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Abstract

Major structural changes to the current fossil-fuel based economic system are needed in order to address the climate change challenge. To this purpose, effective Renewable Energy Sources (RES) support policies, along with concrete efforts towards the improvement of energy efficiency, have been adopted in many countries. One of these policies is the feed-in-tariff (FiT) mechanism, according to which electricity produced by RES is sold at guaranteed prices (feed-in tariffs), which are higher than market ones, for fixed periods of time.

In this paper, we investigate how to foster a sustainability transition of the energy system towards an economically and ecologically sustainable growth path by using an enriched version of the Eurace model. Eurace has been enriched by including an energy sector where electricity is demanded by domestic producers and is supplied by a fossil-fuel based power producer as well as a renewable-energy based one. Both power producers undertake pricing and capacity investment decisions based on the price of imported fossil fuel and feed-in tariff government policy. In particular, we investigate how the economy is affected by the fiscal costs of financing the feed-in tariff mechanism and by the benefits of lower fossil fuels imports, in order to devise the policy with the best cost-benefit trade-off for the macroeconomy as a whole.

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 in the economy with a slightly positive impact on the unemployment rates. Moreover, we observe that its financing costs do not impact government finances in a relevant way. On the other hand, the higher level of investments occurs at the expense of the production of consumption goods, therefore with a negative impact for the living standards, at least according to the perspective of a consumerist society. However, if factors like better employment rates and the reduced GHG emissions are also taken into account, along with consumption, by an appropriate preference function, the final outcome on well-being should be probably deemed as favourable.

Keywords: sustainability transition, energy sector, feed-in-tariff, agent-based modelling

JEL classification: Q01, Q42, Q43, Q56, C63

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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 degrees 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 degrees 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 feed-in tariffs (FiTs) (IEA, 2015). Each support mechanism offers both pro 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).

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 advocated by (Battiston et al., 2016; Farmer et al., 2015; Rezai and Stagl, 2016). Agent-based modelling (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 heterogenous and interacting agents, endowed with adaptive expectations, and by the ensuing evolutionary macroeconomic dynamics emerging from those endogenous interactions. Therefore, this modelling framework is more suitable 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 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. Furthermore, other tools that consider out-of-equilibrium dynamics in economic systems, have been applied in order to investigate the climate change and relative economic policies. In Safarzyska and van den Bergh (2016), 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. In Monasterolo and Raberto (2016), the authors propose the ϵIRIN System Dynamics 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. Also in Jackson and Victor (2015), the authors develop a system dynamics macro-economic 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).

In this paper, we address the question on how to foster the rebuilding of the energy system with the aim of reaching a low carbon economy, and whether rebuilding the energy system has the potential to trigger a sustainability transition towards an economically and ecologically sustainable growth path. In this respect, abstracting from the obvious improvements in GHG emissions, we aim to assess the trade-off between the fiscal economic costs of financing a transition to a renewable and fossil-fuels free energy system and the benefits of reducing substantially fossil fuels imports, in particular in the long term. Our goal is to devise the better policy combination that improves the long-term benefits with respect to the short-term costs for the macroeconomy as a whole. In order to investigate the macroeconomic effects of the sustainability transition in the energy sector, we employ and enrich the agent-based macroeconomic model and simulator Eurace as it will be outlined in the following section (Cincotti et al., 2010, 2012a,b; Raberto et al., 2012; Teglio et al., 2012; Raberto et al., 2014; Teglio et al., 2015).

The paper is organized as follows: Section 2 describes the main enrichments made to the Eurace model in order to address the issue of the sustainability transition in the energy sector, Section 3 shows the results of the computational experiments and, finally, Section 4 provides our concluding remarks.

