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Analyzing Climate Policy Utilizing Financial and Energy Industry Models

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ABSTRACT

This paper outlines a critical gap in the assessment methodology used to estimate the macroeconomic costs and benefits of climate policy. The vast majority of models used for assessing climate policy use assumptions about the financial system that sits at odds with the observed reality. In particular, the models' assumptions lead to the "crowding out" of capital, which causes them to show negative impacts from climate policy in virtually all cases. We compare this approach with that of the Energy-Environment-Economy macro-econometric (E3I) model, which follows non-equilibrium economic theory and adopts a more empirical approach. The non-equilibrium model also has limitations, its treatment of the financial system is more consistent with reality and it shows that green investment need not crowd out investment in other parts of the economy – and may therefore offer an economic stimulus. The implication of this finding is that standard Computable General Equilibrium (CGE) models consistently overestimate the costs of climate policy in terms of Gross Domestic Product (GDP) and welfare, potentially by a substantial amount. These findings overly restrict the range of possible emission pathways accessible using climate policy from the viewpoint of the decision-maker, and may also lead to misleading information used for policymaking. Improvements in both modeling approaches should be sought with some urgency – both to provide a better assessment of potential climate policy and to improve understanding of the dynamics of the global financial system more generally.

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1. INTRODUCTION

The need for energy resilience has never been more urgent. Ramping up energy industry generation, accelerating energy diversification and increasing energy storage are global priorities amid heightened geopolitical tensions and fluctuating commodity prices, supply chain shortages, and an increase in extreme weather events. Further, a confluence of external factors is pushing producers of traditional energy sources to evaluate operating in cleaner, more efficient manners. The United States and China have long been appealing markets for certain renewable energy technologies and investments, as well as for the developing energy-transition-related market. Specific to the energy industry models and financial analyzing policy to forecast climate change. Moreover, this landmark legislation increased the incentives to energy-transition-related investments and core renewables projects and boosted the economic attractiveness of additional alternative energy technologies.

Energy storage will see benefits, with financial and energy industry models to analyze the climate policy by introducing a meaningful tax credit and incentive for stand-alone battery storage. Energy consumption has grown about 20% year over year in the last five years. It is outpacing the market, and it is not just solar farms: It is also manufacturing, transportation, services, and technology. In the future, we will see the sector become more resilient to downturns given strong demand trends and new policy underpinnings. There is also been an outstanding volume of late-stage investments that are going to be maturing in the market, and that is important for climate policy because financial and energy-consuming models need targets. Here, this paper outlines a critical gap in the assessment methodology used to estimate the macroeconomic costs and benefits of climate policy.

2. METHODS

We used a mixed method to analyze the research data concerning the minimum service standards to draw the final picture of the research results. This study used questionnaires and semi-structured interviews for gaining quantitative and qualitative data. We used descriptive statistics methodology through means analysis, standards deviations, ANOVA, and KMO and Bartlett's Test. Further, the qualitative data were analyzed by using the integrative components model.

The gathered data were verified, classified, and analyzed using qualitative theory. We have made descriptive statistics analysis by using SPSS, and we find the reliability scale. Then, we have analysis the KMO and Bartlett's Test by using the Kaiser-Meyer-Olkin Measure of Sampling Adequacy and found the results of the analysis showed that the Kaiser-Meyer-Olkin Measure of Sampling Adequacy is that 0.941.

3. RESULTS AND DISCUSSION

3.1. We Can Meet the 2◦C Target– But Who Will Pay?

There is a gradually emerging consensus that a global emissions pathway that is consistent with the target of keeping emissions concentrations below 450 ppm, and thus of having a 50%chance of limiting anthropogenic climate change to 2◦C above pre-industrial levels, is technologically feasible. The question of whether the 2◦C target will be met or not is therefore a political one to do with the allocation of scarce resources – essentially to determine who will pay if the world is to meet its collective target. It seems beyond doubt that targets for emissions levels will not be met without the introduction of the new policy. There are three main forms this policy could take:

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(i) Policies to improve the use of energy with existing technologies, such as enforcing efficiency standards through regulation.
(ii) Policies to ensure an efficient allocation of resources given existing technologies, for the main part through market-based mechanisms (demand-pull policies).
(iii) Incentives to develop new technologies, for example through providing tax credits on R&D expenditure (supply push policies).

