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An Agent-based Stock-flow Consistent Model of the Sustainable Transition in the Energy Sector

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ABSTRACT

In this paper, we investigate the effects on the economy of a feed-in tariff policy mechanism aimed to foster investments in renewable energy production capacity. To this purpose, we employ an enriched version of the agent-based Eurace macroeconomic model, where we have included an energy sector with a fossil-fuel power producer as well as a renewable-energy based one. Both power producers take pricing and capacity investment decisions based on the price of imported fossil fuel and the feed-in tariff government policy. Results show that the feed-in tariff policy is effective in fostering the sustainability transition of the energy sector and that it increases the level of investments with a positive impact on the unemployment rates. Moreover, we observe that its financing costs do not impact government finances, which actually improve following the better economic conditions. For high policy intensity, however, we observe an increasing GDP share of the investment sector in the economy, due to the building-up of renewable production capacity, with a resulting crowding out of consumption, higher interest rates and prices. The final outcome on household well-being therefore depends on what extent the chosen value judgment recognizes the importance of an economically and ecologically sustainable growth path.

1. Introduction

Sustainability transitions are long-term, multi-dimensional, and fundamental transformation processes that bring socio-technical systems to shift to more sustainable modes of production and consumption. Sustainability challenges can be observed in several domains, for example, energy supply, water supply, sanitation systems, transportation sector, agriculture and food system (Geels, 2011; Gil and Beckman, 2009; Gleick, 2003).

Focussing to the energy sector, major structural changes to the current fossil-fuel based economic systems are needed in order to address the challenge of climate change and economic recovery (Zysman and Huberty, 2013). In this respect, the European Union, has displayed a series of documents to reach the greenhouse gas (GHG) emission reduction level necessary for staying below the politically agreed limit of 2° temperature increase (European Commission, 2011a). The current EU roadmap is based on the so called "20-20-20" target, i.e., a 20% reduction in GHG emissions, a 20% share of renewable energy in gross final energy consumption and a 20% reduction in total primary energy consumption for EU, by year 2020 compared to year 1990. In 2011, the European Commission defined the long-term GHG emission reduction target for 2050 as 80%–95% below 1990 levels in order to reach the global political goal of staying below a 2° temperature increase (see the "Energy Roadmap 2050", European Commission (2011a), and the "Roadmap Towards a Competitive Low-carbon Economy Until 2050", European Commission (2011b)). Moreover, two intermediate goals for 2030 have been defined in 2013: the reduction of 40% GHG emission and 27% share of renewable energy with respect to 1990 levels, see European Commission (2013a,b). Finally, in 2015 the critical role that finance needs to play in enabling the resource efficient and low carbon transition has been discussed in Paris at the 21st Conference of the Parties (COP21) organized by the United Nations Framework Convention on Climate Change (UNFCCC) (McInerney and Johannsdottir, 2016; Johannsdottir and McInerney, 2016).

These challenging goals will only be achieved with an effective Renewable Energy Sources (RES) support policy and with a concrete effort towards the improvement of energy efficiency. Within various renewable energy technologies, Photovoltaic (PV) system has become one of the major actor in the electricity sector in Europe, and different PV support measures have been introduced, for example capital subsidies, VAT reduction, tax credits, quota obligation, net-metering and

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feed-in tariffs (FiTs) (IEA, 2015). Each support mechanism offers both pros and cons for the producers and the collectivity. The most diffuse PV support policy is the Feed-In Tariff (FiT) system that is considered the most effective policy in order to stimulate the rapid development of RES (Couture and Gagnon, 2010; Menanteau et al., 2003; Stern et al., 2006; Butler and Neuhoff, 2008; Fouquet and Johansson, 2008). In this regard, Mazzucato (2015) points out that the feed-in tariff (FIT) policy adopted in Europe, e.g Italy and Germany, is a good form of public 'patient capital' supporting the long-term growth of renewable energy markets, whereas tax credits employed in the US and the UK are a form of 'impatient capital', due to their frequent uncertainty, and which indeed has not helped industry take-off (Porritt, 2011; Cowell, 2013).

According to the feed-in tariff policy, electricity produced by RES can be sold at guaranteed prices for fixed periods of time. These prices are generally guaranteed by the government in a non-discriminatory manner for every kWh of electricity produced, so that a large number of investors can participate, including households, landowners, farmers, municipalities, and small business owners (Klein, 2008; Lipp, 2007).

Integrated Assessment Models (IAMs), based on computable general equilibrium, are the most common models for the analysis of climate policy and physical and socio-economic effects of climate change (Pindyck, 2015). In a general equilibrium framework, where economies are considered as "static, unchanging and perfectly efficient" (The Global Commission on the Economy and Climate, 2014), and the economic agents optimize their individual state and neglect external effects, climate policies are introduced as an additional constraint leading to less optimal (or efficient) outcomes. The overall economic costs (mainly in terms of GDP) of climate and energy policies and how these costs can be shared, e.g. among the member states of EU are the main important points of discussion about sustainability (Wolf et al., 2016).

Therefore, the cost of climate mitigation can lead only to lower economic welfare, with no room for possible long-term economic benefit. The only possibility of not reducing welfare is if the models assume very large damages in the future (in combination with lower discount rates).

