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Money, Finance and Climate: The Elusive Quest for a Truly Integrated Assessment Model

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Abstract In this paper, we show how existing IAMs generally omit any representation of a financial sector. We then discuss the potential impacts of climate change policies and climate change events on the financial sector as shown in the existing literature. We underline how the structure of the financial sector itself could impact the carbon trend of the economy. We then see how these specific linkages between the financial and the climate sector can be represented in new types of IAMs, and how they have already started to be addressed, notably in the stock-flow consistent models literature. We conclude on the necessary convergence agenda between climate policies addressing the financial goals in article 2 of the Paris Agreement and financial sector reforms to dampen the intrinsic financial instability.

Keywords Climate finance · Paris Agreement · IAM · Financial instability · Stock-flow consistent models

JEL Classification Q54 · Q57 · E6 · E12 · G1

The adoption of the Paris Agreement on December 12, 2015, as a conclusion of the 21st Conference of the Parties (COP21) at the United Nations Framework Convention on Climate Change (UNFCCC), is a milestone in the emergence of the notion of climate finance at the highest level of climate negotiations. Article 2 of the Agreement stipulates that the Parties commit to make financial flows consistent with a low level of carbon emissions and an economic development adapted to

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climate changes. [1] This very general term, "financial flows," is very different from the usual calls for "financial transfers" targeted to mitigation or adaptation actions.[2] While "financial transfers" generally refer to public (or public supported) North–South aid from multilateral or bilateral development banks, "financial flows" naturally target the whole spectrum of financial activities, public and private, in developing as well as in developed countries. The change of words is indeed a significant step toward convergence between a financial sector reform agenda and climate policy design.

At the same time, climate economics remains relatively silent on the possible meaning of this alignment of financial flows with the climate objectives of the UNFCCC. At the end, civil society organizations, in particular in the financial sector, seem to have taken this question more seriously and anticipate the possible consequences of the climate question for their business. At the central bank level, Mark Carney's speech at the Lloyd's in London in September 2015 (Carney 2015) discusses the interactions between climate change and financial stability. Soon after, a private sector taskforce on climate-related financial disclosure, launched in 2016 by the Financial Stability Board (FSB), proposes a unified framework to share information on the carbon content of financial portfolios. In parallel, the Green Climate Study Group (GCSG) created by the G20 under Chinese presidency, also in 2016, addressed the opportunity to create new markets for green bonds.[3] At the European commission level, and with the same spirit as the FSB and the GCSG, the High-Level Group on Sustainable Finance was created for the year 2017.

The sectoral initiatives related to the COP21 momentum offer a business-oriented vision of the role that the financial and insurance sectors will have to play in the future. But the financial intermediation necessary to accomplish the final objectives of the Convention (that is global carbon emission neutrality during the second half of the century) is still far from clear. This requires much more in depth research at the crossroads of climate economics and financial macroeconomics. Such programs are today (at best) in their infancy. Paradoxically, current worries related to the fragilities of the global financial system (FSB 2016) could offer the opportunity for institutional innovation in the climate field. The ambivalence of the financial sphere toward the effects of climate change will have to be overcome. This includes the perception of the opportunities that such new risks could create (Carney 2015) and the difficulty in recognizing the systemic character of the climate change phenomenon (Aglietta and Espagne 2016). This paper will analyze this research gap, starting from the drawbacks of most Integrated Assessment Models (IAMs) in taking money and finance into account, and going on to potential strategies for improvement.

In the first section, we will show how IAMs omit any representation of a financial sector. We will then discuss the potential impacts of climate change policies and

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[1] «*Making finance flows consistent with a pathway toward low greenhouse gas emissions and climate-resilient development*».

[2] This approach remains in the Decision preceding the Paris Agreement, with the recognition of an objective of 100 billion dollars of annual transfers to be reached by 2020 (paragraph 53).

[3] Many more initiatives can be quoted. They are more systematically described in Aglietta et al. (2016).

climate change events on the financial sector as shown in the existing literature. We will then see how these impacts can be represented in new types of IAMs, and how they have already started to be addressed, notably in the stock–flow consistent models literature. We will conclude with the necessary convergence agenda between climate policies addressing the financial goals in article 2 of the Paris Agreement and financial sector reform to stabilize intrinsic financial instability.

