CHARGING THE MACROECONOMY WITH AN ENERGY SECTOR: AN AGENT-BASED MODEL

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Overview

Energy has always been a crucial element in economic development. In recent years, it is assuming an increasingly important role. The fight against climate change (see IPCC 2021 and COP26) has pushed States to define transition processes towards renewable resources, reducing greenhouse gas emissions and imposing implementation targets, such as net zero emission (NZE) for 2050 for the European Union (EU). It is widely recognized that the likelihood of a low-carbon transition will crucially depend on the policy makers' ability to spur the economic system towards cost-effective and environmentally sustainable energy sources. However, it is still unclear how long the process will take and what are the major macro-financial risks associated with it. The global decarbonisation process has also involved the beginning of the coal phase-out. At the same time, the post-covid recovery has increased energy demand for all countries seeking to restart. Not least the political crisis between US and Russia in Ukraine has further contributed to overheating energy markets and prices. All this has profound repercussions on the level of inflation, which is reaching values not seen for decades. According to the last World Energy outlook (Birol et al., 2021), energy will assume an even-more central role in the lives of households and worldwide economic growth. People's well-being and industrial competitiveness strongly depend on safe, secure and affordable energy.

In light of this, understanding the major challenges and opportunities resulting from the energy transition requires a modelling framework capable of capturing market imbalances and out-of equilibrium dynamics that may arise along the transition pathway. According to Hansen et al. (2019), the interactions in the energy sector, influenced by network and governance structures, require a methodological approach that can deal with complexity and non-linear dynamics. The agent-based modelling constitutes a promising approach since it introduces heterogeneous agents whose characteristics and behaviour can enhance the realism of the analysis (Delli Gatti et al., 2011). An Agent-Based Model (ABM) is a computational framework representing the economic system as an evolving environment where autonomous interacting agents behave according to fixed or evolving rules of thumb (Tesfatsion, 2006). Agents may represent individuals, firms, groups of individuals, policy makers or even countries, depending on the problem that is being treated. In the ABM literature, the macroeconomic outcome emerges from the interactions of the heterogeneous agents and does not coincide with the micro-representative agent behaviour (Bonabeau, 2002).

As highlighted by Karimi and Vaez-Zadeh (2021), the ABM framework is an appropriate methodology to investigate the energy transition because it allows studying the (suboptimal) macro-dynamics emerging from locally optimal but uncoordinated micro-interactions. Moreover, agent-based modelling is a useful approach to test policies and better understand the responsiveness of a complex system to small or big changes in its structural parameters or rules of behaviour, allowing for a better description of the system transition (Farmer and Foley, 2009; Helbing, 2012).

Despite a growing interest of the ABM literature in the role of energy in the macroeconomy, little effort has been made to endogenise the energy sector, assuming, on the contrary, an infinitely elastic energy supply and rolling out the possibility of supply shortages and energy market feedbacks.

Methods

We propose an ABM with an endogenous energy sector to evaluate the likelihood that insufficient investments, supply shortages, market disruptions, and coordination failures may generate recessions in the macroeconomic cycle. The model nests optimal decision rules into an agent-based computational economic framework. Agents are heterogeneous and take decisions derived from profit/utility maximization in a context characterized by limited information and bounded rationality. Further, interactions between agents occur through decentralized matching protocols built to represent real-world markets. The simulated economy is populated by a corporate sector consisting of consumption, capital, and energy firms; a banking sector; a household sector, namely workers and firms' owners (i.e., entrepreneurs and bankers); and a public sector, including a government and a central bank. Moreover, the business sectors have interlocked input demands. Therefore, the energy sector is endogenous to the economic system as it combines labour and capital to generate energy services that are functional to the production of consumption and capital goods. For the sake of realism, we assume that energy firms employ a foreign input (e.g., oil or natural gas) to produce their services and thus control for the presence of exogenous shocks in the global demand for raw materials.