These policies differ substantially in scope, and their responsibility may not even fall under the same government departments, but they do have some common characteristics. All will involve a reallocation of economic resources compared to what would have happened without government intervention. Most will involve substantial amounts of investment. This means that the policies will have impacts on both the real economy and across the financial system; understanding the interaction of investors in low-carbon technologies with the banks that provide the necessary credit and the companies that produce or install the equipment will be key to assessing overall impacts.

In summary, all of these types of policies will lead to economic winners and losers, with financial consequences at both the micro and macro levels. In a modern economy, all must therefore be justified before implementation. Quantitative models contribute to this process by providing evidence of the likely costs and benefits of potential policy.

3.2. The Role of Energy-Environment-Economy (E3) Models and IAMs in Policy Analysis

The emphasis placed on computer modeling in climate policy has been increasing steadily as data have improved and additional computer power has allowed the development of more complex tools. Large-scale climate models and Integrated Assessment Models (IAMs) are central to the analysis carried out by the IPCC both to estimate the current emissions trajectory and paths with which there is a reasonable chance of staying within the 2◦C target. When it comes to assessing the implications of climate policy on the wider society, Energy-Environment-Economy (E3) models are applied to estimate impacts on indicators such as Gross Domestic Product (GDP), welfare, and employment. As is often the case, the terminology is not always used consistently but here we define E3 models as essentially macroeconomic models that have been extended to include some physical relationships.

Their use has been well-established since at least the IPCC's second assessment report, and the relative weight placed on model results has increased over the past decade. For example, the European Commission's Impact Assessment guidelines state that for any policy assessment or evaluation: You should keep in mind that the credibility of an IA depends to a large extent on providing results that are based on reliable data and robust analysis, and which are transparent and understandable to non-specialists. This exercise will usually require inference from the collected data, either formally through statistical analysis or model runs or more informally by drawing on an appropriate analogy with measured impact or activities.

This assessment should go beyond the immediate and desired aspects (the direct effects) and take account of indirect effects such as side effects, knock-on effects in other segments of the economy, and crowding out or other offsetting effects in the relevant sector(s). And also that: If quantification/monetization is not feasible, explain why. Taken together, and given the often-disparate effects of climate policy on the economy, the message is quite clear – for any new climate policy proposals to be accepted at the European level it is necessary to provide model-based evidence of the macroeconomic impacts.

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3.3. Different Types of Macroeconomic Models

In many cases, policymakers' understanding of macroeconomic models has not kept pace with the more prominent role that the models play in policy analysis. This is unfortunate as it is not possible to properly interpret the results from the model without understanding the underlying mechanisms; furthermore, there are substantial differences between the ways the models work. It is recognized in the field that there is an inherent difficulty in communicating an understanding of complex tools to time-pressured policymakers who may not come from a quantitative or economic background. There are efforts to address this, for example by providing specialized training. The models that are used to assess the macroeconomic impacts of climate policy fall broadly into two groups. This is:

(i) Computable General Equilibrium (CGE) models are usually described as being based on neoclassical microeconomic assumptions. These models assume that agents (e.g. firms, and households) optimize their behavior to maximize their gains. Well-known international CGE models include GEM-E3 (Capros *et al*.,2013) and the Monash model. The Handbook of Computable General Equilibrium Modeling describes in detail how these models work. Model intercomparison exercises, such as those carried out by the Energy Modeling Forum (e.g. Weyant *et al*., 2006) typically compare the results from different CGE models.

(ii) Macro-econometric models that are derived from a post-Keynesian economic background. These models do not assume that agents optimize their behavior but instead derive behavioral parameters from historical relationships using econometric equations (which allow for 'bounded rationality'). Well-known international macro-econometric models include Energy-Environment-Economy macro-econometric (E3I) and GINFORS (Lutz *et al*., 2009).

