MACROECONOMICS AND THE ENVIRONMENT

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This article examines the recent literature on macroeconomics and the environment from the perspective of the methodological approach, the questions asked and the types of responses given. It also reviews the place of the environment in textbooks and major macroeconomics journals. It shows that almost no space is given to environmental issues in short-term macroeconomics. Environmental issues are perceived as affecting the long-term and the structure of economies rather than the current situation. It can therefore be expected that studies on growth and the teaching of theories of growth would give them an important role. The article shows that while this is partly the case with regard to the literature, it does not hold at all with regard to teaching. The road ahead for truly integrating environmental issues into macroeconomics remains long.

Keywords: macroeconomics, environment, modelling, growth.

Herman Daly, one of the fathers of ecological economics, wrote in 1991: "*Environmental economics, as it is taught in universities and practiced in government agencies and development banks, is overwhelmingly microeconomics. The theoretical focus is on prices, and the big issue is how to internalize external environmental costs so as to arrive at prices that reflect full social marginal opportunity costs. Once prices are right the environmental problem is 'solved' – there is no macroeconomic dimension*" (Daly, 1991). This observation is still partially valid: environmental issues occupy a very small place in macroeconomic models, and their

1. I would like to thank Mouez Fodha, François Langot and Aude Pommeret for their insightful rereading.

study remains largely the prerogative of microeconomics and public economics. It could even be said that short-term macroeconomists are not interested in it, or more precisely, that whatever interest they have is confined to the question of the macroeconomic impact of oil shocks. The situation is different for growth macroeconomists. Indeed, environmental problems are perceived as long-term problems, affecting the structure of the economy and influencing its growth path, but having little relation to its current performance. And even in models of growth, environmental issues are mostly external, in the sense that they do not affect the drivers of growth such as education, public infrastructure, technology and institutions. They are perceived as constraints rather than as an essential dimension of our developmental choices.

This article examines the recent literature on macroeconomics and the environment from the perspective of the methodological approach, the questions asked and the types of responses given. It also reviews the place of the environment in textbooks and major macroeconomics journals. It shows that there is still a long road ahead for truly integrating environmental issues into macroeconomics.

1. Short-Term Macroeconomics and the Environment

A careful review of the literature and a hopefully exhaustive study of the most widely used short-term macroeconomics textbooks and macroeconomics journals unambiguously shows that they give almost no space to environmental issues.

1.1. The literature

The pre-crisis macroeconomic literature contains numerous studies on the macroeconomic effects of oil shocks, but this is almost the only angle from which environmental issues are addressed. This work, which is overwhelmingly empirical, started in the mid-1970s, and falls into the more general category of work on the impacts of commodity price fluctuations. This will not be examined in greater detail here.

The more recent literature can be reviewed quickly: there are, to my knowledge, only some dozen published papers that introduce the environment, in one form or another, into the tools of today's short-term macroeconomists, i.e. the Dynamic Stochastic General Equilibrium models (DSGEs). These articles are of two types: they are interested, like the above-mentioned older works, in the impacts of energy prices and oil shocks on macroeconomic fluctuations, or, more innovatively, they evaluate the short-term costs of environmental policies.

In the first category, the article by Kim and Loungani (1992) stands out as a precursor. The authors introduced energy as a factor of production in a Real Business Cycle (RBC) model of the Kydland-Prescott-Hansen type in order to study the impact of energy price shocks on the economic cycle. Bodenstein *et al.* (2011), Schwark (2014) and Acurio-Vasconez *et al.* (2015) pursued the same goal using DSGE models.

Work in the second category belongs to recent literature that seeks to identify the least costly environmental policies in terms of economic activity. Indeed, if, in the long term, environmental protection and growth can, under certain conditions, go hand in hand and not come into conflict, the studies dealing with the short term put them in opposition. Protecting the environment is expensive, and it is important to analyse and quantify the terms of the trade-off with economic activity.