Money and Finance in IAMs

The Problematic Monetization of Damages

The DICE (Dynamic Integrated Climate-Economy) model developed by Nordhaus (1993) starting in the early 1990s will be our case study. It is the most widely used model in the academic world of climate economists, and the first model proposing a synthesis between neo-classical growth theory (Solow 1956) and the climate question. A very detailed critique of this model can be found in Pottier (2016). Without reproducing the entire structure of the model and its equations, we schematize its most salient features in Fig. 1. All the links between climate change and the economy in the model are concentrated in the damage function, which translates into monetary terms the effects of an increase in the average atmospheric and oceanic temperatures.

Two aspects are crucial in the monetary evaluation of climate damages: first, the form of the damage function itself, which is based on uncertain empirical grounds; second, the way damages affect the economy (output, productivity, population growth, etc.)

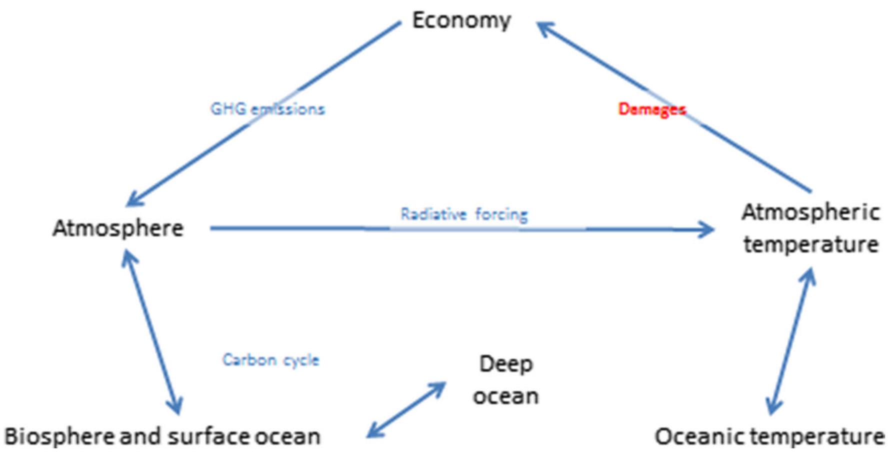

Fig. 1 The main modules of the DICE model: the economic module generates emissions which disturb the dynamics of the carbon cycle. Through a radiative forcing, the increase in the emissions in the carbon cycle generates a temperature increase. The cycle between temperature increase and the economy is closed through the damage function, which represents a monetary valuation of climate impacts

The damage function in the DICE model uses the most optimistic assumptions (Moyer et al. 2014): damages have a quadratic form, and simply affect the level of production in each period. With this structure, the losses linked to climate change only reach 10% of world GDP at the end of the century, while the growth in temperatures would reach 6 °C in the same period. The climate crisis is thus structurally of second order in comparison with the long-run growth of the economy. Less favorable assumptions lead to far more massive impacts on growth (Dietz and Stern 2015) and could even lead to a contraction of the world economy before the end of the century. These recent more pessimistic simulations are confirmed by new empirical assessments of the damages from climate change for the USA (Hsiang et al. 2017).

Any variation on the form of the damage function, on the economic variables affected by these damages, or on its perception by economic agents (Stern 2007; Espagne et al. 2018), tends to increase the monetary impact of climate change on the economy, compared with the original DICE model. In particular, the notion of catastrophic damages, of very low probability of occurrence and huge impacts, leads to a totally different implications: ambitious climate policies are necessary as soon as possible (Weitzman 2009) because they act as an insurance mechanism against catastrophic outcomes. This contrasts with the initially modest and progressive efforts proposed by Nordhaus.

These variations on the form of the damage function account for the diversity of monetary impacts that climate change can have on the economy. However, these different estimates do not provide a representation of the financial flows which would not be "aligned" with the 2 °C or even the 1.5 °C objective, as article 2 of the Paris Agreement officially states. Economic agents cannot have a biased understanding of damages or of climate policies because financial markets in these models give the best available information to all economic agents. Financial markets are considered by assumption as complete, or perfect, so that the modeler does not even feel the need to explicitly include them.

The Perfect Financial Markets of IAMs

To be fair, DICE and its numerous avatars include some sort of financial market. It is even possible to formalize this in an evolution of the preceding graph.