The aim of this paper is not to describe in detail the differences between the modeling approaches. The focus of this paper is instead on describing how the different models represent the global investment that will be required to meet the 2◦C target, how such representations influence model results, and how this information can be interpreted by decision-makers. Closely tied to this issue is the question of how the models treat banks, money, and the financial sector, which we introduce below.

3.4. Why is the Treatment of Money and Finance Important in Macroeconomic Models?

It is beyond doubt that substantial investment will be required to meet the 2◦C target. The global level of $2.4trn (2013 prices) 'clean energy investment' must be made annually in its 450-ppm scenario. All of this investment must be financed somehow; although some could be diverted from investment in developing fossil fuel resources, the investment-intensive nature of low-carbon technologies (e.g. renewables, energy efficiency) means that any policy scenario in which emissions are reduced is likely to require an increase in energy sector investment.

The question of how the investment is financed, and whether more investment resources can be mobilized, is therefore key to understanding the economics of a low-carbon transition. There are, however, also other reasons to focus attention on finance. As was made painfully aware by the financial crisis and subsequent recession, even sophisticated macroeconomic models have only a rudimentary treatment of finance. While there have been attempts outside mainstream economics to build macroeconomic models with better links to finance, these are not developed enough to apply to climate policy.

The treatment of banks and the financial sector is therefore done largely by assumption. Furthermore, as we shall demonstrate, these assumptions vary enormously between the

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different modeling approaches. These modeling approaches are described in Section 3. First, however, we describe the underlying theory and how it relates to the different schools of economic thought. In Section 4 we turn attention to the lessons for policymakers from our analysis. Section 5 concludes.

3.5. Money and the Financial Sector in the Different Schools of Economic Thought

The focus of this paper is on the impacts of assumptions in macroeconomic modeling approaches, and thus it is necessary to have a basic understanding of the underlying theory and philosophy to understand how the models work. This section, therefore, gives a brief overview of how finance is treated in the most relevant schools of economic thought.

3.5.1. Money and finance in neoclassical economics

Most readers will be familiar with the Efficient Markets Hypothesis (EMH) that forms the core of financial theory in neoclassical economics. The EMH postulates that markets are 'efficient' and that the prices that are set accurately reflect all of the available information. The underlying assumptions, such as the same information being available to all individuals who act rationally, are broad, if not entirely, consistent with those used in CGE models. Although the EMH has been criticized heavily for making these assumptions, especially since the global financial crisis, it is still the standard approach that is taught in economics textbooks. While the EMH is certainly relevant to the modeling of energy and climate policy, for example in the way that optimal carbon prices are determined in most modeling approaches, the neoclassical theory of the money supply is much more important in determining the macro-level impacts of climate policy in CGE models (e.g. GDP, welfare) – as we shall show in the next section.

In neoclassical theory, the money supply is effectively determined by the central bank which, in modeling terms, makes it exogenous. If there is an increased demand for money from commercial banks, government, or private sector institutions, interest rates (i.e. the price of money) will adjust in response and there will be no change in the overall supply of money. Furthermore, if the central bank does increase the money supply (in nominal terms) this does not have any impact on real rates of economic activity. Instead, prices and inflation rates automatically adjust by the same relative amount, an approach that is consistent with the optimization principles applied in the modeling; if all available resources are being used optimally already then making more money available will just lead to higher prices for these resources. Within economics, this theory is referred to as the neutrality of money.

3.5.2. Money and finance in new keynesian economics

New Keynesian economists (not to be confused with post-Keynesian economists) also accept money neutrality in the long run but allow for changes in the money supply to have real impacts in the short run. This is because under New Keynesian assumptions interest rates are set by the central bank rather than the market and there are time lags in adjustments in prices; these are reflected in the Dynamic Stochastic General Equilibrium (DSGE) models that are used by central banks and can include an explicit representation of money. Nevertheless, the long-run outcomes will be the same as those described above, with prices adjusting to the equilibrium value. As climate policy analysis typically focuses on long-run outcomes, and DSGE models are not commonly used in assessing climate policy, we do not develop this further in the present paper.