Actually, the structural changes required to realize the transition to a low carbon economy are beyond the horizon of standard climate policy analysis models, and thus are the potential benefits from these changes. In fact, the possibility that climate policy offers economic opportunities has been largely neglected in previous macroeconomic modeling. The economic state of the European Union, characterized by low investment rates, low growth and high unemployment, however, suggests that there is an urgent need for new economic opportunities. To explore such opportunities, Burke et al. (2016) outline the need of research progress on climate economics, and in particular on refining the social cost of carbon (SCC), improving understanding of the consequences of particular policies and better understanding of the economic impacts and policy choices in developing economies.

The need of new approaches and tools based on complex system and network analysis has been recently advocated by many authors, see e.g. Battiston et al. (2016), Farmer et al. (2015), Rezai and Stagl (2016). Agent-based modeling (ABM), already employed for the study of complex systems, such as financial markets (Farmer et al., 2005; Ponta et al., 2011b; Pastore et al., 2010; Ponta et al., 2011a, 2012) and economic systems (Raberto et al., 2008; Dosi et al., 2010; Raberto et al., 2012; Caiani et al., 2016; Russo et al., 2016), is an alternative approach able to address shortcomings of IAMs because it provides a way for addressing out-of-equilibrium dynamics in economic systems (Farmer et al., 2015).

In particular, while general equilibrium models are characterized by rational and optimizing representative agents and by equilibrium solutions subject to exogenous shocks, agent-based models are characterized by a large number of heterogeneous and interacting agents, endowed with adaptive expectations, and by the ensuing evolutionary macroeconomic dynamics emerging from those endogenous interactions. In this regard, it is interesting to consider the recent and comprehensive survey by Fagiolo and Roventini (2017), where the theoretical, empirical and political-economy pitfalls of the equilibrium approach to policy analysis, in particualr the DSGE modeling framework adopted in macroeconomics, are discussed and a more fruitful research approach addressing the economy as a complex evolving system has been advocated. In particular, Fagiolo and Roventini (2017) point out the importance of taking into account the far-from-equilibrium interactions that continuously change the structure of the economic system, i.e. what is exactly the methodological core of agent-based computational economics, whose successful applications to different economic domains they present and discuss in details, including the ones on climate change economics.

The ABM framework looks indeed the appropriate modeling approach to investigate the transition to a sustainable low carbon economy, because ABM allows the study of the sustainability transition not as an equilibrium suboptimal solution but as a possible dynamic path emerging from the appropriate coordination of the endogenous interactions and decisions of different economic agents characterized by limited rationality and information.

A recent detailed review of the literature on complex systems, related to the climate issues, with particular attention to ABM, is provided in Balint et al. (2016), where the authors identify different areas where accounting for heterogeneity, interactions and disequilibrium dynamics provides a complementary and novel perspective to the one of standard equilibrium models. In particular, two early contributions about the application of the ABM methodology to climate issues deserve attention: the ENGAGE model by Gerst et al. (2013) and Lagom regiO by Wolf et al. (2013). ENGAGE is a multi-level, multi-agent, evolutionary economic model, where a diverse set of agents (negotiators, firms, and consumers) engages in purposeful behavior by observing and interacting with their surrounding environment and other agents, and whose purpose is to simulate the two-way dynamic feedback between international agreements and domestic policy outcomes. Lagom regiO is a multi-agent model of several growing economic areas in interaction with the purpose to understand equilibrium selection and identify win-win opportunities for climate policy. Both ENGAGE and Lagom regiO provided insights on the importance of multi-country interaction for climate policy. On the other hand, the study presented in this paper focuses on a singe-country economy and on the fiscal costs and the macroeconomic impact of green investments subsidies.

Among more recent contributions, the papers by Safarzyńska and van den Bergh (2016) and by Rengs et al. (2015) are worth mentioning. In the former study, the authors propose a formal behavioral-evolutionary macroeconomic model populated by heterogeneous consumers, producers, power plants and banks, interacting through interconnected networks, and examine how decisions by all these economic agents affect financial stability, the direction of technological change and energy use. In Rengs et al. (2015), the authors propose a macroeconomic multi-agent model with agents that change the behavior associated with carbon-intensive goods to test the effect of various policies on both environmental and economic performance. Furthermore, besides agent-based modeling, the use of other approaches encompassing out-of-equilibrium dynamics in economic systems to investigate the climate change and relative economic policies is worth mentioning. In this respect, Monasterolo and Raberto (2018) propose the EIRIN flow-fund behavioral model with heterogeneous agents as a tool to simulate green fiscal and targeted monetary policies, displaying their effects on firms' investments, unemployment, wages, credit market and economic growth. Jackson and Victor (2015) develop a system dynamics macroeconomic model for describing financial assets and liabilities in a stock-flow consistent Framework (FALSTAFF) and use this model to explore the potential for stationary state outcomes in an economy with balanced trade, credit creation by banks, and private equity. Then, this model has been enriched developing a socio-economic sustainability transition in order to analyze the economic, ecological and financial aspects (Jackson et al., 2015).