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Avoiding misuses of energy-economic modelling in climate policymaking

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Energy-economic models are increasingly being used to inform climate mitigation policies. This Comment describes three situations where models misinform policymakers and calls for more iterative, policy-orientated modelling exercises that maximize learning in the pursuit of long-term emissions reductions goals.

Energy-economic models are complex quantitative tools used to inform climate policymaking by projecting future energy systems, economies and environmental outcomes. They derive relationships between large numbers of variables using a combination of theoretical concepts and historical data. Energy-economic models can be useful tools to help answer questions about policy design and costs, likely responses to incentives, how effects cascade across interconnected economic sectors, and more.

Policymakers look to modelling to support policy development or to help justify their preferred strategies. Analysts benefit when policymakers use their models to inform real-world decisions. Few incentives, if any, encourage the cautious and limited use of modelling in climate policymaking.

The general limitations of modelling are well documented[1], but the modelling of climate mitigation policies may be especially prone to misuse. To help policymakers avoid these misuses, we describe three common situations that show how models can misinform climate policy decision-makers: (1) when the time horizon of the analysis is too long; (2) when the analysis is insufficiently comprehensive; and (3) when the analysis is insufficiently detailed. We finish with a discussion of how more limited and iterative modelling exercises can inform decision-making more effectively.

The time horizon of the analysis is too long

Decarbonization strategies span decades or longer, yet projections of energy systems and economies become less useful with longer time horizons. As the duration of an analysis lengthens, an inherent tension exists between models' declining capacity to produce meaningful projections of critical outputs (for example, prices) and policymakers' desire for such projections.

Consider the long-run effects of climate policies on economic growth. Certain energy-economic models simulate macroeconomic outcomes by changing prices or constraining outputs and measuring how those 'shocks' percolate throughout an economy[2]. Such models can produce policy-relevant insights over time horizons for which future responses to the shocks can plausibly be expected to resemble the past responses upon which the model relationships are built.

However, as the duration of the analysis lengthens — and showing results to 2050 is common in climate policy modelling — the assumption that historical data will be a good guide to future behaviour becomes unreasonable[3]. Technologies, preferences and the structures of energy systems change dramatically over decades. Indeed, recent changes in the costs of natural gas, solar energy and batteries have transformed expectations about future energy systems[4].

Modellers understand they cannot predict such changes. To avoid this uncertainty, they commonly assume relatively static energy systems that underestimate the flexibility of households, firms and supply chains, which leads to highly misleading estimates of macroeconomic outcomes. For example, the latest IPCC Working Group III Summary for Policymakers[5] finds that actions to limit warming to 2 °C would reduce global gross domestic product by 1.3–2.7% in 2050 — a loss of trillions of dollars in economic value. However, this range is effectively meaningless because the underlying models are incapable of depicting the plausible changes to energy systems over this period.

To be sure, certain projections are valuable over long durations. For example, policymakers can have some confidence in projections of the warming that will result from a long-term emissions pathway because the interactions between emissions, atmospheric concentrations and the greenhouse effect are relatively well understood. By contrast, outcomes such as prices and technological change depend on changes in human behaviour, which in turn hinge on future policies (which often induce innovations) and other economic shocks that are unpredictable over long horizons. The final section of this Comment explains that in these situations, policymakers are better off using short-term projections combined with iterative policy applications designed to trigger maximum learning.

The analysis is insufficiently comprehensive

Decarbonization strategies have economy-wide and global effects, while the sectoral and geographic scopes of energy-economic models are limited. Models therefore inevitably omit important dynamics.

Consider the economic modelling of 'green industrial policies', which are efforts by governments to spur climate-friendly economic activity in specific domestic sectors. A recent International Monetary Fund (IMF) report discusses a range of justifications for green industrial strategies, including boosting economic competitiveness, avoiding disruptions in labour markets, accelerating innovation in sectors that generate knowledge spillovers, improving environmental outcomes and enhancing security[6]. Meanwhile, the adverse effects of these strategies include the risks of imposing trade barriers and the dangers of government actions that favour certain private firms.

No model is comprehensively equipped to weigh these benefits and drawbacks, yet modelling efforts purport to estimate the economic effects of green industrial strategies.

BOX 1

Examples of iterative processes in climate policymaking

The Montreal Protocol is an international agreement that was adopted in 1987 to phase out the use of substances that deplete the ozone layer in the atmosphere. It tasks key stakeholders — including regulators, regulated firms and scientists — to experiment on the best ways to achieve the Protocol's goals, and to learn from iterative successes and failures. For example, regular reassessments of progress and available options, including with modelling exercises, lead to adjustments to the phase-out schedules, the financial and organizational support for developing countries, and the rules for compliance monitoring and enforcement. The 2016 Kigali Amendment added the commitment to phase out heat-trapping hydrofluorocarbons to the Protocol, which could prevent up to 0.5 °C of warming by 2100. The United States, China, the European Union and other countries have since adopted stricter regulations on hydrofluorocarbons[13].