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3.5.3. Money and Finance in post-keynesian economics

Money plays a central role in post-Keynesian economics, the term appears in the full title of Keynes' *General Theory*; in the recent textbook by Lavoie at 2014, money and finance are introduced before the real economy. In contrast to the neoclassical approach, post-Keynesian economists follow a theory of "endogenous money". The approach is based on the fact that in a modern economy, most of the money is created by commercial banks through the advancement of new loans. Due to leverage effects, banks do not need to receive additional deposits to make new loans. When the banks do make new loans, they create simultaneously a matching deposit in the borrower's bank account, thereby creating new money.

McLeay provide a very clear summary of the processes involved but, in summary, the volume of loans and therefore money supply is at least in part determined by broader macroeconomic conditions (i.e. whether the banks see profitable commercial opportunities). Depending on whether reserve requirements exist, and their magnitude, central banks are assumed to print 'on demand' the amount of money required by the commercial banks to underwrite these loans. In advanced economies, this is what the central banks generally do. In post-Keynesian economics, the money supply is also important because it leads to real economic effects, particularly in the short run but potentially with long-run impacts. As prices do not adjust instantly (or even at all), providing more money to make purchases can lead to an increase in aggregate demand, pulling previously unused resources into the system. It is in this way that interest rate policy is applied (encouraging banks to make loans that would stimulate aggregate demand).

Quantitative easing follows a similar idea, although in both cases the banks must be willing to make the loans if demand is stimulated. While the New Keynesian theory described above also favors these policies, post-Keynesian economists stress features such as uncertainty and path dependence, i.e. that short-term developments can influence long-term outcomes.

The post-Keynesian economists are themselves divided into two groups: horizontalizes and structuralists (Pollin, 1991). The names reflect the shape of the money supply curve (in neoclassical theory it is vertical, i.e. fixed). If the money supply curve is horizontal, banks are free to lend infinitely without restriction; the sole limit on lending is thus the degree of profitable opportunity. Interest rates are exogenous under this approach, although some variants with upward-sloping curves have been suggested.

Structuralists endogenize the interest rate by adding further real-world factors, but at the expense of a more complex theory (Palley, 2013) of crucial importance is that the empirical evidence supports the post-Keynesian formulation. Anger and Barker (2015), list numerous studies that show the limited role of the central bank in controlling the amount of credit available, and therefore the supply of money to the economy. Arestis and Sawyer (2011) conclude that "the analysis of macroeconomics cannot be reduced to studies of economies without money and finance" – as noted in the introduction above, this finding is particularly relevant to policies that are designed to promote investment, including climate policy.

3.5.4. Money and finance in the post-Schumpeterian (evolutionary) school

Money creation is also a key component of the post-Schumpeterian school, also known as evolutionary economics. Productivity growth is effectuated by the entrepreneur, who has no funds but has ideas. He innovates in the production process by inventing new combinations of resource use (*ibid*) which increase productivity and/or lower costs. If he is successful, innovation confers him a temporary monopolistic profit, until the time when the competition catches up, at which point economy-wide prices have declined. In the long run, this generates economic development. To carry this out, the entrepreneur needs finance, however, which is

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provided for by banks, based on the credibility of his business plans, past successes, and general confidence in the economy.

Banks create loans, which the entrepreneur pays back with his profits. In a volume published posthumously, Schumpeter gives a completely positive theory of the money supply and of the role of banks, which is, in its broad lines, equivalent to that of the post-Keynesian school. In this perspective, Schumpeter's view of the economic process reveals another side of the same coin, in comparison to the post-Keynesian view: money and finance come first, and productivity growth and economic activity follow. That perspective implies, equally to Keynes', that the economy is demand-led. However, it also adds a new micro perspective: that of the entrepreneur. Effectively, money creation comes with trust, by finance institutions, that the entrepreneur's innovation will generate profits and those loans will be paid back with interest.