The model presented here includes some novel elements to the energy-related ABM literature. First, it allows addressing the effects on the real economy of possible energy shortages which may arise endogenously as a consequence of suboptimal investment decisions. Second, it introduces a financial accelerator to investigate the direct and indirect effects of corporate defaults (also in the energy sector) on the banking industry. In this way, we can investigate how changes in the net worth of lenders can amplify and propagate fluctuations to the whole system (Van Der Hoog and Dawid, 2019). We expect our framework to be suitable for future policy analysis on energy transition and technological innovation. At the same time, we aim at contributing to the still young and growing ABM literature on energy transition from a macro perspective and provide an additional modelling framework that can be used to address policy-relevant research questions.

Results

We employ the model to simulate the functioning of a complex adaptive system characterized by economic and financial interactions. The model, calibrated on US quarterly macroeconomic data, can account for a wide ensemble of micro and macro empirical regularities. The standard deviations of the simulated time series are in line with the observed data. Since the model introduces an endogenous energy sector, we test the observed long-term positive relationship between energy demand and aggregate production (see Ozturk, 2010, for a review). The simulations confirm the empirical evidence of a strong, positive relationship between energy demand and aggregate production with an estimated elasticity equal to 35%, in line with the findings of Burke and Csereklyei (2016). Moreover, the model can reproduce the average expenditure on oil over GDP observed in the US between 1973 and 2019, that is around 3%. Moving to the dynamical properties of the times series, the autocorrelation functions of simulations are generally correct and follow the patterns observed in US data. In particular, the key macroeconomic variables display a positive auto-correlation in the first four to eight quarters, while negative in the medium term. Similarly, our model correctly predicts the co-evolution of US economic variables with the unemployment rate, the consumer price index, and the policy rate.

The business fluctuations are generated endogenously as a result of the adaptive behaviour of heterogeneous interacting agents in decentralized markets and policy makers' response to the changing economic environment. Having explored the properties of the model and its ability to replicate empirical regularities, we carry out a battery of experiments to investigate the economic impact of two types of energy shocks: (i) a positive energy input price (EIP) shock (e.g. oil price shock); and (ii) a negative energy productivity (EP) shock (e.g. adoption of a new technology). Our analysis indicates that the effects of energy shocks on prices and quantities vary substantially depending on the type of shock: an energy input price shock leads to a higher price inflation and a lower GDP, reminiscent of the stagflation scenario of the 1970s, while a shock to energy productivity have a negative impact on both price and aggregate production. The reason is that the energy supply shocks eventually trigger a demand crisis due to the presence of feedback loops and coordination failures giving rise to non-linear dynamics. Indeed, in the EP scenario, whereby the complex interaction between supply and demand shocks leads to a W-shaped recession which amplifies the effects of the initial shock. Furthermore, we investigate the economic impact of the energy shocks at the sectoral level. We find that an energy input price shock, by fostering a permanent increase in the relative price of energy, leads to a redistribution effect in favour of the energy sector, with this coming at the expense of the capital sector. On the contrary, we find that the energy sector net worth declines in response to a productivity shock.

Conclusions

In this paper, our effort is oriented to bridge the gap by presenting a new full-fledged macroeconomic ABM with an energy sector which endogenously supply energy services to the consumption and capital good sectors. The model is calibrated on US quarterly macroeconomic data. It does a fairly good job at replicating selected statistics from real data in terms of aggregate volatility and business cycles' properties. The business fluctuations are generated endogenously as a result of the adaptive behaviour of heterogeneous interacting agents in decentralized markets and policy makers' response to the changing economic environment. We employ the model to investigate the economic impact of two types of energy shocks: (i) a positive energy input price (EIP) shock; and (ii) a negative energy productivity (EP) shock. Our analysis indicates that the effects of energy shocks on prices and quantities vary substantially depending on the type of shock. The model presented here could be extended along many directions to address several questions related to energy transition and climate change. Some of the extensions we have in mind for future research are the following: (i) introducing a climate box to explore the relationship between GHG emissions, global warming and climate damages, and analyse the economic impact of global warming; (ii) adding endogenous technical change for studying the adoption of emission-reducing and energy efficient techniques and the role of policy measures geared to promote energy transition; (iii) developing a multi-regional framework with trade to investigate international mitigation policies; (iv) exploring the role of social interactions in shifting consumer preferences towards low-carbon footprint goods or firms.