THE STATE OF APPLIED ENVIRONMENTAL MACROECONOMICS

Gissela Landa Rivera, Paul Malliet, Aurélien Saussay
Sciences Po OFCE
Frédéric Reynès
NEO (Netherlands Economic Observatory), TNO (Netherlands Organisation for Applied Scientific Research) and OFCE

To a large extent, environmental macroeconomics is developing outside of the theoretical debates taking place in other fields of research in applied macroeconomics. This is evidenced by the low representation of environmental issues in mainstream economics journals and in advanced macroeconomics textbooks. While the environment has not up to now been considered as a subject in itself for advancing knowledge in macroeconomics, since the 1990s it has at least been an important topic for applying macroeconomic models. These models have been used in particular to analyse and quantify the economic effects of the transition to a sustainable system of production and consumption. We propose to shed light on the state of the art in applied environmental macroeconomics. More specifically, we will endeavour to identify the specific features of this area of research that explain the theoretical and empirical choices made.

Keywords: environmental macroeconomics, macroeconomic modelling, IAM, CGE.

It should be emphasized first of all that in the vast majority of cases, environmental macroeconomics is primarily *climate* macroeconomics. The other major themes of environmental economics – the limitation of negative externalities, the management of the commons, the exploitation of renewable and non-renewable resources – are treated in other branches of the discipline of economics, such as microeconomics or experimental or behavioural economics. Conversely, the climate issue is largely a macroeconomics issue. Reducing greenhouse gas emissions is a sine qua non for limiting climate change and therefore for reducing the associated risks for the environment and ecosystems (IPCC, 2014). This implies a profound change in behaviour related to the production and consumption of energy, which affects the entire economy. Likewise, the consequences of climate change, which are beginning to manifest themselves through an increase in extreme weather events and a continuous rise in the average temperatures observed, are leading to profound and abrupt changes in the ecosystem equilibrium on which all human economic activities depend.

The study of the economic aspects of climate change therefore requires taking into account all of these dimensions. The relevant models can be of help in the formulation and evaluation of public policies aimed at reducing the greenhouse gas emissions responsible for climate change. These policies – carbon pricing, global or sectoral ceilings on emissions, regulatory standards or similar interventions – require a degree of guidance by the public authorities. This necessitates the use of applied macroeconomic models that can simulate realistic economic dynamics.

The primary use of the models produced by environmental macroeconomics is to provide support for public decision-making and for the continuous assessment of the transformations needed to achieve the environmental objectives that society has set itself. This role imposes an applied approach. The intention is in this sense quite comparable to the role of Dynamic Stochastic General Equilibrium (DSGE) models in the implementation of monetary policy. Central banks use these to help answer concrete macroeconomic and monetary policy issues. Environmental macroeconomic models are intended to play a similar role in the fight against climate change. However, their task seems more difficult than that of DSGEs, which are nevertheless the subject of intense debate over the nature of the tool, its real explanatory power and its complementarity with other tools.[1] Environmental macroeconomic models face similar challenges but with a higher degree of complexity. As will be seen, this stems from a lack of consensus concerning the theoretical framework of the model, and the need to take into account the heterogeneity of the agents and to incorporate modelling techniques borrowed from other disciplines (physics, engineering, climatology), but also from the diversity and complexity of the economic policies that must be taken into consideration.

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1. See in particular the recent vigorous exchanges concerning the article by Christiano *et al.* (2017).

This article describes the main features of the contemporary macroeconomic models that deal with the climate issue and sheds light on the controversies surrounding them. In particular, we review existing models in order to present their main characteristics, in terms of both the structure and object of study. Finally, we propose a number of improvements that could deal with certain criticisms, both in approaches to modelling and in methods of dissemination.

1. Integrated Assessment Models (IAM)

As is pointed out, and regretted, by Katheline Schubert (see her article in this issue), the problem of climate change, and more generally of the increasing use of natural resources, is largely ignored by advanced research in macroeconomics, which often favours analytical coherence to the detriment of applied research. This is evidenced by the low representation of environmental issues in mainstream economics journals and in advanced macroeconomics textbooks. Thus, recent works that are part of the neo-Keynesian synthesis and use DSGE models do not deal with these issues, preferring to focus instead on short-term matters. And while neoclassical growth models regularly incorporate environmental components, these do not affect the structural determinants of growth, unlike education, public infrastructure, technology, or institutions. While the environment is not considered a topic that can in itself advance knowledge in macroeconomics, it is nevertheless a subject for which there is a strong social demand and for which economics has proven to be relevant for highlighting existing trade-offs by determining the costs and benefits to be considered.[2] It has also been the subject of numerous applications of macroeconomic models since the 1990s. These have been used in particular to analyse and quantify the economic effects of the transition to a system of sustainable production and consumption. Two main classes of macroeconomic models are used: Integrated Assessment Models (IAMs) and Computable General Equilibrium (CGE) models, which will be discussed in the next section.