Angelopoulos *et al.* (2010, 2013), Heutel (2012), and Fischer and Springborn (2011) studied the performance of different types of environmental policy in RBC models incorporating pollution. The question asked is which environmental policy is the most efficient in terms of price (tax) or quantity (emissions permit market), from the point of view not only of well-being but also of the volatility of the macroeconomic variables, in a context where fluctuations are caused by productivity shocks (see Heutel and Fischer, 2013). Dissou and Karnizova (2016) did the same using a multi-sectoral RBC model incorporating sector-specific productivity shocks. They distinguished several imperfectly substitutable sources of energy that emit more or less CO2. Annicchiarico and Di Dio (2015) also took an interest in how different environmental policies interact with the economy's response to nominal and real shocks. They constructed a New Keynesian macroeconomics model with Calvo-type nominal rigidities, incorporating different types of shocks: productivity shocks, public consumption shocks and monetary policy shocks. CO2 emissions are a by-product of production. The reduction of emissions can have two sources in this type of model: environmental policy or a negative shock to production. Three environmental policies were examined: a carbon tax, an emissions permit market, and an emissions intensity target (i.e. an emissions ceiling per unit of production). The authors assessed the extent to which imperfect competition and nominal rigidities alter the conclusions of previous studies, namely, that the emissions trading market, which sets a cap on emissions, is more likely than other environmental policies to smooth macroeconomic fluctuations. They showed that price rigidity significantly modifies the performance of environmental policies, and that the optimal response to environmental policy shocks depends heavily on the extent of price adjustment and the response of monetary policy. Annicchiarico and Di Dio (2017) continued this work by examining in greater depth the optimal response of monetary policy to shocks when an environmental policy is in place, as well as the way in which monetary policy and environmental taxation interact.

This work is interesting because it provides a short-term perspective on environmental policies that complements the usual insights provided by microeconomic models of static partial equilibria on the one hand, and growth models on the other hand.

Sachs (2009) explained that the new macroeconomics must be structural, but that "*both the neo-Keynesians and the free-market school regard structural issues such as energy, climate, and infrastructure to be of little macroeconomic significance. Perhaps these factors require a modicum of policy attention, but they are certainly not regarded as critical to restoring jobs, growth, and prosperity, and could even be a hindrance in the short term; for example, if climate-change policies hike up the price of energy*". We are very far from this ideal of a structural macroeconomics, and the crisis seems to have changed nothing. Blanchard *et al.* (2010), for example, in their frequently cited paper on the revival of macroeconomics after the crisis, did not say a word about the environment, climate, energy, health or education.

The point is not to introduce the environment everywhere. But it must be noted that short-term economic decisions have an impact on the environment and that, in turn, environmental degradation weighs on economic activity, so it is necessary to understand the interactions between environmental policies and other levers of economic policy. One particularly interesting juncture between short-term macroeconomics and the environment is the financing of the energy transition. How can savings be directed towards the financing of long-term projects to bring this transition to a successful conclusion and ensure investment in appropriate technologies and infrastructures? The most immediate response is to make these projects and investments profitable through the pricing of environmental externalities, in particular by introducing a carbon tax. A complementary response is to put in place proactive policies to direct funds towards low carbon projects. For example, shoots of literature on smart unconventional monetary policy and green quantitative easing are beginning to sprout. This involves questioning the sectoral neutrality of corporate bond purchases by central banks in the context of quantitative easing in favour of a policy of buying green corporate bonds and abandoning the purchase of "dirty" corporate bonds, typically from the fossil fuel sector (Aglietta *et al.*, 2015). Campiglio (2016) presented other proposals for financing the transition. This literature still represents the work of a small number of environmental economists and has not yet penetrated the major macroeconomics journals.

1.2. The textbooks and macroeconomics journals

As far as education is concerned, to my knowledge short-term macroeconomics courses never include environmental considerations. Nor is there any place for the environment in short-term macroeconomic textbooks, neither new or old, neither basic or advanced. There is no reference in Romer (2011), Bénassy (2011), Krugman and Wells (2012), Wickens (2012), Ljungqvist and Sargent (2012), Abel *et al.* (2013), Blanchard (2017), Burda and Wyplosz (2017), or Uribe and Schmitt-Grohé (2017), to name only the most common post-crisis textbooks. The Acemoglu, Laibson, and List (2016) text does not talk about the environment either, but note that the authors have introduced an online chapter entitled "Economics of Life, Health and the Environment" (Web Chapter 2).

As for academic publications, a review limited to the top-level journals in France's CNRS ranking in macroeconomics from May 2016 for the period 2009-2016 reveals the following:

— *American Economic Journal*: Macroeconomics: 2 articles, out of a total of about 240 (30 articles in 2016, multiplied over 8 years);

— *Journal of International Economics*: 9 articles out of about 800;

— *Journal of Monetary Economics*: 4 articles out of about 540;

— *Journal of Money, Credit and Banking*: 6 articles, covering the macroeconomic impacts of oil shocks, out of about 480;

— *Journal of Economic Dynamics and Control*: 52 articles out of about 820, which makes this journal stand out, partly because many of the articles seriously address the long-term outlook and growth.

2. The Environment in Long-Term Macroeconomics

Since environmental matters are considered long-term issues, it would be expected that studies on growth and the teaching of theories about growth would give them an important role. As we shall see, this is partly the case with regard to the literature, but not at all with regard to education.

