUSSION

We have made a number of simplifying assumptions in our prototype, proof-of-concept model that, at this point, preclude meaningful interpretation of the results in a real-world setting. Perhaps most significantly, we disregard population growth, which is likely to have a substantial effect on the timeframe over which resource limitations become a motivating force for adoption of energy efficient technologies. Similarly, the number of firms is fixed in our model, which is likely to introduce inaccuracies related to scaling as the simulated economy grows. The current simplicity of the energy sector representation may also misrepresent the opportunities for technology innovation and adoption.

In addition to resolving the oversimplifications of our prototype, future work will attempt to expand the capabilities of the model along several social and natural scientific dimensions. Importantly, to comply with the Putnam two-level international negotiation framework, the policy preferences of households and firms will need to be represented, along with a description of their influence on national policy making. Climate damages and adaptation costs appropriate to each of the agent types will need to be considered, including a representation of agents' beliefs regarding the future severity of damages and efficacy of adaptation measures. As the prototype model currently represents only a single, closed economy, issues of trade will also need to be addressed when the model is applied for the international setting.

Recognizing that further progress is necessary in order for ENGAGE to provide useful support for climate policy evaluation, we see great potential in the integration of an agent-based model of innovation and economic growth within the framework of a two-level game. While game theoretic models have been used to study international negotiations, historically they have not considered feedback from domestic actors who have heterogeneous beliefs and vulnerability to climate change. Similarly, agent-based models have typically been developed to represent specific geopolitical levels and have not linked multiple scales. Considering that the interplay between domestic and international forces will be crucial to agreements between important players such as the United States, Europe, and China, a multi-level understanding of the factors enabling or constraining successful climate policy is essential.

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