The IAMs include PAGE (Hope, 2006) and FUND (Waldhoff *et al.*, 2014) models as well as the suite of models developed under the Integrated Assessment Modelling Framework (IIASA).[3] But the DICE model

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[2] See on this subject the article "Acid Rain" (Newberry *et al.*, 1990).

[3] See http://www.iiasa.ac.at/web/home/research/researchPrograms/Energy/IAMF.en.html.

developed by Nordhaus (1991, 2013) is still today the flagship of this class of models. While IAMs can be very complex due to the interdependence of many economic and technical modules, the success of DICE is probably due in large part to its transparency and relative simplicity. DICE is composed of a climate module and a macroeconomic module. The first represents the relationship between the increase in the concentration of greenhouse gas emissions (measured in CO_2 equivalent) and the rise in global temperature over time. The second converts this rise in temperature into economic damages (using a damage function). The macroeconomic module also determines the link between economic activity and emissions as well as the cost associated with their reduction (*via* an abatement curve). Assuming that a representative economic agent maximizes his or her inter-temporal utility under the assumption of perfect expectations, DICE endogenously determines the social cost of carbon as measured by an "optimal" carbon tax. The latter is defined by the trade-off between short-term profits and the long-term costs of economic growth for well-being. While the standard version of DICE is deterministic, recent research has been developing stochastic IAMs to account for the uncertainty surrounding the model's key parameters.[4] Despite the relative simplicity and transparency of the DICE model, it is still subject to the virulent criticism of Pindyck (2017) against IAM: "In a recent article, I argued that integrated assessment models (IAMs) 'have crucial flaws that make them close to useless as tools for policy analyses'. In fact, I would argue that calling these models 'close to useless' is generous: IAM-based analyses of climate policy create a perception of knowledge and precision that is illusory, and can fool policy-makers into thinking that the forecasts the models generate have some kind of scientific legitimacy. IAMs can be misleading – and are inappropriate – as guides for policy, and yet they have been used by the government to estimate the social cost of carbon (SCC) and evaluate tax and abatement policies." Pindyck (2017) criticizes IAM for the arbitrary calibration of some of their parameters, even though they are crucial for the model's properties and results. These include the discount rate, the damage function and climate sensitivity (the link between temperature and concentrations of greenhouse gases).[5]

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[4] See, for example, the applications and the literature review of Hwang *et al.* (2013, 2017).

This calibration problem amounts to a criticism that is generalizable to almost all economic models used in different fields. But beyond this criticism, Pindyck especially blames IAM's developers and users for their lack of humility and scientific honesty about the limitations of their model, out of a desire to feign expertise and hide their ignorance behind mathematical abstractions. Another underlying criticism is the largely normative nature of the main area where IAMs are applied, namely the endogenous estimation of the social cost of carbon. But the determination of the social cost of carbon goes far beyond the scope of economics, as in essence it reflects our degree of altruism vis-à-vis future generations and therefore is more akin to a question of moral ethics than it is a simple calculation of inter-temporal optimization. The way in which this question is translated into economic terms in IAMs leads to questionable simplifications. While it offers a useful abstraction, maximizing an inter-temporal utility under the assumption of a discount rate does not capture the full complexity of our trade-offs with the well-being of future generations. It reflects only one possible way (among many) to resolve the conflict posed by climate change over distribution between present and future generations.

To overcome this limit, Pindyck outlines a more positive approach to determining the social cost of carbon. The first step is to define an emissions trajectory that is compatible with some desired result. Pindyck proposes as a criterion the avoidance of the catastrophic consequences of climate change. Other criteria could be bequeathing the environment to future generations in a certain state of conservation. The second step involves deducing the economic costs associated with one or another objective. The economist no longer claims to give an optimal trajectory of emissions. Instead this trajectory primarily reflects a sovereign choice (preferably *via* a democratic process) and is recognized as such. This trajectory is therefore a constraint to be respected that needs to be defined outside the model, on the basis of diverse scientific expertise, but also through political and social compromise. While IAMs cannot be used to define such a trajectory, they have nevertheless made it possible to gain policy makers' interest and to shed light on the climate issue, as shown for example in the work on the social

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5. In particular, the publication of the Stern Report (2006) sparked a broad debate on the very issue of the discount rate but also on taking into account uncertainty, especially that relating to the occurrence of extreme events. See Beckerman and Hepburn (2007), Nordhaus (2007), Weitzman (2007, 2009) and Dasgupta (2007, 2008).

cost of carbon of the Quinet Commission (2008) in France or of the working group under the Presidency of the United States (Environmental Protection Agency and Change Division Council, 2016).