2. Modeling the sustainability transition in Eurace

2.1. Overview of the Eurace model

The model presented in this paper is an enrichment of the macroeconomic agent-based simulator Eurace (Cincotti et al., 2010, 2012a,b; Raberto et al., 2012; Teglio et al., 2012; Raberto et al., 2014; Teglio et al., 2015). Eurace originally included the following agents: households (HHs), acting as workers, consumers and financial investors; consumption goods producers (CGPs), which are firms producing a homogenous consumption good; a capital goods producer (KGP), commercial banks (Bs) and two policy makers, namely a government (G) and a central bank (CB), in charge of fiscal and monetary policy, respectively. A detailed description of agents behaviour and interactions in the different markets is provided in (Teglio et al., 2015). To address the issue of the sustainability transition in the energy sector, the following agents have been included now in the model: a fossil-fuels based electricity company, which imports fossil fuels and produces electricity with decreasing returns to scale, a renewable-source based (e.g. solar or wind power) electricity producer, which invests in renewable technology subject to government sustainability policy, and a fossil-fuels exporting foreign economy.

The new agents interact on a monthly basis with the original agents through the (newly introduced) electricity market.

A complete and compact description of all Eurace agents and sectors is provided in the Appendix by Tables 2, 3, 4 and 5, where we have highlighted the 'stock-flow consistency of the model, according to the methodology described by (Godley and Lavoie, 2012) and along the lines of post-Keynesian economics, see (Caverzasi and Godin, 2015). The tables highlight a set of relevant identities that need to be taken into account to check for the consistency between stocks and flows in the simulated data.

2.2. New features: the energy sector

In order to investigate how to foster the sustainability transition in the energy sector, a feed-in-tariff system is considered. A feed-in tariff mechanism is a policy mechanism designed to accelerate investment in renewable energy technologies (Couture and Gagnon, 2010). The feed-in-tariff system usually has three components:

- a fixed price for a fixed amount of years (long-term contract),
- grid priority to electricity produced by renewable energy (meaning renewable energy will be bought first),

- financing costs covered by a mix of a reallocation charge τ_E, paid only by electricity consumers, and general taxation.

The feed-in tariff mechanism is modelled in Eurace in a similar way. In particular, we postulate that the renewable energy producer is entitled to sell electricity at a feed-in tariff p_E^r, assumed constant and guaranteed forever by the government. The value p_E^r is set exogenously and is the parameter characterizing our experiments. The difference between the feed-in-tariff price p_E^r and the market electricity price p_E, paid by electricity consumers, is paid by the government by using its general tax revenues[1].
Two types of electricity producers, i.e. a fossil-fuel based one, henceforth PP, and a renewable-source based one, henceforth RP, have been included, along with a fossil-fuels exporting foreign country, henceforth foreign economy (FE). In particular, the renewable electricity producer uses renewable technology, say solar panels or wind turbines, to produce electricity that will be sold to electricity consumers (firms), whereas the non-renewable electricity producer employs fossil fuel imported from the foreign economy to produce the residual demanded quantity, as we assume that renewable energy has priority in the market.
Both PP and PP are characterized by a balance sheet, described in Table 2, in the same way of the other agents. In particular, both PP and RP are characterized by liquidity M in the assets side and by equity E in the liabilities side. Moreover, the RP is also characterized by a capital endowment, say the number of solar panels (or wind turbines) installed, n_{sp}, in the assets side and by debt D in the liabilities side. As the solar panels (or wind turbines) are identified as capital goods in the model, they are produced domestically by the capital goods producer that employs labor force as production factor.

2.2.1. Electricity demand

Electricity is demanded by consumption goods producers (CGPs) on a monthly basis. Firms need electricity as it is a non-substitutable production factor, in addition to labor and capital, that any firm f employs to produce the monthly amount of output q_{C_f}. To this purpose, we consider now a production function characterized by a nested Cobb-Douglas and Leontief technology where the usual Cobb-Douglas production function, characterized by labor N and capital K inputs (see Eq. 8 of Teglio et al. (2015)), is coupled with a third non-substitutable input, i.e. the amount of electricity q_{E_f}, as follows:

$$q_{C_f} = \min(\gamma N_f^{\alpha} K_f^{\beta}, \eta_E q_{E_f}) \,, \tag{1}$$

where η_E is the electricity efficiency parameter (supposed uniform across firms), which gives the amount of output per unit of electricity.