Thus, expectations are a key feature of the model. A second key element is added by Schumpeter in his work on business cycles: technological change comes in waves and innovation clusters. It can readily be seen that if, for any reason, innovative activities are linked to one another in some way (e.g. constellations of innovations related to the steam engine), and limited in the extent of development (e.g. covering Britain with railways), then limited waves of activity arise in different sectors at different times, corroborated to waves and slumps in investment. Thus, the *clustering of innovative activity* leads to *economic cycles* of different lengths. Additionally, the success of some innovations may lead to euphoria in the financial sector, while the depletion of innovative possibilities leads to pessimism, and thus bubbles can arise (for example, the dotcom bubble).

Throughout his work, Schumpeter insists on adopting a historical approach. Following this, work has been done on characterizing the great historical waves of innovation (Freeman & Perez, 1988), and matching them to the structure of investment fluctuations and technology-related financial crises over history. Meanwhile, the network nature of the clustering of related innovations has been studied computationally by Arthur and Polak (2006). These analyses provide a structure to the process of clustering of investment related to productivity growth, and thus to business cycles. While such insights cannot readily be brought into economic models without prior descriptions of the technologies in question, they suggest a very clear methodology for how to study given problems of technological change, including notably the challenges involved in climate change mitigation.

3.6. Money and the Financial Sector in the Different Modeling Approaches

The previous section showed that the treatments of money and finance vary considerably between the different strands of economic theory. In this section, we turn attention to the practical application of these theories through computer models. The explanations focus on the assessment of energy and climate policy but it would be possible to draw the same conclusions for any type of policy that was investment intensive and for which we were interested in the long-run outcomes.

Our review is carried out at the global level. International financial flows can complicate the issue when considering policies at the regional level, due to interactions with exchange rates and international trade. The aim of this paper, however, is to provide a basic understanding of the most important differences between the modeling approaches, so we focus on the simpler case. It is important to note that all the different models we look at observe the macroeconomic identity that savings should equal investment but, as we shall see, they have quite different interpretations of how the balance is met. First, we describe the processes involved in the neoclassical CGE models before explaining the roles of money and finance in the post-Keynesian E3ME macro-econometric model. The table towards the end of this section summarizes the key differences between modeling approaches and the section finishes with an example relating to climate policy.

3.7. The Role of Money and Finance in CGE Models

The sixth part of Walras' Elements of Pure Economics, widely regarded as the bible for CGE modeling, is titled 'Theory of Circulation and Money'. This title hints at the role of money in the economy in CGE models – as a means to allow the transactions of goods and services. Lessons 28 and 29 of the book expand on the approach; the demand and supply of money are described in micro terms, with money being held to allow the immediate purchases of goods and services – e.g. for consumers: a certain quantity of cash on hand and savings which are mathematically determined by the same attainment of maximum satisfaction, under the same aforementioned conditions, following each consumer's initial quantity of money and not only his utility or want functions for the services of availability of new capital goods in the form of money rather than in kind; a similar definition for producers is provided on page 317.

The passage goes on to describe an agent's cash balance as: not only to replenish these stocks [final products] and make current purchases of consumers' goods and services for daily consumption while waiting to receive rents, wages, and interest payable at fixed future dates but also to acquire new capital goods. After explaining the reasons for holding cash, Walras describes the role of lending and borrowing money in the economic system: That is not all capital is defined as "the total of fixed and circulating capital goods hired, not in kind, but in money, utilizing credit" This quantity of repaid capital, to which land-owners, workers, and capitalists add a certain excess of consumption over income, or from which they subtract a certain excess of consumption over income, constitutes the day-to-day amount of savings available for lending in the form of money.

The implications are quite clear – savings are defined as the difference between consumption and income and this difference is equal to the sum of money available for lending, i.e. a change in lending must be compensated by a change in current consumption. The price of money is adjusted to obtain equilibrium in the market for money, there is no explicit role for the banking sector and it is assumed that either savers and borrowers interact directly or the banks act as frictionless paths in which money is channeled between the savers and borrowers. Furthermore, risk on investment is not part of the theory, and all of the money available for lending is always fully used.