2. Computable General Equilibrium (CGE) Models

Computable General Equilibrium (CGE) models make up the second category of macroeconomic models being applied to the environment. These models are often relatively large, because they have a sectoral representation calibrated on the Input-Output data from the national accounts. Unlike IAMs, CGE models do not incorporate intertemporal optimization behaviour. They are not trying to derive optimal trajectories for a carbon tax or emissions. Indeed, the trajectory of emissions is often an exogenous target defined outside the model. The carbon tax and other economic policy instruments are used to hit this target, and the model measures the associated economic impacts. For some scenarios, the CGEs seek to take into account policies that promote social acceptability (e.g. redistribution of part of the carbon tax revenue to the poorest households) but also possible technical or temporal constraints related to the reduction of emissions. The CGEs are therefore based on a more positive approach than IAMs. They seek more to understand and quantify the consequences of certain economic policy choices rather than to determine the economically optimal environmental policies. Their specification is the result of a trade-off between complexity, internal and external coherence, and the possibility of answering the questions posed. They are thus often criticized for their lack of transparency. There are basically three reasons for this.

The first arises from the lack of consensus on the theoretical underpinnings of the model. Although subtleties exist, one can subdivide the literature into two classes of CGEs. There are the neoclassical CGEs, which assume that the perfect flexibility of prices and quantities ensures the full use of the factors of production at all times. These include (but are not limited to) the following models: OECD ENV-Linkages multi-country (Chateau *et al.*, 2014); Centre for Global Trade Analysis (GTAP, 2014); GEM-E3 (Capris *et al.*, 2013); and the multiregional RHOMOLO (Brandsma *et al.*, 2015).

Other models use neo-Keynesian-inspired hypotheses by introducing friction: price, capital and labour adjustments are assumed to be slow because of empirically observed rigidities and adjustment costs. Neo-Keynesian CGEs applied to environmental issues include the E3ME macroeconometric models (Cambridge Econometrics, 2014), GINFORS (Lutz *et al.*, 2010) and NEMESIS (ERASME, n.d.).[6] The latter estimate the elasticities and adjustment times of the main behavioural equations. The ThreeME model developed by the OFCE in collaboration with the ADEME is also a CGE of neo-Keynesian inspiration. [7] Note that it is not easy to classify some CGEs because some models combine neo-classical and neo-Keynesian assumptions. For example, FIDELIO (Kratena *et al.*, 2013) uses slow adjustments on consumption whereas they are instantaneous for the price-setting and the demand for inputs.

The coexistence of models applied with divergent theoretical foundations is a source of confusion, even of mistrust, especially for the policy makers for whom the results of these models are intended. The theoretical choices are important since these condition the results obtained. The disagreement between models over whether a double dividend (economic and environmental) exists in relation to climate change mitigation policies is typical in this respect. Substantial differences may arise with regard to orders of magnitude, the sign of effects and the underlying economic mechanisms. While the neoclassical CGEs often conclude that there are negative macroeconomic impacts due to crowding out effects, the neo-Keynesian-inspired models highlight the existence of multiplier effects for public investment in the energy transition, which give rise to favourable economic dynamics. The existence of a double dividend in a neo-classical model thus generally results from a positive impact on supply (improvement of competitiveness or increase of the labour supply), while the neo-Keynesian-inspired models will also highlight demand-driven mechanisms (increased consumption and investment).

The choice of a neo-Keynesian framework seems preferable because the assumptions on which it is based are more realistic than those of the neoclassical framework. The fact that frictions are taken into account also makes it possible to take on board phenomena of

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6. The authors of the E3ME and GINFORS models define their macroeconometric model in opposition to the CGE models. However, from a technical point of view, the difference between the standard CGEs and the macroeconometric models depends on the calibration procedure used and the feedback rules adopted. For this reason, we consider that macroeconometric models belong to the category of CGE models.