2.1. The literature

With the exception of Ricardian growth models in which the Earth is a scarce resource imposing physical limits on growth, modern growth theories have long ignored the environment, perceiving it as inexhaustible. They have focused on the study of a stylized world in which agents produce with the help of manufactured capital and labour, and derive satisfaction from the mere consumption of manufactured goods. The archetypes of this approach are Solow's model (1956) and Ramsey's optimal growth model (1928). Starting in the 1970s with the oil shocks, however, some economists have recognized the need to take various aspects of the natural environment into account in growth models. Events have driven them to focus first on non-renewable resources and in particular on fossil fuels. In the Ricardian tradition, they have sought mainly to understand the circumstances in which the finite nature of the environment and the scarcity of natural resources constitute a physical limit to growth, and at what rate non-renewable resources should be extracted. The founding articles in this line of research were all written by famous economists whose specialty was not the economics of the environment, which did not exist at that time as a specific field of research; many of these articles were published in a special issue of the 1974 *Review of Economic Studies* (Vol 41, No. 5, December), including seminal articles by Dasgupta and Heal (1974), Solow (1974) and Stiglitz (1974).

Very quickly, however, the introduction of environmental considerations into growth models became the preserve of environmental economists alone. The pioneering work of Dasgupta, Heal, Solow and Stiglitz had little impact on the vast majority of macroeconomists who, once the effects of the oil shocks faded, returned to focusing exclusively on traditional macroeconomic variables like inflation, output and employment, or on monetary and fiscal policies alone. The literature reviews by Xepapadeas (2005) and Brock and Taylor (2005) also verify this.

The lessons of the growth models that incorporate natural resources from this era are clear. The economy's growth depends partly on the characteristics of its technology and partly on the preferences of the agents that populate it. Depending on these characteristics, growth may or may not be sustainable, in the sense that well-being does not decrease over time.

Production is characterized by a certain intensity of use of natural resources as factors of production (fossil fuels, ores, but also air, water and renewable resources) as well as the pollutants emitted and the waste generated. The consumption of resources and environmental services for productive purposes depends on the characteristics of the technology used, and in particular on the substitutability between natural resources and manufactured capital that this allows. If it is easy to substitute natural resources for manufactured capital, that is, if the substitutability is great, the finiteness of the environment will not necessarily constitute a drag on growth. If, on the other hand, the substitutability is limited, the only way to push back the physical limits constituted by the finiteness of the environment is to change the technology and / or the resource, which amounts to replacing the natural resource with a non-rare equivalent, assuming that this is possible.

The preferences of the agents are distinguished by their character as more or less "green", reflecting the importance they attach to the environment, and by the discount rate, reflecting their impatience, i.e. how much weight they place on the present in relation to the future. Once again, a central issue is the extent to which agents are willing to substitute the consumption of goods for environmental quality. As for technology, these behavioural characteristics change over time along with changes in awareness of the seriousness of environmental problems and the need to pass on sufficient resources and a quality environment to future generations. Finally, when considering optimal growth, it is not only individual preferences that come into play but also social preferences. In particular, the value of the social discount rate is central when it comes to intergenerational equity and the sustainability of growth. Weitzman (2001) described the issue of the social discount rate as "one of the most critical problems in all of economics". It has given rise to extensive debate and controversy, and it is the subject of an extremely abundant literature, which seems very far from converging on a consensus.

Finally, public intervention is needed in order to implement the optimal growth path in decentralized economies. This is because natural resources are very often used inefficiently, as their market price does not reflect the full social cost associated with their use. This is particularly the case for renewable resources (problem of open access, tragedy of the commons) and fossil fuel pollutants. In this context, the literature examines the design and effects of environmental policy, extending the principle of Pigouvian taxation to a dynamic framework.

The literature on growth and the environment has seen a revival due to climate change. The focus has shifted from the question of the scarcity of non-renewable resources to that of the pollution associated with their use. The combustion of fossil fuels leads of course to CO2 emissions that accumulate in the atmosphere. The increase in the carbon concentration in the atmosphere is in turn causing a worsening of the infamous greenhouse effect that is responsible for global warming. If we really want to avoid catastrophic warming, the amount of carbon we have left to emit is small, much less than what is contained in the fossil fuels still present in the earth's subsoil (see for example IPCC, 2014). The problem is therefore not scarcity, but the accumulation of carbon in the atmosphere.