Figure 2 shows the implicit hypothesis regarding a financial sector of the majority of IAMs in the DICE type. The financial sector only appears through the equality between savings and investment, so that in the original model, savings do not even appear. In these models the representative agent has full information which implies an investment trajectory which is also the savings trajectory. The DICE model relies on the idea of an efficient financial sector: efficient to the point of becoming invisible in the equations themselves. What type of crisis can appear in such a modeling environment? Which uncertainty regarding the scope of climate change can modify the dynamics of the economy through the expectations of the financial sector? Several recent papers have attempted to answer these questions without renouncing the simple reductionist financial framework of the DICE model.

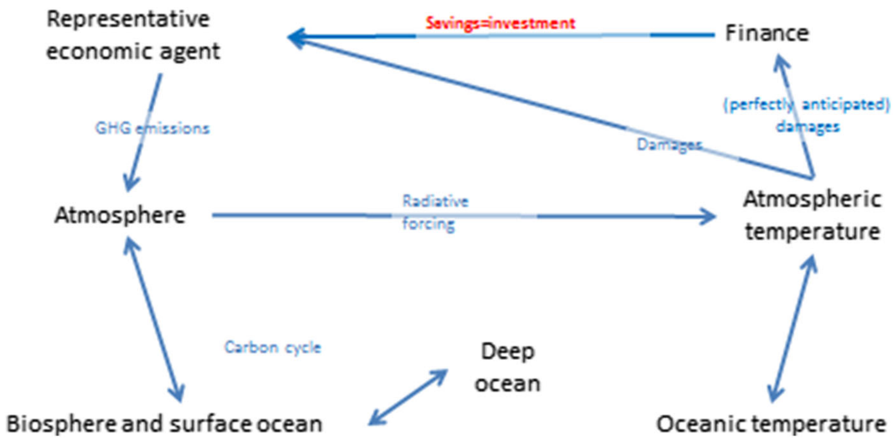

Fig. 2 The implicit financial sector of the DICE model: savings being at each period equal to investment, the financial sector only has one asset. The representative agent, operating in perfect expectations, takes into account all the available information on future climate damages. This information is immediately reflected in the price of the unique financial asset

This recent works makes use of one of two equally unsatisfying modeling choices regarding the introduction of uncertainty.

On the one hand, you can consider that only probabilities can be explicitly represented. This amounts to a certainty equivalence version of DICE, where possible future outcomes are only weighted according to a predetermined distribution of outcomes. Efficient financial markets react to this "certain weighted" choice in an absolutely rational way according to their degree of risk aversion and time preference.[4] There is of course a form of portfolio optimization among the different possible future outcomes. But no systemic crisis can appear, which would imply the arrival of totally unanticipated information affecting all possible futures. This certainty equivalence approach is the (unsatisfying) way of representing uncertainty in most IAMs derived from the DICE model. Such a restricted framework has been used to evaluate the financial losses linked to some mitigation scenarios (Dietz et al. 2016). It is no surprise, based on their underlying assumptions, that these authors reach relatively optimistic conclusions regarding the potential financial losses linked to climate change scenarios (i.e., 1.77% of average present value of global financial assets at risk from climate change between 2015 and 2100 in a 2.5 °C scenario, 1.18% in a 2 °C scenario). Dietz et al. (2016) has the merit of being one of the first studies of the effect of climate risks for the financial system. However, the work has at least three important biases in my view: (1) a model derived from DICE in order to deduce growth trajectories (which minimizes a priori the impact of climate damages on growth); (2) the hypothesis (simple but wrong) that the present value of finance covers the entire present value

[4] An important part of academic debates between climate economists focuses on the «right» value for this discount rate (Espagne et al. 2012).

of the real economy; and (3) an analysis of financial risk with a *Value at Risk* approach (that minimizes the possibility of extreme events).

On the other hand, you can consider that new (and unexpected) information, on the real nature of climate damages for example, would perturbate the initially forecasted dynamics of the economy. In this case, we talk about stochastic shocks, which are really unanticipated, even if the distribution of possible values of the shock is, itself, well known to the modeler. All endogenous variables are, however, supposed to regain an optimal trajectory as soon as the shock dissipates. Models of the DSGE type, derived from DICE, allow for this kind of representation of extreme and unforecasted events. They have begun to be applied to environmental questions as well (Golosov et al. 2014). Although the DSGE literature has enormously expanded the representation of financial dynamics since the financial crisis (Iacoviello 2015), it remains mute when the interactions between finance and the environment are at stake.