Walras also discusses the impact of changes in the money supply. The assumption is that the value of money is only determined by the value of the goods and services it may purchase and hence is "inversely proportional to its quantity". Interestingly, even in the 19^{th} century, Walras was aware of the restrictive assumptions relating to price adjustments that were necessary to justify this proposition; he describes the treatment as one of 'almost rigorous exactness'. The treatment of money in modern CGE models is based on the approach described by Walras, with the total money supply fixed in real terms and money used as a means of exchange rather than something that can have an impact on rates of real economic activity.

The current handbook pays little attention to money. A search for the word 'money' reveals first a description of the MAMS model that includes: Like most other CGE models, MAMS is a 'real' model in which inflation does not matter (only relative prices matter). Given this, there is no significant gain from having a separate monetary sector (Lofgren *et al*., 2013). Then a similar paragraph for the 1-2-3 model: It [the exchange rate] can be seen as a signal in commodity markets and is in no sense a financial variable since the CGE model does not

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contain money, financial instruments, or asset markets (Devarajan & Robinson, 2013). Only the G-Cubed model description (McKibbin & Wilcoxen, 2012) talks about money at length, although it must be noted that it is in the context of non-equilibrium (i.e. it is not pure CGE). The other search results (excluding DSGE descriptions) refer to money as a metric for presenting model results rather than something that can impact these results.

3.8. The Role of Money and Finance in the post-Keynesian E3ME Model

E3ME is a global macro-econometric model. It combines input-output analysis with sets of econometric equations that determine the components of aggregate demand and price levels. The basic economic framework is extended to incorporate physical flows of energy use, materials consumption, and greenhouse gas emissions. The model's parameters are derived from time-series historical data and it projects forwards annually to 2050. The role of money and the financial system is not covered directly in the current version of the E3ME model manual, although there are several references to related features. Essentially the model provides a 'horizontalist' approach (see previous section) to banks, lending, and the money supply. Investment is determined by expectations of future output levels, which are based on current activity.

The interest rate is fixed as exogenous and there are no set limits on the amounts that banks can lend. It should be noted that this does not mean that banks are allowed to lend completely freely as past regulations will be factored into the model's econometric parameters which are derived from historical data. However, the implication is that an improvement in economic conditions will lead to an increase in the demand for money which will be followed by an increase in the money supply. This means that an increase in investment does not need to be financed by an increase in savings or a reduction in investment elsewhere. Instead, an increase in investment can be financed by an increase in public and/or private debt – and the savings-investment identity is maintained through an expansion of the economy that generates additional savings. Or, to put it another way, capital markets do not enforce a crowding out of the investment.

This feature would possibly not matter if the model embodied other equilibrium properties. For example, if full employment were obtained, there would be no additional workers left who could be employed to build any new equipment or infrastructure. However, the demand-driven nature of the model means that this is not usually the case, and unemployment exists in E3ME. So, an increase in investment levels can lead to an overall increase in economic activity rates. This sets the model apart from the results that are typically obtained by CGE models. The treatment raises the question of what the capacity constraints in the model are. Would it be possible to keep on financing higher levels of investment through ever-increasing levels of debt? The answer to this question is somewhat mixed.

First, as the public sector is treated as exogenous in the model it is up to the model user to enter assumptions, including on borrowing rates; if these assumptions are not realistic then the model responses will not be either – although of course there is considerable uncertainty about how much a country can borrow under different economic conditions (as has been highly evident since the 2008 global financial crisis). Second, there is one obvious capacity limit imposed by the stock of available labor. While involuntary unemployment is a standard endogenous feature of the model, if the economy moves towards full employment, then wages increase and labor market crowding out occurs.

More generally, the modeler faces the same challenges as economists who try to measure the 'output gap' or the potential levels of debt that individuals, firms, or national governments

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are willing or able to take on. There is considerable uncertainty over the level of any economy's actual capacity to produce a complex range of goods and services to meet global demands, at present and even more so in the future. For this reason, expected future capacity is modeled implicitly through econometric equations that take into account past growth rates. If a sector's output increases more quickly than expected, it will increase prices and there may be import substitution. Workers in that sector may also work longer and receive higher wages (e.g. through bonus payments). In summary, inflationary pressures will start to build at a time of rapid economic expansion.

