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An Evolutionary Model of Industry Transformation and the Political Sustainability of Emission Control Policies

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Summary

Limiting the extent and effects of climate change requires the transformation of energy and transportation systems. Holding global atmospheric concentrations of greenhouse gases (GHGs) below what appear to be unreasonably dangerous levels will require the carbon intensity of these systems to drop more rapidly over the coming decades than it has in the past.

Market-based policies should prove useful in promoting such transformations. But studying which policies might be most effective toward that end is more difficult because, while standard economic theory provides an excellent understanding of the efficiency-enhancing potential of markets, it sheds less insight on their transformational implications. In particular, the introduction of markets often also leads to significant changes in society's values, technology, and institutions, and these types of market-induced transformations are generally not well understood. Our current analytic tools are often inadequate for comparing and evaluating policies that might promote such transformations. Therefore, a better understanding of the interacting socioeconomic mechanisms and processes involved in market-induced transformations would be important for effective policy and decisionmaking.

This technical report focuses on such issues in the context of climate change. The document describes a model that tracks the evolution of an industry sector and its market and tests the outcomes under different carbon emission control policies. The model is a tool to support the design of a government's regulatory policy by examining how measures intended to reduce emissions of climate-changing GHGs may give rise to market-induced transformations that in turn may ease or hinder the government's ability to maintain its policy. This technical report focuses on a description of this model; as we discuss later, the model contains novel features among simulations designed for the assessment of climate change policies. Later publications will focus on the results of policy analyses using the model.

The simulation in this volume examines how the choice of the initial design of GHG emission reduction policies affects how the policies evolve over time. In the spirit of effective long-term policy analysis, we are interested in how the choice of an initial, near-term policy architecture affects the long-term path to zero emissions over many decades. Political scientists have studied the long-term trajectories of initial policy choices in such areas as social protection and deregulation. In particular, Patashnik (2003) has studied cases in which new legistation is put into place during a brief period of focused public concern, and notes the conditions that do or do not lead the policy reform to persist over time after the public concern dissipates. The author found that new policies are more likely to persist when they create supportive and enduring constituencies.

Following this framework, we envision that policymakers have a brief window of opportunity for implementing policies with the ultimate goal of eliminating GHG emissions

(e.g., by passing legislation). Once implemented, policies will evolve along paths no longer under the control of the initial policymakers. In this report, we examine how policymakers might use their window of opportunity to choose a set of initial actions and means that increases the chances of achieving their long-term goal, in part by causing transformations that will yield future conditions supportive of these goals. This general framework seems relevant to the challenge policymakers interested in limiting the magnitude of future climate change face, but no such framework has been widely treated, if at all, in previous model-based climate policy studies.

The new simulation tool involves three key components. At its core is an evolutionary economics model (Nelson and Winter, 1982) that focuses on how the structure of an economic sector evolves as firms make investment decisions in production and new emissions-reducing technologies. An evolutionary economics formalism is ideal for our purposes because its focus on the diffusion of innovation and on firm entry and exit directly addresses processes of transformation in technology and industry structure. This approach not only allows us to simulate agent behavior and market outcomes but also provides a laboratory for testing the linkages that give rise to the observed behavior. Our model builds on recent work by Dosi et al. (Dosi, Fagiolo, and Roventini, 2006, and Dosi, Fagiolo, and Roventini, 2010).

As a second key component, we modified the Dosi et al. model. The most significant modification involved developing a generalized version of the game theoretic "protection for sale" model from the trade economics literature (Grossman and Helpman, 1994), which Polborn (2010) applied to GHG regulatory regimes. This component of the simulation represents the process firms use to attempt to influence the stringency of future GHG regulations as the competitive landscape changes under the influence of innovation (which is driven in part by a firm's research and development [R&D] investment decisions), expectations about future regulatory policy, and changing industry structure. Some firms may find more-stringent regulations beneficial, while others may find them less so. The influence of both sets of firms on government decisions may importantly affect any transition to a low-carbon economy. We have added a simple representation of the economy's interaction with a changing climate to Dosi's model and included carbon intensity as a factor that firms may improve through innovative activities.

As the third component, we embedded this simulation in a set of methods and supporting analytic tools called *robust decision making* (RDM) (Lempert, Popper and Bankes, 2003; Lempert et al., 2006; Lempert and Collins, 2007). RDM seeks strategies that are robust, that is they exhibit adequate performance when compared to the alternatives over a wide range of plausible futures under conditions of deep uncertainty, defined here as the situation in which decisionmakers do not know or do not agree on the structure of the model relating actions to consequences, the probability distributions describing key inputs to the model(s), or the criteria for assessing model outcomes. In this report, we use RDM to compare the consequences of alternative near-term decisions regarding the design of market-based policy architectures for reducing GHG emissions. As the case study work associated with this project emphasized,[1] the available evidence poorly constrains many of the processes expected to prove most important to the comparison of such policy architectures. RDM appears particularly useful for this project because it is designed to provide policy-relevant conclusions under such conditions of deep uncertainty.

This evolutionary, agent-based simulation model and the RDM framework for exercising it are intended to serve as a laboratory for examining how the choice of the initial design of GHG emission reduction policies may affect how the policies evolve over time and the extent to which intended goals are achieved. Initial experiments reported here have generated both expected and surprising results. We explored the model's behavior with over 20,000 different sets of assumptions about future states of the world. We found, as expected, that assumptions about the potential for significant advances in carbon emission reducing technology are key drivers of both the economy's overall decarbonization rate and the strength of the high-carbon-price lobby. In general, decarbonization is fast and the high-carbon-price lobby is strong when opporunities for carbon reducing R&D are strong compared to opportunities for labor-reducing R&D. As an example of the richness of the model's behavior, we also found some situations in which, despite a lack of low-carbon R&D opportunities, a strong high-carbon-price lobby nonethless pursues a high carbon tax to remain competitive with firms with much higher labor productivity.

Initial experiments with a grandfathering policy, in which incumbent firms do not have to pay the full carbon tax on any current capital, suggest that, contrary to our initial expectations, such a policy may have little effect on the decarbonization rate. We had expected that grandfathering would reduce the initial strength of the low-carbon lobby by reducing the incentive for established firms to advocate for a low carbon price. But, on average, this effect is countered by new entrants' increased need for a low carbon price to remain competitive with established firms.

In the next steps of our work, we will continue to explore the effects of alternative policies and the specific types of circumstances in which policies, such as grandfathering, may prove more or less effective. Overall, it is our intention to apply this model to an examination of how the interaction between firms and the government may affect government choices about how to design market-based regulatory policies to improve their prospects of catalyzing potential carbon-reducing transformations of the economy. The current model is clearly a first step, but its combination of elements, combined with the means for exercising it, provide a unique platform for addressing such issues.

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[1] Eric L. Kravitz and Edward A. Parson, "Markets as Tools for Environmental Protection," *Annual Review of Environment and Resources*, Vol. 38, 2013