[1] In order to investigate the system behaviour at high feed-in tariffs (relative to the electricity market price) and then huge financing costs, our experiments have been designed with τ_E set to zero, then considering feed-in tariff costs always fully financed by general taxation, to better distribute the burden on a broader fiscal base and then avoid too high electricity surcharges.

We assume that electricity is immediately delivered to CGPs by one of the two electricity producers and that firms are never rationed in their demand for electricity. Electricity demand (and consumption) q_{E_f} is then given for any firm f by its output q_{C_f} as follows:

$$q_{E_f} = \frac{q_{C_f}}{\eta_E} \,. \tag{2}$$

Aggregate demand (and consumption) of electricity is then given by $\sum_f q_{E_f}$.

2.2.2. Renewable power producer (RP)

The Renewable Power Producer (RP) produces electricity using renewable energy sources, which from now on we will call solar energy. For this purpose, the RP employs solar panels, built and sold by the capital goods producer (KGP). The level of production of renewable electricity depends on the number of solar panels installed, n_{sp}, as follows:

$$q_{E_{RP}} = q_{E_{sp}} n_{sp} \,, \tag{3}$$

where $q_{E_{sp}}$ is the amount electricity supplied on a monthly basis by any single solar panel. The number of installed solar panels is the cumulative result of monthly investment decision, Δn_{sp}, made by the renewable producer RP. The investment decision is based on a Net Present Value (NPV) calculation, which assesses if the (discounted) expected future cash flows given by the additional electricity sales are larger than the initial investment cost in the solar panel infrastructure, i.e.,

$$NPV(\Delta n_{sp}) = -p_{sp}\Delta n_{sp} + \sum_{m=1}^{\infty} \frac{p_E^r q_{E,sp} \Delta n_{sp}}{(1 + r/12)^m} \tag{4}$$

where p_{sp} is the price of a single solar panel, r is the yearly average cost of capital for the RP and m represents the index of months. Assuming p_E^r constant over time, considering that $q_{e,sp}\Delta n_{sp}$ is constant as well (we assume that solar panels are not subject to wear), and using the well-known properties of geometric series, Eq.(4) can be written as:

$$NPV(\Delta n_{sp}) = -p_{sp}\Delta n_{sp} + \frac{p_E^r q_{E_{sp}} \Delta n_{sp}}{r/12} \,. \tag{5}$$

Eq.(4) points out that, given the costs of solar panels, the expected revenues from selling the electricity at the feed-in-tariff price p_E^r determine if the NPV is positive or negative, then if an investment to acquire additional solar panels should be made. If NPV is positive, the investment is undertaken and new solar panels are purchased from the capital goods producer. However, it is worth noting that, as the NPV increases linearly and monotonically with Δn_{sp}, the size of investments should be as large as possible according to Eq.(4). Therefore, we postulate that the size of investment Δn_{sp} depends on the liquidity available to the renewable power producer.

Investment in new solar panels, financing of investment and then production of electricity occur sequentially, during the same day at the beginning of each month. New solar panels are immediately delivered to the RP agent by the KGP and employed for the production of electricity.

Table 2 presents the balance sheet of the RP agent. All balance-sheet entries are updated on a monthly basis. In particular, liquidity M^{RP} is updated according to RP' cash flows[2], i.e., investment cost, electricity sales and interests on debt; physical capital is given by the number n_{sp} of solar panels installed and is updated following new acquisitions; the change of debt level D_{rp} depends on the borrowing of new loans and repayment of old loans, whereas equity E_{RP} (net worth) is calculated as a residual according to the usual accounting rule:

$$E_{RP} = M_{RP} + n_{sp} p_{sp} - D_{RP} \tag{6}$$

where p_{sp} is the monthly price of solar panels. We assume that the RP equity capital is divided equally among households; however, the agent does not pay out dividends and retains all its earnings in order to increase the liquidity available for future investments