7. See Callonnec *et al.* (2013 a, 2013 b, 2016) or Landa Rivera *et al.* (2016). ThreeME is calibrated so as to reproduce the econometrically estimated short-term dynamics.

particular interest to policy makers, such as the impact of a policy on (involuntary) unemployment or inflation. However, the environmental CGEs of neo-Keynesian inspiration do not integrate some specificities of the most advanced neo-Keynesian macroeconomic models, i.e. the DSGE. In particular, expectations are assumed to be adaptive (backward-looking) rather than rational (forward-looking). This choice is guided by the need to maintain a certain simplicity to the model's solutions, whereas the DSGE hypothesis of inter-temporal optimization with perfect information has not demonstrated its empirical robustness. Environmental CGEs thus favour the coherence and manageability of the model in order to take into account certain elements specific to the climate change issue.

The criticism of a lack of transparency also stems from the fact that the CGEs are often large models. Because of their detailed sectoral disaggregation, they include numerous parameters that are defined at the sectoral level, such as the elasticities of substitution between factors of production, whose calibration is not very well documented. Constituting the calibration database often requires modifying the raw data by implementing a series of hypotheses that are at the discretion of the modeller. Yet these are crucial to the model's properties. For example, the disaggregation of a sector such as electricity into several sub-sectors requires breaking down not only output but also the different factors of production between the sub-sectors. The data needed to perform this work correctly is not always available. When the model is multi-country, it is necessary to establish consistency between the national accounts and international trade data. This work, already difficult at the aggregate macroeconomic level, can be very complex when taking the sectoral component into account. At the impetus of projects such as GTAP (www.gtap.agecon.purdue.edu), EXIOBASE (www.exiobase.eu), and WIOT (www.wiod.org), great progress has been made in building international and multi-sector Input-Output (IO) databases. In addition to developing consistent national economic and international trade data, these databases provide environmental extensions (CO2 emissions or the use of various natural resources) that are very useful for the construction of environmentally applicable CGEs. Better clarity is nonetheless still needed for these resources, and in particular the steps involved in constructing these databases are generally not accessible. They are based on the crossing of different occasionally contradictory statistical sources that more or less complex algorithms make consistent.

The third reason for criticizing the lack of transparency of environmental CGEs is that they are sometimes coupled with bottom-up techno-economic models. This approach is known as hybridization.[8] While the linking methods vary and can be more or less integrated into a coherent ensemble, they all aim to give a richer representation of reality in its different dimensions, by integrating in particular technical and sociological constraints specific to certain economic sectors or categories of households. Since these constraints are not sufficiently taken into account by the standard analytical tools used in the economic sciences (production or utility function), it is necessary to include them if one wishes to propose a suitable policy that includes this complexity in its analysis.

For example, in a standard CGE, the representative household maximizes a utility function under an income constraint. Depending on the assumed value of the elasticity of substitution, the consumption of each good follows income more or less proportionally. This representation has the advantage of being relatively simple, but it may be problematic for energy consumption. As theoretically formulated by Lancaster (1966a, 1966b) and applied in some hybrid models (Laitner and Hanson, 2006), a household does not consume energy for its direct utility, but rather for the service it provides when its consumption is combined with the use of an equipment, such as a car or a dwelling. Indeed, it is useless to buy gasoline if you don't have a vehicle. A more realistic theoretical representation is to assume that energy is an "input" used in combination with different types of capital in the household's production function. This represents the fact that some services are produced directly (rather than purchased) by households, such as transport, for example. Households can purchase this service directly from the public transport sector. Alternatively, they can invest in the purchase of a vehicle and then buy the amount of gasoline they need for their mobility. This is for example the assumption used in the hybrid version of ThreeME (see Callonnec *et al.*, 2013, 2016). This representation has several advantages. Energy consumption is no longer mechanically related to income but to the stock of housing and equipment. The use of the equipment (and therefore energy consumption) can increase with income, but it is possible to impose saturation

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[8] For an overview of this method, see the special issue edited by Hourcade *et al.* (2006) in *Energy Journal*. IMACLIM (Crassous *et al.*, 2006; Sassi *et al.*, 2010) is one of most advanced hybrid CGE models.

thresholds on the basis of physical criteria. Rising energy prices no longer lead to higher consumption of all other goods but only to the purchase of less energy-intensive capital goods.