Results from these two modeling options can help justify proposed financial sector initiatives related to climate finance, such as favoring the transparency of carbon-related information in financial portfolios which offers financial actors the opportunity to respond rationally to incoming climate change information or policy changes. Such an approach is in article 173 of the energy transition law in France and is part of the recommendations of the Taskforce on climate-related financial disclosure of the Financial Stability Board. The explicit goal of such initiatives is to transform climate uncertainty into a simple financial risk, in other words, to re-establish the illusion of a perfect efficiency of finance (Christophers 2017).

The Growing Role Attributed to Finance in Climate Issues

Money as a Veil and the Separation Between the Short and the Long Run

If finance plays a minimal role in the DICE model as we have seen, it is possible to include money by imagining a central bank which maintains a constant money supply for each unit of production. As in almost all computable general equilibrium models, money is thought of as a veil, which does not interfere with economic exchanges, and where perfectly flexible prices can adapt to any quantity of money. Thus, money in DICE can be considered as exogenous in the sense that it will not impact production in the short or medium run. If prices become sticky, then only the short run might be affected by monetary issues. This initial hypothesis of money neutrality, common to all neo-classical or neo-Keynesian models, automatically dissociates environmental (long run) economics questions from monetary (short run) issues. Long-term issues on the one hand, short and medium run on the other, do not interact in any way, as shown by the "neo-classical" arrow on Fig. 3. The recent exploration of interactions between climate policies and business cycles challenges this approach. By representing the reactions of economic cycles to different forms of climate policies, Heutel (2012) considers it necessary to adapt the strength of climate policies to cyclical fluctuations, whatever their origin: technological shock, demand shock or something else. It is justifiable to transform

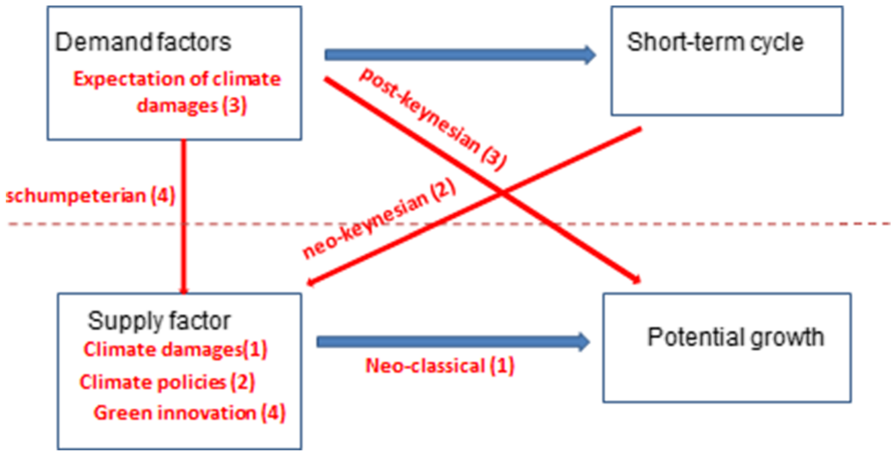

Fig. 3 The retroactions between short and long run and the climate question, according to different types of integrated models: neo-classical models consider long-term through the interaction between climate damages and growth only; neo-Keynesian models admit that interactions between climate policies and short-term fluctuations occur, justifying an adaptation of monetary policy; post-Keynesian models consider that growth is determined by investment demand, which must fully integrate the expectation of climate damages; Schumpeterian models of innovation activate fiscal policy in order to facilitate green innovation, as the only source of sustainable growth in the long run

the reaction function of monetary policy, not so much because it could impact the growth path of the economy in the long run, but because it is the rational reaction to cyclical fluctuations that climate policies could amplify (Annicchiarico and Di Dio 2016). Money remains neutral in the long run while short-run fluctuations are exclusively dependent on demand factors, which climate policies can potentially affect through various channels (Annicchiarico and Di Dio 2015). In this neo-Keynesian approach, the short run and medium run do indeed interact, but without any meaningful consequences on the long run, as shown by the "neo-Keynesian" arrow in Fig. 3.