2.2.3. Power producer (PP)

The power producer (PP) agent produces electricity using a non-renewable energy source, say oil, according to a production function characterized by decreasing returns to scale[3], as follows:

$$q_{E_{PP}} = \gamma_E \; q_O^{\beta_E} \quad \text{with} \quad \beta_E < 1, \tag{7}$$

where γ_E and β_E are positive parameters and q_O is the oil input amount. The PP buys oil abroad, i.e. from a representative agent of a foreign economy, say Foreign Economy (FE) agent.
As we assume that the RP has priority in the power grid, the quantity of electricity $q_{E_{PP}}$ that the PP will sell during the month is set by the electricity market agent as a residual between the aggregate demand of electricity, $\sum_f q_{E_f}$, and the supply provided by the RP, $q_{E_{RP}}$, i.e.,

$$q_{E_{PP}} = \sum_f q_{E_f} - q_{E_{RP}} \, . \tag{8}$$

It is worth noting that the aggregate demand of electricity, $\sum_f q_{E_f}$, is unknown at the beginning of the month because electricity is demanded by firms at their activation day, i.e. the day of production planning and execution, which are different across firms, see Teglio et al. (2015) for further details. However, at the beginning of each month the PP agent has to set the electricity price p_E that will be valid for the rest of the month and will be taken into account by firms for their production planning cost assessment. To this purpose, as the price of electricity p_E is set by the PP according to a mark-up on unit costs, the power producer needs to estimate in advance, its incoming month production/sales, say $\widehat{q}_{E_{PP}}$, and related unit

[2]It is worth noting that the RP agent has no direct electricity production costs whereas negative cash flows are given only by investment costs and services of debt

[3]Production technology is characterized by decreasing returns to scale to mimic the upward-sloping supply curve made by the aggregation of different producers with increasing unit costs in a competitive market

costs $\widehat{c}_E$. The estimate is based on the electricity sold in the previous month increased by 10 %, so to take into account a possible demand increase.

Given the estimate $\widehat{q}_{E_{PP}}$ and the production technology set by Eq 7, the quantity of oil $\widehat{q}_O$ that would be necessary to meet the production plan is given by

$$\widehat{q}_O = \left(\frac{\widehat{q}_{E_{PP}}}{\gamma_E} \right)^{(1/\beta_E)} . \tag{9}$$

Then, the PP, estimates the unit costs $\widehat{c}_E$ that are equal to

$$\widehat{c}_E = \frac{p_O \widehat{q}_O}{\widehat{q}_{E_{PP}}} = \frac{p_O \widehat{q}_{E_{PP}}^{(1/\beta_E - 1)}}{\gamma_E^{1/\beta_E}}, \tag{10}$$

where p_O is the oil price set by the foreign economy. Accordingly, the PP sets the electricity price p_E as:

$$p_E = (1 + \tau_E)(1 + \mu_E)\widehat{c}_E \tag{11}$$

where μ_E is a fixed markup and τ_E is the reallocation charge, whose value depends on the policy adopted. It is worth noting that the unit cost, and therefore the price, increases with the estimated electricity production/sales $\widehat{q}_{E_{PP}}$ because $1/\beta_E - 1 > 0$.

The revenues of the PP are evaluated at the end of each month by summing up the effective quantity of electricity sold during the month at the market price p_E. Costs are given by the effective amount of oil imported paid at price p_O. Profits, if positive, are paid out to shareholders as dividends. Table 2 presents the balance sheet of the PP. Liquidity M_{PP} is updated monthly following PP cash flows.. Equity E_{PP} is also updated once a month at the beginning of the month according to the usual accounting rule.