While the aim of hybridization is commendable, this approach has several disadvantages. It increases the complexity of the model, especially if the CGE is hybridized with multiple bottom-up modules. It is a potential source of instability because it introduces non-linearities or threshold phenomena that disturb the solution algorithms. Finally, the results are based on the calibration of certain parameters such as the sensitivity of investment choices to energy prices in the example provided above. And the calibrated value sometimes has little empirical evidence.

3. Towards Greater Transparency and Tractability of Models

Applied environmental macroeconomic models aim to serve as support tools for policy decision-making. It is therefore essential that they succeed in generating sufficient confidence to overcome the transparency issue. A first commonly proposed approach would be to aim at simplification by adopting the dominant practice in theoretical environmental economics, which relies on small models in order to derive properties analytically. This is the approach adopted by the DICE model. Because of its small size and open source nature, its results are easy to replicate. But is it really desirable to transpose the constraints of theoretical modelling onto applied economics?

The simplifying hypotheses retained in theoretical models generally make it possible to obtain an analytical solution. This solution has the advantage of unambiguously demonstrating the mechanisms at work and confirming or invalidating certain intuitions or economic rationales indisputably. But these simplifications have a cost. Their use sometimes comes from a “technical” choice by the modeller, namely facilitating the derivation of closed-form solutions, without any justification in the economic reality being modelled. The dominance of neoclassical approaches in environmental economics is a clear illustration: certain hypotheses (e.g. inter-temporal optimization with perfect information, or full use of the factors of production) continue to make up the foundation of many models, even though they have been rejected empirically.

While the use of simplified models for applied purposes allows for a more analytical rather than numerical approach to environmental policy analysis, it can also lead to questionable conclusions. The empirical failure of the Real Business Cycle (RBC) models, which assume that unemployment is always voluntary and reflects the inter-temporal trade-off between work and leisure, is a typical example of possible shortcomings related to the use of overly simplified models for applied purposes.

As we have seen above, Pindyck reproaches IAM (and the DICE model in particular) for using mathematical formalism to benefit from a scientific validation, when these models are in fact often based on unrealistic assumptions. Thus, while the modelling of the damage function and the role of the discount rate are analytically simple in DICE, they do not have a solid empirical foundation. In addition, recent research on the DICE model and other IAMs is essentially theoretical (introduction of uncertainty into the model, analysis of properties on the basis of a reduced form). They rarely try to make the model more realistic. Pindyck draws the harsh conclusion that IAMs are of virtually no benefit to policy makers.

In an applied approach, the realism of the model's assumptions is crucial, especially since the results are intended to support policy decisions. The subject of environmental macroeconomics requires a relatively faithful representation of the complexity of the phenomena at stake. It is important to integrate a broad set of dimensions such as technological changes, market failures, the structure of production, heterogeneities between countries or in consumer behaviour, divergences of interest or the economic characteristics of existing infrastructure such as the irreversibility of investments. Since some dimensions fall within disciplines – physics, engineering, climatology – external to economics, there is often a need for dialogue between environmental macroeconomic models and their counterparts in the "hard" sciences based on common objects – energy and materials flows in physical units or stocks of energy-consuming capital, including buildings, vehicles and equipment for industrial production. It is also important to be able to take into account the various supporting policies, since climate issues are essentially multi-sectoral issues that generate inequalities. They require compensation policies or programmes that can be rolled out on fine scales. These are all points for which a realistic representation is necessary if one wishes to propose a relevant analysis.

Shedding light on public decision-making about the energy transition requires explicitly representing the economic and environmental heterogeneity of the different sectors of production. Using a sectoral segmentation of economic activities, Howitt (2006) describes how the use of a representative agent in the main macroeconomic models constitutes a fallacy of composition, which limits their explanatory power. Colander *et al.* (2008) come to similar conclusions about models applied to decision-making. In their view, it is important to go beyond this synthetic representation of the agents' behaviour by introducing heterogeneity.[9] They also propose the use of a non-parametric approach that is closer to the engineering sciences, adopting an agnostic position as to the model's theoretical foundations.

While the multi-sectoral structure of CGEs already reflects a certain heterogeneity in the data, the introduction of differentiated behaviours for certain types of agents forms part of this approach. This hybridization process is aimed at capturing the behaviours specific to energy use by basing them on technical engineering models particular to certain economic activities, such as the structure of energy networks. The search for the micro-foundations of key behaviours and comparisons with empirical data leads to more complex models. However it seems to be the best way to inform public decision-makers. It is up to the modellers to limit this complexity to the very essential so as to make it as easy as possible to read and understand.