3.8.1. Summary of features of the models – and a worked example

To illustrate these features, we can take the example of a carbon tax with revenue recycling (e.g. through reduced income/corporate taxes) (Shaturaev, 2023). If the policy is revenue neutral overall, then in a CGE model we are considering a reallocation of resources – a new optimal point in sectoral prices space – which will take us away from the optimal economic starting point and therefore reduce rates of economic activity. But in the E3ME framework, there is the possibility that the policy stimulates additional investment financed by borrowing, in which increasing debt levels contribute to aggregate demand, drawing upon unused economic resources to increase overall production levels. Higher current rates of output will lead to expectations of higher future rates of output, and there is a long-run increase in production levels which will be used to pay down the initial borrowing.

This results in higher GDP and (possibly) employment levels. In fact, in E3ME there need not be an increase in low-carbon investment following such a carbon tax. If the consumption of oil and gas falls then the income of oil and gas exporting countries will also fall. As the saving ratios of oil exporters are typically higher than the saving ratios of fuel consumers (e.g. compare sovereign wealth funds to households with cars), then there can be a similar stimulus-type effect: net global debt is still higher but through reduced saving rather than increased borrowing. We can see this in reality when there are reductions in the global oil price; even if the consumption of oil does not change there can be a noticeable boost to global GDP growth rates due to a shift in global saving rates, although the GDP of the major oil and gas exporting countries will fall. In a CGE model, the basic reallocation of resources without changes in net savings would not produce this result.

3.8.2. A post-Schumpeterian view: the entrepreneur borrowing to invest in new technology

Modeling climate change mitigation is often done from a 'bottom-up' technology perspective, and this provides an opportunity to study its relationship with the economic process. Indeed, while in E3ME the process of money creation for productivity growth is implied but not described explicitly, connecting explicit models of technological change to E3ME, with investment and price feedback, enables us to do precisely that: studying the process of money creation for financing technology ventures (Shaturaev, 2023). It furthermore adds a clear post-Schumpeterian perspective to modeling through an explicit representation of the entrepreneur seeking finance to invest in technology.

In the context of climate change mitigation, this is a crucial aspect to explore. Indeed, for purposes of studying emissions reduction policies, an evolutionary model of technology selection and diffusion was recently connected dynamically to E3ME, the only one of its kind, named 'Future Technology Transformations' (Mercure, 2012, Mercure *et al*., 2014). In its application to the electricity and transport sectors, this model explores the impact of policies on the choice of investors or consumers for technologies that provide various societal services (electricity and mobility in this case), of which the demand is evaluated econometrically by

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E3ME. As noted above, low-carbon technologies tend to be, in general, more capital-intensive than incumbent fossil fuel systems.

In scenarios where policies incentivize investors to adopt new technologies, the additional investment, in comparison to a baseline, does not 'crowd out' investment elsewhere: money is created to finance these ventures (Gazi *et al*., 2022a). However, given the assumption that banks consider these ventures profitable, the self-consistent structure is adopted where firms pass on higher financing costs to consumers, for example with a higher price of electricity. This, therefore, creates a modeling system that contrasts quite starkly with equilibrium approaches: money is lent by banks for financing evolving technology developments, which are paid back through higher receipts from consumers over the lifetime of the new capital. Therefore, in contrast to equilibrium approaches where *economic costs are incurred first, and benefits may arise later, here, economic benefits arise first, and costs are incurred later.*

For instance, if high investments are made early to radically transform the electricity sector to reduce emissions (e.g. replacing coal power in China), high increases in employment and income may temporarily take place (Dhar *et al*., 2023). However, when the technological transformation is completed, significant levels of debt may remain, which leaves society to live with a legacy of debt servicing payments, of which the costs are given to consumers through prices. Depending on whether this transformation has enhanced productivity growth and/or international competitiveness, the transformation may be beneficial or detrimental to economic performance in the long run.