2.2.4. Foreign Economy

The Foreign Economy (FE) is a stylized agent that works as provider of the oil that the PP needs in order to produce electricity. The FE sets the oil price and receives the oil export payments which are accumulated as liquidity. The FE balance sheet is simply characterized by a liquidity entry on the asset side and the corresponding net worth (Equity) on the liabilities side.

2.2.5. Calibration

The monthly electricity $q_{E,sp}$ supplied by a single solar panel as well as its unit cost p_{sp} have been calibrated to values consistent with the size of the other Eurace economic variables, considering real solar panel costs and performance. The average cost (including installation) of a solar panel of power 1 kW has been reported[4] to be around 5000 €, whereas, at the present state of the art of technology, its average monthly performance could be approximated to 100 kWh.

[4] `http://www.ecoage.it/mappa-solare-italia.htm`

In order to put the above numbers in the context of Eurace, we devised a sort of equivalence between the Euro (€) and the currency unit used in Eurace, let's call the Eurace €(E€). For this purpose, considering that in Italy there are around 30 millions of families (households) with a net monthly labor income at around 1500 Euro per family, and that the computational experiments have been performed with 3000 households with an initial money wage set to 1.5 E€, the equivalence between the euro and the Eurace euro has been obtained by equating the aggregate labor income of households in Italy and Eurace, that is

$$3\,10^3 * 1.5E€ = 3\,10^7 * 1500€\,, \tag{12}$$

that gives

$$1E€ = 10^7€\,. \tag{13}$$

In our model design, solar panels are identified with the capital goods units, whose initial unit cost is set to 1 E€; therefore, we need to characterize the Eurace solar panel with a monthly performance consistent with its high initial cost, i.e. 10 million Euro, as stated by Eq. (13). As a real solar panel, characterized by 1 kW of power and a monthly performance of 100 kW, is valued at around 5000 €, we assume that the Eurace solar panel is equivalent to 2000 real solar panel and, accordingly, is characterized by a power 2 MW and a monthly performance q_{sp} = 200 MWh, i.e. 0.2 GWh. Moreover, it is worth noting that, as we identify solar panels with regular capital goods, the equivalence between the price of an Eurace solar panel unit (p_{sp}) and the price of capital goods p_K, will hold for the entire duration of the simulation.
Furthermore, we have set electricity demand and market prices similar to the one observed in a reference country, say Italy. According to Terna[5], the monthly electricity consumption of the Italian industrial sector is around 10,000 GWh; therefore, considering that, with the parameters used for the production sector, see (Teglio et al., 2015), the monthly aggregate production capacity of 50 CGPs in Eurace is around 10,000 units of consumption goods (u.c.g.), then according to Eq. (2), the electricity efficiency η_E of each CGP has been set to 1.0 u.c.g. / GWh.
According to GME[6], the order of magnitude of the electricity market price is tens of /MWh, i.e. centimes of E/GWh; therefore, according to Eqs. (6) -(10), we have set the electricity production function parameters, γ_E and β_E, as well as the price of oil, here assumed constant and equal to 0.0035 E, to values consistent with the monthly electricity production of 10,000 GWh at a unit cost around 0.01 E/GWh.

Finally, it is worth noting that with the calibration here described, the oil bill of the economy is set to be of the order of 1% of GDP, see Figure 8c, then consistent with the ratio observed in the reference country considered[7].

[5]`http://www.terna.it/default/Home/SISTEMA_ELETTRICO/statistiche/consumi_settore_merceologico.aspx`
[6]`https://www.mercatoelettrico.org/it/`
[7]"Foreign trade and import prices", April 2016, ISTAT

Table 1: Relevant parameters values used in the simulation

symbol	Parameter	value
η_E	electricity efficiency	1.0 u.c.g./GWh
p^r_E	feed-in-tariff	[0.09-0.5] E€
$q_{E,sp}$	quantity of electricity produced by a single solar panel	0.2 GWh
k_E	electricity efficiency coefficient	1.0
β_E	electricity production exponent	0.9
p_O	oil price	0.0035 E€
μ_E	markup	10%
τ_E	reallocation charge	0.0