In this framework, recent growth models have focused on how to replace fossil fuels with renewable energies and polluting technologies with clean technologies, so as to move from "growth to green growth" (Hallegatte *et al.*, 2011; Smulders *et al.*, 2014). The novelty of these models is that they deeply dissect technical progress, its orientation and the conditions for its emergence. They show that innovation is rarely spontaneous and has no reason to be spontaneously oriented in the desired direction. For example, since the industrial revolution, innovation has been largely aimed at saving labour. This has made it possible to equip people with better tools, first and foremost machines powered by fossil fuels. If society wants innovation to move in a different direction, so as to conserve natural resources and environmental services, then an economic policy is needed that provides researchers with the proper incentives. But this will have a cost in terms of growth, both directly, for example because of the rising cost of fossil fuels, and also in terms of the crowding out of technical progress aimed at increasing the productivity of labour, which is the engine of growth (Henriet *et al.*, 2014).

A more disaggregated approach that has generated a substantial literature is known as "directed technical progress" (see, for example, Smulders and de Nooij, 2003; Grimaud and Rouge, 2008; Di Maria and Valente, 2008; Acemoglu *et al.*, 2012). The economy has a "dirty" production sector and a "clean" sector, and research can be directed towards the development of new technologies in one or the other of these sectors. Innovations boost labour productivity in the sector where they occur. If there are more numerous innovations in the "clean" sector, the economy's share of the "dirty" sector gradually shrinks and the economy is on a green growth path. Environmental taxation and subsidies for research in clean technologies are key elements for initiating technical progress in this direction. These incentives must be particularly strong if there is a phenomenon of historical dependence in the growth path (Acemoglu *et al.*, 2012): innovation is more easily achieved in the most advanced sectors, for the goods with the largest market shares and lowest prices, yet currently the most advanced sectors are the "dirty" sectors.

The long-term benefits of moving to a clean growth model should not obscure the short-to-medium-term costs. The "marketing" discourse of green growth asserts that environmental policies not only reduce the consumption of natural resources, pollution and environmental degradation, but also stimulate growth in the medium term through innovation, the creation of new investment opportunities, the emergence of new trades and activities, etc. The theoretical studies make it possible to go beyond this type of discourse, which is intended to increase the acceptability of environmental policy but is often misleading, so as to examine the precise conditions for the emergence of spill-over effects from medium-term environmental policies and the obstacles to sustainable growth.

The applied tools used by climate change economists include Computable General Equilibrium Models (CGEs) and Integrated Assessment Models (IAMs). The methodology used by the former is either classic and well known, or ad-hoc or so-called hybrid models. This is examined in depth in the article by L. Gissela, A. Saussay, P. Maillet and F. Reynes in this issue. The focus here is on the second type. IAMs combine an economic model and a physical model describing the climate system in a simplified way. The latter models the ways in which the increase in the concentration of greenhouse gases in the atmosphere due to human activity, derived from the economic model, result in raising the earth's temperature. The mechanism is complex and subject to multiple uncertainties, due to feedbacks between increased temperature and carbon uptake by oceans and forests and to other atmospheric phenomena such as cloud formation and precipitation. In turn, the rise in the Earth's temperature is causing damage, which is introduced in the economic model; these are sometimes production losses and sometimes direct losses in well-being. The "damage functions" are themselves very poorly understood, especially since a more aggregated level is being considered.

The first integrated assessment model, the culmination of a research programme that began in the late 1970s, was William Nordhaus's Dynamic Integrated Climate-Economy (DICE) model (1991, 1994, 2008). This remains the reference today, and it has had many avatars. It is a deterministic model of classical growth of the Ramsey type, with emissions arising from economic activity, a climate module and damage. DICE models are small in size, and the mechanisms they incorporate are transparent. The other IAMs do not all have such solid theoretical foundations. Some of them abandon microeconomic fundamentals and intertemporal optimization under perfect anticipation and introduce ad-hoc formalizations that are supposed to better represent the real world, or exogenous economic growth scenarios. They can be very large, so quite difficult to comprehend other than as black boxes.

Integrated assessment models are mainly used to calculate a social value for carbon in order to give public decision-makers an order of magnitude of the initial level and temporal profile of the carbon tax needed to bring the damage back to an optimal level or to contain global warming below a certain threshold. They are widely used in international circles and have a certain influence on the recommendations made in the field of climate policy. They are also subject to vigorous criticism, which is ultimately not so different from the criticism directed at other applied modelling exercises, such as the DSGE. Robert Pindyck, one of the most outspoken critics, wrote: "(Integrated assessment models) have crucial flaws that make them close to useless as tools for policy analysis" (2013). Or again: "IAM-based analyses of climate policy create a perception of knowledge and precision that is illusory and can fool policymakers into thinking that the forecasts the models generate have some kind of scientific legitimacy. Despite the fact that IAMs can be misleading as guides for policy, they have been used by the US government to estimate the social cost of carbon (SCC) and evaluate tax and abatement policies" (2017).