To paraphrase a quote attributed to Albert Einstein, the models should be as simple as they can be, but not simpler. It must be accepted that applied macroeconomic models require a certain minimum complexity. Otherwise, they lose their realism and cannot aspire to be tools for political decision-making. It is obvious that when simplifications are possible they must be implemented. But simplifying the models is not an end in itself.

On the other hand, developers of tools to support policy decision-making need to make a major effort in terms of transparency. Ideally, economic modelling applied to the environment should comply with a

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[9] Note that DSGE models are currently at the heart of an economic debate about their (in)ability to predict financial crises. In a recent article, Christiano *et al.* (2017) defended DSGEs by arguing that while these criticisms might apply to pre-2008 crisis models, recent developments that in particular take into account frictions and introduce heterogeneity into agents' behaviour now enable these models to represent non-linearity phenomena specific to the appearance of crises in a faithful and realistic way. A summary of these debates proposed by the Bruegel Institute is available here: http://bruegel.org/2017/12/the-dsge-model-quarrel-again/

standardized protocol that facilitates comparison, and thus greater transparency of models. We will briefly discuss three points on which this approach could be based.

First, economic modelling should focus on measuring the effects of a given policy using specific economic indicators such as employment, inflation, GDP, income and so on. Given the state of current knowledge about economics, a model that claims to calculate the optimal tax policy or the optimal level of CO_2 emissions as an endogenous variable is not credible to policy makers. On the other hand, a model can help the latter to identify economic policies that would facilitate achieving a given emissions reduction target by measuring the economic impact of each policy, by integrating different types of instruments and by identifying the redistributive effects. From the perspective of developing modelling tools to support decision-making, the approach taken by the CGEs seems to be preferable to that of the IAMs.

Second, it is necessary to try to rationalize the complexity of the models, in other words, to make them more tractable in order to make their properties more transparent. The advances made in the last 25 years in terms of computing capacity have favoured the development of large-scale models. The temptation is great for the modeller to integrate as many dimensions as possible into a single model. This temptation is strengthened by a “marketing” factor: a model's apparent exhaustiveness often helps to obtain funding from research or consulting contracts. Applied models have thus experienced a significant increase in their level of disaggregation based on sectors of activity, geographical zones or types of consumer. Furthermore, hybridization techniques have been developed with techno-economic models, which further complicate the understanding of the model's properties. While complexity can have the benefit of improving a model's realism, it also has disadvantages. For example, a model's level of detail may be only fictitious when the data used for the disaggregation is of poor quality and actually does not provide information relevant to the analysis. In addition, complexity increases the risk of error and often makes the results more difficult to interpret. It is therefore important to have a clear justification for the level of disaggregation used in a model by showing what it adds compared to a simpler analytical framework. Ideally, the level of complexity of an applied model should be scalable to the issue being studied so as not to incorporate a superfluous level of detail that would obscure the analysis of the results.

Third, it seems that making economic models applied to the environment more transparent demands better collaboration between modelling teams. At present, exchanges are generally limited to comparing the different approaches or the results of simulations of common scenarios. Due to a lack of time and resources, these comparisons are often limited to taking note of the differences rather than trying to resolve them. Collaboration between modelling teams upstream of model construction is almost non-existent. One could, however, imagine pooling certain types of knowledge through the use of modelling platforms, as is the practice in other disciplines (for example, climate models). The collaborative construction and use of databases would thus allow economies of scale while above all ensuring that the models are based on hypotheses that are discussed and accepted by different research teams. This approach would also make it easier to compare the results of scenarios that are based on standardized assumptions. Ideally, full transparency would imply the possibility of being able to replicate the results of another model, but that would mean overcoming problems of confidentiality. As a start, pooling blocks of models seems like a more realistic goal. In the longer term, we can hope that open source models become the benchmarks in the field.

4. Conclusion

This article provides an overview of the main macroeconomic models that deal with environmental issues. The limits of these models are all the more problematic as they are destined to be used more and more as decision-making tools, as evidenced by their increasing use in the so-called grey literature (reports from government agencies, think tanks and supranational institutions). In the context of the fight against climate change, it is important to have tools for evaluating economic policies. The energy transition leads to important economic structural changes. It is therefore essential to be able to anticipate their effects in order to determine a trajectory that is achievable. To do this, developers of applied models must make significant progress in terms of transparency. We have outlined a possible strategy that could help. It is all the more urgent to put in place such a strategy as the questions posed to applied environmental macroeconomics are constantly widening. Beyond the climate change issue, it should in particular analyse the complete environmental footprint of our production systems.

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