3.8.3. Implications for policymakers

So far in this paper we have outlined the following:

- Macroeconomic models are used frequently to estimate the economic costs and benefits across a range of policy areas, including climate policy.
- Much climate policy (e.g. renewables, energy efficiency) requires substantial investment and financing for this investment:
  marginal returns, this reallocation of investment is effectively certain to have a negative effect on total economic production levels. In contrast, in a non-equilibrium macro-econometric model, if investment opportunities are sufficiently commercially attractive, banks may choose to increase their lending, leading to an increase in net credit and the broad money supply, in turn stimulating real economic activity and leading to higher rates of output and employment. While in the longer term, there may be costs as loans are repaid, higher rates of production can stimulate further activity, meaning long-term impacts need not be negative.

To put it another way, a CGE modeling approach represents a worst-case outcome for policymakers; the starting point is one of optimal use of resources (including in the financial sector) from an economic perspective and the policy shows the negative impacts of intervention and a reallocation of limited resources. This raises the question of how close we are to an optimal starting point. In 2015 the answer seems to be 'not very' with a combination of economic recession, demographic change, and a shift to less capital-intensive industries leading to a persistent 'global savings glut'. The continuation of Quantitative Easing (QE) in Europe, a policy designed to increase the money supply directly without the intermediation of banks, suggests a position that is far from optimized. However, while all of this suggests benefits from encouraging investment in the short term, climate policy scenarios usually consider the period out to 2030 and beyond; a wide range of possible outcomes can be predicted for macroeconomic conditions so far ahead.

The simulation-based approach offered by the non-equilibrium macro-econometric model is much more in line with how the financial system works in most countries but is by no means perfect. It does not present a best-case outcome but, by not having an explicit treatment of possible financial constraints, it is more likely to be erring on the optimistic side (Gazi *et al*., 2022b). Indeed, the power of decision for the creation of loans belongs to banks, and banks can at any point refuse to lend. It would, therefore, be desirable to test the sensitivity of model results to the addition of constraints (e.g. by adjusting interest rates or changing baseline unemployment rates) to see how important the assumptions are – a similar exercise could be carried out with a CGE model but the model would become difficult to solve in non-equilibrium conditions. One possible solution to the problem is to use both modeling approaches to test climate policy, as is now common within the European Commission. Although this requires additional resources for policy analysis, there are benefits both in terms of obtaining a range of results also in the discussion between the model results, which can help policymakers to understand some of the key assumptions that are involved (including the treatment of money and finance).

4. CONCLUSION

If the world is to meet the 2◦C target, it is clear that substantial levels of additional investment will be required. How this investment is financed is a key question for policymakers, as has become clear from the UNFCCC negotiations in recent years. In attempting to assess the costs and benefits of climate policy (and also other policy areas), policymakers now frequently turn to macroeconomic models to provide estimates. However, as shown in this paper, the majority of these models assume that the investment can only be financed by taking investment from elsewhere in the economy, or by reducing current consumption (and welfare) levels. This is not consistent with how the financial system works in the real world, as demonstrated by the real-world use of interest rate policy and QE, which would have no impact on these models.

The alternative approach, offered by the relatively few models that follow post-Keynesian principles, is not without limitations either but offers a version of the financial system that is closer to that which we can observe. However, questions of economic capacity which have only a limited representation in the model place a burden on the model operator to ensure that policy scenarios are realistic. In summary, the analysis in this paper shows that the post-Keynesian approach appears to be the best that the research community can offer at present but both modeling approaches could and should be improved further. On the surface, it looks like the post-Keynesian modeling approach is in a better position to adapt, as assumptions about optimization and fixed supply are fundamental to the CGE approach, which lends it significantly less flexibility. Thus, when assessing policy, decision-makers and policy analysts must identify what the implications are of their choice of models and associated underlying assumptions.

The simultaneous use of models with different theoretical underpinnings allows for safer identification of possible ranges of economic outcomes. Given how important issues of finance are in estimating the impacts of climate policy in the models, our view is that improving the treatment of finance in the models should be given priority in coming years – the benefits would be a more accurate representation of the impacts of climate policy and investment across the world's economies more generally.

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5. AUTHORS' NOTE

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