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Environmental impact assessment for climate change policy with the simulation-based integrated assessment model E3ME-FTT-GENIE

Jean-Francois Mercure [a, b, c, *], Hector Pollitt [b, c], Neil R. Edwards [c, d], Philip B. Holden [d], Unnada Chewpreecha [b], Pablo Salas [c], Aileen Lam [c, e], Florian Knobloch [a, c], Jorge E. Vinuales [c]

[a] Radboud University, Netherlands, Department of Environmental Science, PO Box 9010, 6500 GL, Nijmegen, The Netherlands
[b] Cambridge Econometrics Ltd., Covent Garden, Cambridge CB1 2HT, UK
[c] Cambridge Centre for Environment, Energy and Natural Resource Governance (C-EENRG), University of Cambridge, The David Attenborough Building, Pembroke Street, Cambridge, CB2 3QZ, UK
[d] Environment, Earth and Ecosystems, The Open University, Milton Keynes, UK
[e] Department of Economics, Faculty of Social Sciences, Humanities and Social Science Building, University of Macao, E21, Avenida da Universidade, Taipa, Macao

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A B S T R A C T

A high degree of consensus exists in the climate sciences over the role that human interference with the atmosphere is playing in changing the climate. Following the Paris Agreement, a similar consensus exists in the policy community over the urgency of policy solutions to the climate problem. The context for climate policy is thus moving from agenda setting, which has now been mostly established, to impact assessment, in which we identify policy pathways to implement the Paris Agreement. Most integrated assessment models currently used to address the economic and technical feasibility of avoiding climate change are based on engineering perspectives with a normative systems optimisation philosophy, suitable for agenda setting, but unsuitable to assess the socio-economic impacts of realistic baskets of climate policies. Here, we introduce a fully descriptive, simulation-based integrated assessment model designed specifically to assess policies, formed by the combination of (1) a highly disaggregated macro-econometric simulation of the global economy based on time series regressions (E3ME), (2) a family of bottom-up evolutionary simulations of technology diffusion based on cross-sectional discrete choice models (FTT), and (3) a carbon cycle and atmosphere circulation model of intermediate complexity (GENIE). We use this combined model to create a detailed global and sectoral policy map and scenario that sets the economy on a pathway that achieves the goals of the Paris Agreement with >66% probability of not exceeding 2 °C of global warming. We propose a blueprint for a new role for integrated assessment models in this upcoming policy assessment context.

1. Introduction

1.1. New questions raised by the Paris Agreement and the role of models

December 2015 saw a historical moment for climate policy in which, for the first time, almost all countries of the world adopted a formal agreement to reduce emissions in order to limit global warming to temperatures below 2 °C [1].[1] This event marked a change in efforts to develop climate policy: the agenda, whether or not to adopt measures to avoid climate change, was mostly set. What remained to be done was to find out how to achieve this objective with public policies, in every country that is party to the agreement.

* Corresponding author. Radboud University, Netherlands, Department of Environmental Science, PO Box 9010, 6500 GL, Nijmegen, The Netherlands.
E-mail address: J.Mercure@science.ru.nl (J.-F. Mercure).

[1] Article 2a of the Paris Agreement sets the following target: “Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change”.

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Developing climate policy is a complex process that could involve planning for dramatic societal changes and socio-economic impacts [2]. Policies can have unintended effects. The far-reaching consequences of adopting particular emission reduction policies can be challenging to fully foresee, as they involve changes in many sectors and for many actors. For example, could adopting a high price of carbon to incentivise electrification increase electricity prices for consumers, thereby reducing access to modern energy for those who cannot afford it? Can biofuels policy lead to unintended land-use change, or lead to water or food scarcity? Could reducing the consumption of fossil fuels globally lead to high rates of unemployment in producer countries? Could a highly capital-intensive, low-carbon transition lead to excessive debt leveraging of government and/or firms, and result in a carbon bubble?

In order to determine the impacts of specific policies, research must move from the agenda-setting stage to the actual impact assessment of policies. This corresponds to a different stage of the policy cycle, and requires analysing the impacts of detailed baskets of policies, as they are envisaged by policy-makers, with all the attendant political and legal complexities, rather than merely recommending – often unrealistic – policies that appear optimal. In the perspective of impact assessment (e.g. see [3]) the policy parameter space is too large to optimise, and individual policies can synergise or interfere [4]. The complexity of the impact assessment problem must account for the uncertainty over the knowledge of the modeller about the way in which decision-making actually takes place with agents [5], and how the heterogeneity of agents might influence policy outcomes [6,7]. Models based on representative agents have therefore insufficient resolution for carrying out realistic impact assessment [8]. It is more and more recognised that increasing the level of behavioural information in models enables them to represent more policy instruments and thus cover a wider policy space [9–12].