3. Computational results

The methodology of the study is based on Monte Carlo computational experiments, consisting in running simulations with different seeds of the pseudorandom number generator for each scenario. Six feed-in tariff electricity price scenarios, and 50 seeds per scenario, for a total of 300 simulations have been considered. Simulations have been performed *ceteris paribus*, meaning that all the parameters are identical across the different policy scenarios, with the exception of the feed-in tariff, i.e. p^r_E, whose value characterizes the policy rule of a specific scenario. In particular, the feed-in tariff price is taken as an exogenous parameter that assumes six values, i.e. 0.09, 0.1, 0.2, 0.3, 0.4 and 0.5. The value 0.09 has been verified to be close to the threshold under which, given the NPV investment rule and the order of magnitude of the parameters and the variables of the system, there are only negligible investments in new solar panels.
Table 1 summarizes the parameter values related to the newly introduced energy sector. The parameters values of the original Eurace model can be retrieved in Teglio et al. (2015), whereas in Ozel et al. (2016) one can find the housing market parameters. Simulations cover a fictitious time span of twenty years.

The Figures from 1 to 6 present a series of boxplots showing, for every value of the feed-in tariff considered, the distribution of several relevant economic variables over the 50 seeds used to initialize the pseudo-random number generator. In particular, the values reported in the boxplots are the time averages, over the entire 20 years long time span, related to any of the 50 seeds (simulations).

Figure 1 shows that the feed-in tariff policy adopted is very effective to spur investments in renewable energy production capacity. This result is clearly evident when one observes how the distribution of the number of installed solar panels and, correspondingly, of renewable energy production capacity (as a percentage of total production), change with respect to the feed-in price value. In particular, we can observe how both the median value (red line) and the mean (blue diamond) of the distribution clearly increase with the feed-in