In fact, only the "Schumpeterian" approach can give a long-term role to finance by considering the links between structural factors such as technical change (Acemoglu et al. 2012; Pottier et al. 2014) and financial policies targeted to them. This is illustrated by the "Schumpeterian" arrow in Fig. 3. These modeling approaches thus seem rather unprepared to tackle the issue of the interactions between climate change (or climate policies) and finance. However, in admitting that climate policies could affect short-term cycles, the papers quoted begin to break the strict separation between the short and long term of neo-classical and neo-Keynesian models. Climate change, an essentially long-term phenomenon, can be the cause of immediate policies, by modifying the dynamics of short-term cycles.

A More Meaningful Role for Money

It is impossible to show in the models discussed above how actors' decisions in the short run can possibly generate multiple long-term equilibria. The rational expectations of agents with supposedly infinite time horizon make a transmission from a short-run cycle to a long-term effect illusory. A fundamental element prohibits such interactions between the short and long run: the absence of a constraint on the transmission of wealth through time. This constraint can be removed when there are money or financial markets which allow actors to modify their choices. Overlapping generation models which add finitely lived agents to the existing neo-classical (or neo-Keynesian) frameworks introduce, as a first step, the possibility of savings strategies along the life cycle, as shown in Eggertsson et al. (2017). To our knowledge, they have not been applied to the climate economics field.

We will explore a different direction, rejecting the somewhat artificial distinction between young and old economic agents that are constrained in their saving strategies. Rather, we will consider the explicit representation of the process of creation of credit by financial institutions. The models quoted so far (all variations around the seminal DICE) imply an exogenous (and neutral) money, which has no role in the long run, and at most a very modest role in the short run. Post-Keynesian models open the possibility of an impact of investment decisions in the short run, on the long-run equilibrium of the economy.[5] They generally suppose that the firm has an autonomous investment demand function. This investment demand is addressed to the commercial bank, which finances the firm through bank loans, possibly with a credit rationing depending on its own understanding of the state of the economy.[6] This approach to the money creation process, which explicitly rejects the idea of a money multiplier (Jakab and Kumhof 2015), is now widely accepted by modelers and policy makers (McLeay et al. 2014).

Balance-Sheet Approaches to Climate Finance

Credit Creation and Unsustainable Growth

Explicitly introducing the role of money in integrated assessment models gives the means to treat new questions at the heart of the ecological question. One of them, regularly raised in ecological economics, is the concern that the financial system (with lending and interest payments) may be intrinsically inconsistent with climate control because it requires GDP growth in order to generate credit repayments (Farley et al. 2013; Costanza et al. 2013). If we consider (as it is our case here) that production takes shape in the mind of producers before money is possibly created to allow for its realization, then the banking system cannot be considered as a cause of an indefinitely growing economy. At most, it could be considered as a benevolent bystander (Cahen-Fourot and Lavoie 2016). If, on the other hand, an economy in a

[5] Following (Kalecki 1971): «*The long-run trend is but a slowly changing component of a chain of short-run situations; it has no independant entity*».

[6] These economies are characterized in Cahen-Fourot and Lavoie (2016): «*Money is created through credit previously to the production process: it anticipates the socially validated production arising from both the market and the non-market sectors. Ultimately, the central bank closes the macroeconomic circuit by refinancing the banks that are in need of central bank money and by lending to the State*».

stationary state is compatible with the existence of interest-bearing debt, the question of the compatibility between such a financialized economy and a temperature objective respecting the 2 °C threshold remains open.

By concentrating on the structure of money as a credit system with interest payments and its implications for growth, these approaches have, however, neglected the mitigating role of inflation. Inflation can arise from the realization of climate risks and notably the possibility of extreme events, empirically considered as non-negligible (Batten et al. 2016; Heinen et al. 2016).

Macro-Prudential and Monetary Climate Policies

The thorough analysis of the links between climate and finance requires that we go farther than simply introducing commercial bank money on the balance sheet of economic actors. On the one hand, financial risks in the face of climate change or climate policies effect financial markets as well as bank balance sheets. On the other hand, it is the complexity of these balance-sheet relations between financial institutions which can ground the argument in favor of a climate systemic risk (Aglietta and Espagne 2016).

Inside this balance-sheet approach, two directions can be distinguished: the analysis of complex systems through real data or agent-based models (Balint et al. 2017); and the development of post-Keynesian models already mentioned, integrating a financial dimension (Nikiforos and Zezza 2017). The two approaches begin to converge, under the name of AB–SFC models (for Agent-based and Stock–Flow Consistent).