The most recent studies seem to favour small, theoretically explicit IAMs, in the DICE tradition, that are solvable analytically (Golosov *et al.*, 2014; see also Hassler *et al.*, 2016) or no longer deterministic but stochastic (Lemoine and Traeger, 2014; Crost and Traeger, 2014) or more like DSGEs (DSGE-IAM, Cai *et al.*, 2013). In this latter case, the numerical resolution is extremely complex, so much so that very few attempts of this type exist today.

Finally, it should be noted that there is nothing comparable either in terms of theoretical models or applied tools to analyse the issue of the loss of biodiversity and the appropriate economic policies. Yet this is the other major global environmental issue of our time, and for the moment macroeconomics is utterly without tools to deal with it.

2.2. The textbooks and growth journals

Strangely enough, from my point of view, textbooks on growth give very little space to environmental issues. At best there is a chapter at the end of the book dealing with the environment (from the perspective of natural resources) alongside geography and institutions, going into what the canonical models (the Solow and Ramsey models and the foundational models of endogenous growth) do not take into account.

Thus, among the pre-crisis textbooks, the reference text by Barro and Sala-i-Martin (1998) makes no mention of the environment. The text by Aghion and Howitt (1998) is an exception, with Chapter 5 entitled "Endogenous growth and sustainable development". The situation is nevertheless changing. Admittedly, the weighty text by Acemoglu (2008) has nothing on the environment, in almost a thousand pages. Nothing can be found either in La Granville (2009) or in Galor (2011). On the other hand, Aghion and Howitt's text (2009) includes a chapter entitled "Preserving the environment" (Chapter 16), Weil (2016) has two chapters on the environment, the last two (15 and 16): "Geography, Climate and Natural Resources" and "Natural Resources and Environment at the Global Level", and Jones (2013) introduces a chapter on the environment (Chapter 10, "Natural Resources and Economic Growth"), which was not present in the first editions of the book (see Jones, 1998).

As for academic publications, over the last ten years the Journal of Economic Growth has published five articles on natural resources or the environment in general, out of a total of about 120 published articles. The end of the period does not pick up: there is nothing between the article by Brock and Taylor (2010) on Solow's green model and the article by Peretto and Valente (2015) on the interactions between technical progress, natural resources and population dynamics

3. Conclusion

Awareness of the limits of the mode of growth initiated by the industrial revolution has been growing gradually, but it is real today. The developed countries have been able to solve some of the local environmental problems created by their production technologies, such as local air and water pollution, while creating new ones. They are still helpless in the face of the two major problems of our time, namely global warming and the erosion of biodiversity. Despite this growing awareness, macroeconomics is not very concerned with these issues, while there is a great need for analysis and work on environmental policy. We are still far from the structural macroeconomics called for by Sachs.

Integrating the environmental sphere into macroeconomic models does, however, open up exciting fields of research. At the centre of the analysis are now uncertainty, irreversibility, and a change of regimes. Uncertainty because the physical phenomena are uncertain, as is the damage. Irreversibility because environmental damage is often irreversible, in the sense that the original situation cannot be restored, nor can economic decisions be taken back (see, for example, Pommeret and Prieur, 2013). In a world where irreversibility is the rule, it is clear that the consequences of any decision are heavier than in a reversible world, and that it is necessary to act in a more precautionary way. Irreversibility can be both environmental and technological. Environmental irreversibility involves the existence of thresholds. Below these thresholds, the environment is reasonably resilient, and technologies and preferences can be characterized by a certain substitutability between the environment and manufactured goods. If the thresholds are crossed, substitutability is no longer possible, and nonlinearities and possibly catastrophic phenomena emerge. Irreversibility can also be technological: it is very expensive to develop a new technology that saves natural resources and to adopt it on a large scale, and it takes the economy onto a new technological trajectory for a very long time. In the opposite direction, deciding on "dirty" infrastructure or capital today also has long-term consequences. Uncertainty and irreversibility are difficult to integrate into normal growth patterns. Their study requires dealing with changes of regimes, transitions and structural change. Because that's what it's all about: moving to a new mode of growth.

The global financial crisis of 2008 forced macroeconomists to question the dichotomy in their models between the real sphere and the financial sphere and to look for representations of the real world in which these spheres are deeply interconnected. As Carraro, Faye and Galleotti (2014) have asserted so forcefully, what kind of catastrophe is necessary for macroeconomists to decide to revise their models so as to genuinely integrate environmental issues?

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