At the country level, the United Kingdom passed the Climate Change Act in 2008, which places legally binding limits on greenhouse gas emissions in the country. The law includes five-year carbon budgets on the pathway to a long-term target of net-zero greenhouse gas emissions by 2050 (the original target of 80% emissions reductions was amended in 2019). To enable long-term planning, the UK government must set carbon budgets 12 years in advance and develop proposals to achieve the successive emissions targets. These carbon budgets are developed using a suite of sector- and economy-wide models of the country's energy and land-use emissions systems. An independent organization (the Climate Change Committee) is tasked with assessing progress and recommending changes to policies and carbon budgets as new information emerges, with the government legally required to respond to its recommendations. Emissions have declined rapidly since the Act was passed, particularly in the electricity sector, although the Climate Change Committee has warned that additional policies will be needed to achieve future carbon budgets[14].

A subnational example is California's Zero-Emission Vehicle standard, which is a programme established by the California Air Resources Board to reduce emissions by requiring automakers to gradually increase the percentage of electric and other low-emitting vehicles in their sales portfolios. To reduce the costs of achieving the overall targets, automakers are allowed to buy and sell credits from other manufacturers. The California Air Resources Board periodically conducts analyses to review the policy, including using sector-specific models, and to make changes that reflect new information about the evolution of the vehicle fleet, consumer demand, anticipated future progress and other factors. Over time, these analyses have led to the refinement of various aspects of the policy, including the list of eligible vehicles (for example, to provide partial credits for hybrid vehicles) and the stringency of the standards as electric vehicle adoption has progressed[15].

For example, the same IMF study highlights an 'illustrative simulation' of the welfare implications of green industrial policies. The IMF model is limited in its portrayal of the economic benefits, with its main scenario including only the benefits of directing investments to sectors that generate relatively high 'knowledge spillovers'. Nevertheless, the IMF draws a broad conclusion, declaring that pursuing industrial policies generates productivity and welfare gains only under stringent conditions, with those conditions essentially requiring a country devoid of corruption[6]. However, the IMF model omits important factors that may be decisive for policymakers, such as the desire to avoid labour market shocks that have previously caused the hollowing out of manufacturing regions[7].

Other studies give policymakers the opposite impression, that green industrial strategies will boost economic growth and generate millions of additional jobs, while failing to capture the drawbacks of trade barriers and targeted government spending[8].

Modelling therefore provides strong but conflicting conclusions, while policymakers would be better served if analysts were transparent about their inability to model the net economic effects of green industrial strategies.

The analysis is insufficiently detailed

Greenhouse gases are emitted from virtually every corner of the economy, so energy-economic models commonly capture a range of sectors and regions. However, they rarely include detailed treatments of individual sectors and regions, which means they can overlook important climate solutions, which are often process- and technology-specific.

Consider the insights from energy-economic models about the role of heavy industry, such as iron and steel, within long-term decarbonization strategies. While the iron and steel sector is the largest source of industrial emissions, decarbonization models typically include limited and oversimplistic options to reduce emissions from these activities[9]. Until recently, these models showed that minimal decarbonization was feasible via energy efficiency and electrification, and 'deep decarbonization' would be achieved mainly using carbon capture and storage (CCS) technologies on coal-driven blast furnace–basic oxygen furnaces (BFBOFs). And because CCS was expensive and underdeveloped compared with decarbonization solutions in other sectors, the decarbonization of heavy industry was seen occurring far in the future.

Buoyed by the momentum for mid-century net-zero emissions targets, a wave of more granular analyses has revealed a host of additional promising decarbonization opportunities[10,11]. Now, a more detailed consideration of material efficiency and substitution opportunities often show relatively inexpensive 25–30% emissions reductions. In addition to CCS on coal-driven BFBOFs, other deep decarbonization options include direct reduced iron furnaces that use reformed natural gas combined with CCS or electrolytic hydrogen as the primary reductant (instead of coal), and eventually direct electrolysis of iron ore.

When interpreted properly, energy-economic models can serve as sophisticated accounting tools that improve policymakers' understanding of the opportunities and challenges of pursuing emissions targets and other policy goals across sectors, including heavy industry. However, the models with CCS as the only option for large emissions reductions from iron and steel led to the misleading impression that its deep decarbonization was beyond immediate policy concern. Policymakers may have been better off eschewing economy-wide models and focusing instead on detailed sector-specific analysis.

Less ambitious modelling can be more useful

The shared theme of our examples is modellers trying to do too much, that is, quantifying the unquantifiable, or drawing overly broad conclusions. Policymakers are often unaware of model limitations and unable to distinguish when complex analytical tools can provide useful results.

Less ambitious modelling exercises may better support effective climate policy formation via 'adaptive management'[12], which emphasizes learning through iterative processes involving policymakers, modellers and other key stakeholders. Unlike a pure trial and error approach, adaptive management has an explicit knowledge-building structure, including the careful identification of objectives, falsifiable hypotheses linking actions to outcomes, and procedures for data collection followed by evaluation and reiteration.

Successful examples, such as the Montreal Protocol, the United Kingdom's Climate Change Act, and California's Zero Emission Vehicle standard, demonstrate the value of this iterative process (Box 1). Each of these policies includes ambitious targets, but policymakers did not require modelling that showed the entire pathway to phasing out emissions. Instead, these climate policy successes benefited from limited modelling exercises combined with iterative policy applications and the shared learning of a broad range of stakeholders.

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Competing interests

The authors declare no competing interests