Climate policy analysis, in the agenda setting perspective (e.g. [13–15]), has focused primarily on total energy system cost, consumption loss and GDP loss as indicators to characterise the socio-economic impacts. This is now insufficient, as policy-makers are increasingly requiring information on many other types of impact [16]. For example, questions arise over large-scale finance of technological change, and its impact on the macroeconomic system [17]. The choice of model type for this purpose pre-determines the results that can be reached [18]. Most equilibrium models of the economy used to analyse climate policy have restrictive assumptions over the functioning of the financial sector such that their outcomes are almost entirely determined by a debatable assumption, that re-allocating finance for technological change to reduce emissions takes away investment from other productive sectors of the economy, which automatically leads to loss of GDP ([19], see also [13] and references therein). In fact, research on innovation tends to suggest the opposite [20–22]. Following the financial crisis of 2008, the key question of many policy-makers is not how many percentage points of GDP loss climate policy might entail, but rather, whether securing large-scale investment is possible without leading countries to financial instability [23–27].

In this paper, we introduce the new integrated assessment model E3ME-FTT-GENIE, which is designed to tackle the question of environmental impact assessment with the most realistic policy definition currently available, while enabling policy-makers to explore macro-financial issues that may arise from the introduction of such policy. We first describe the policy context that the model attempts to address, as well as the origin and history of economic thought behind its assumptions. We then describe its components: climatology, non-equilibrium macroeconomics and evolutionary technology modelling. We subsequently provide an example of environmental policy analysis under several socio-economic indicators. We conclude with an outlook for future research in the field of integrated assessment modelling.

2. Context: fundamental uncertainty in impact assessment

2.1. Pervasive property: fundamental uncertainty means no equilibrium

The modelling approach described in this paper is one of simulation. Each part of the E3ME-FTT-GENIE modelling framework attempts to represent real world relationships, in terms of accounting balances, physical interactions and human behaviour. This consistency in approach throughout the suite of linked models is crucial to providing insights that are useful to policy-makers. The results from the model are predictions of outcomes based on empirical behavioural and physical relationships observed in the past and the present.

The starting point of this methodology regarding human behaviour is one of fundamental uncertainty [28,29]. This premise expresses limitations to knowledge and to the knowable for agents that take part in the economic process. This position runs contrary to the assumptions of perfect knowledge and/or perfect foresight that underlie many other modelling tools, which are used in order to simplify theories and models to a tractable state. Fundamental uncertainty recognises that it is not possible for individuals, firms or other agents to know all the possible outcomes from a decision-making process, and thus that ‘unknown unknowns’ exist. Under these conditions, it is not possible to estimate probabilities of different outcomes of particular agent decisions, as, with unknown outcomes, the probabilities would never sum to one. From this standpoint, some aspects of decision-making by agents lacking knowledge cannot be reduced to pure risk (as it is in standard Expected Utility Theory). Hence, it is therefore not possible to optimise the decision-making process, and agents either make decision errors, or plan ahead for uncertain outcomes (e.g. with spare production capacity).

As noted by Keen [30], it only requires one agent to make sub-optimal decisions for the system of optimisation to break down as a whole. The consequences are profound. For example, without full knowledge by every economic agent of supply- and demand-price elasticities, there is no guarantee that prices will move to market-clearing rates, where resources would be used in the most efficient manner. The level of output is no longer determined by supply-side constraints (e.g. the number of factories), as the available resources will not necessarily be used (there may be too many factories for the demand). Alternatively, given fundamental uncertainty in the knowledge of the demand function by agents, agents may decide to build spare capacity in preparation for possible demand fluctuations.

2.2. There is no optimality in policy-making

Without optimizing behaviour, it is not possible to design optimal policy. Probst and Bassi [2] recognize the shortcomings of attempting to optimise public policy. The authors advocate an approach that is based on identifying policy that is found to be effective in the real world, rather than aiming for optimal outcomes. Learning-by-doing in policy-making reduces fundamental uncertainty. To be effective, the policies must first address the issue they are designed for, but ideally, also avoid negative consequences in other policy areas (for example, large economic costs or negative impacts on social cohesion). Due to the complex nature of contemporary economies and the heterogeneous nature of agents that interact within these economies [8], it is not sufficient to