The analysis in the first direction can illustrate climate financial stress tests (Battiston et al. 2017). They bring some evidence of the possible propagation of shocks from a climate-related origin on the valuation of asset on the balance sheets of financial institutions (Comerford and Spiganti 2016). Results so far generally show limited systemic risk, without being fully convincing, because of the absence of a macroeconomic scenario to close the model. They can, however, help build tools to practically measure financial risks from climatic changes such as the carbon content of output or the exposure to greenhouse gases (Monasterolo et al. 2017). By using agent-based models, Safarzynska and van den Bergh (2017) underline the financial risk linked to a too rapid transition toward renewable energies, cumulating the financial fragility of old installations and the high initial cost of the renewable sector. From a strict financial point of view, the intermediary option of natural gas mitigates this transition risk.

In the second direction, the works of Jackson and Victor (2015) and Jackson et al. (2016) are among the first to introduce the environmental constraints in post-Keynesian models. However, Dafermos et al. (2016) and Dafermos et al. (2017) go a step farther, on the one hand by introducing the notion of stock–flow consistency to physical resources as well as emissions, then by integrating a central bank and financial markets in the measurement of physical risk generated by climate change. Campiglio et al. (2015) consider the transition risk for the financial sector in a rather similar framework. Even more recently, Naqvi and Stockhammer (2017) propose a stimulating convergence between the Schumpeterian approach to green innovation and the driving role of money in post-Keynesian models, while Rezai et al. (2018) consider the impact of climate change on income distribution in the same kind of balance-sheet-based approach.

Conclusion: An Agenda for Climate Policies, an Agenda for Climate Research

We can find two future areas for the expansion of these balance-sheet approaches, beyond the possibilities already described in Hardt and O'Neill (2017). On the one hand, the complexity of the financial sectors represented in these models remains well below the complexity of real financial systems. One can notably think of the markets for derivatives and the growing importance of shadow banking. The speculation motives of the financial sector are also absent so far. It is clear that these financial fragilities, which exist independently of the climate question and are analyzed in the academic and institutional literature (FSB 2016), would be reinforced by climate-related risks. On the other hand, the way of financing a low carbon transition has not yet been thoroughly addressed. If the computable general equilibrium models imply a strong substitution effect between public and private investments (Pollitt and Mercure 2017), the way a low carbon transition is financed is not stable in post-Keynesian models either. They give a priori a far greater role to the structure of financial and monetary sectors in order to initiate or accompany the transition, without further justification (Matikainen et al. 2017).

To summarize, environmental constraints follow nonlinear dynamics through the brutal alteration of an ecosystem ("systemic" risk), so that the hypothesis of rational expectations and perfect knowledge of natural processes are unable to rightly orient financial flows in line with environmental policies. Green finance, understood as the simple rebuilding of efficient financial markets through the transparency of carbon-related information, will soon reach its limits. And the integrated assessment models which can only support this kind of conclusion will soon appear relatively useless to the climate finance debates. The 2008 crisis has not (yet) provoked the tectonic changes it should have in the understanding of the role that money and finance play in long-run economic cycles. It has, however, remobilized interest in the financial sector as an economic actor to be taken into account in the positive and negative dimensions of the externalities it produces in the other sectors of the economy, where it was simply ignored before, because of its supposed neutrality. The coincidence between the 2008 crisis and the failure of the climate negotiations in Copenhagen in 2009 can, in this regard, be seen as a signal of the more general exhaustion of a certain approach to externalities. Civil society initiatives as well as some paragraphs in the Paris Agreement seem to prove that these defining moments have had an impact. But climate research also seems to have lagged behind for too long in order to catalyze and rationalize these policy initiatives.

This article proposed a critical analysis of the most recent literature that attempt to integrate finance and money in the so far way too simple links between climate and the economy. The models derived from the seminal DICE model are inadequate to clearly represent the different channels by which finance and money could destabilize the equilibriums between growth and climate damages. New possibilities are investigated, mostly borrowing from post-Keynesian models for the key role they give to money. Such models should include complex systems for that tackle the interactions between financial balance sheets, and elements of ecological economics to fully consider the non-substitutability between financial and physical capital. However, the integration of monetary, financial and climate questions, remains to this day an agenda where much future research is called for.

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