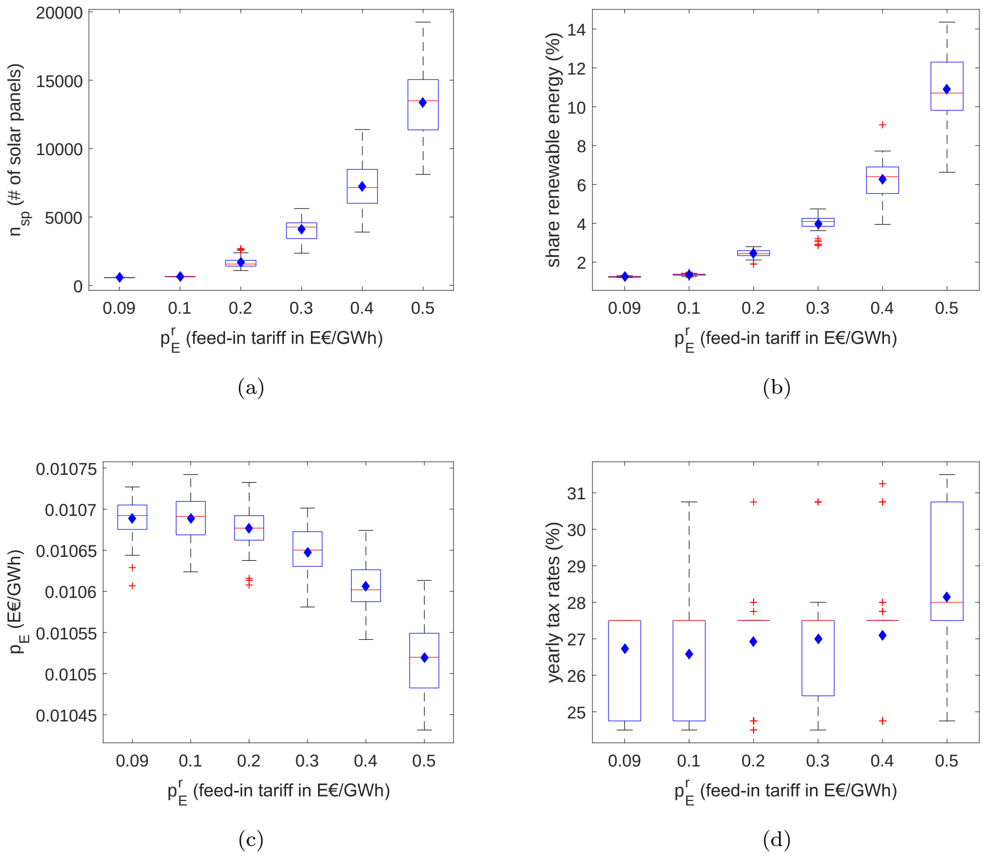


Figure 1: The Figures present a series of boxplots showing, for any value of the feed-in tariff, p_E^r, considered, the distribution of the number of solar panels installed, n_{sp} (a), the share of renewable energy (b), the monthly electricity market price, p_E (c) and the general tax rate (d) over the 50 seeds of the simulation. The values in the range represented by the boxplots refer to time averages over the entire 20 years long simulation related to any of the 50 seeds.

tariff, whereas the relative position of the box edges, which delimitate the 25th and 75th percentiles, indicates a clear difference between the outcomes related to two consecutive feed-in tariff values considered. Panel (c) of Figure 1 shows how the policy affects the distribution of electricity market prices, whose values decrease for high values of the feed-in tariff p_E^r. This happens because higher feed-in tariffs lead to more renewable capacity and consequently less electricity produced by means of fossil fuels, which in turn implies lower unit costs/market price for electricity due to the decreasing returns to scale of power production based on fossil fuels. Finally, panel d of Figure 1 reports the distribution of average tax rates. It is worth remembering that the government budget finances the difference between the revenues of the RP agent, which are based on the feed-in tariff p_E^r, and the amount paid by electricity consumers, which is evaluated at the market price p_E, where $p_E < p_E^r$. Therefore, it is important to investigate how fiscal policy (tax rates), which is stick to the usual 3 % deficit targeting rule, is affected by the additional feed-in tariff financing costs. Panel d shows that there is some impact on average tax rates at the highest considered values of p_E^r, but that the impact is limited, in particular if we consider the median value which increases only for the maximum value assumed by p_E^r.

Figures from 2 to 5 aim to assess the impact of the feed-in tariff policy on the real economy and in particular on the labor, consumption goods and capital goods markets. For this purpose, we employ again the boxplot representation to show how the distribution over 50 seeds of the time averages of relevant economic variables changes with respect to the feed-in tariff. In particular, we consider the employment rates, real consumption and investment levels, and prices. Figure 2 shows that high feed-in tariffs have a clear impact on the employment rate in the capital goods production sector (panel b). In particular, we observe that a larger demand for solar panels, due to higher p_E^r, determines higher employment rates at the solar panel supplier, i.e., the capital goods producer (KGP). This is not a surprising outcome, indeed, but it is worth to point out that the supply of more solar panels creates a sort of crowding out effect on the labour market as it can be observed that, while the employment rate at the KGP agent increases, the employments rate at the CGPs decreases (panel a).

On the other hand, this sort of crowding out effect of solar panel production has a very moderate negative impact on the capital accumulation of firms, whose capital endowment seems meaningful lower only for the highest value of p_E^r, see Figure 5(a) and (b). However, the lower employment rates in the consumption good sector, combined with an equal or lower capital base, clearly diminish the supply of consumption goods in the economy. Finally, the total effect in the labour market, is a slight reduction of the total unemployment rate (panel c) and then an increase of the nominal wage level (panel d) because of the higher pressure[8] on the labor market. Higher wages imply higher general unit production costs and then higher prices both for

[8] If firms have difficulties in increasing the labor force, then they raise their wage offer. A detailed description of the labor market in Eurace is provided in Dawid et al. (2014)

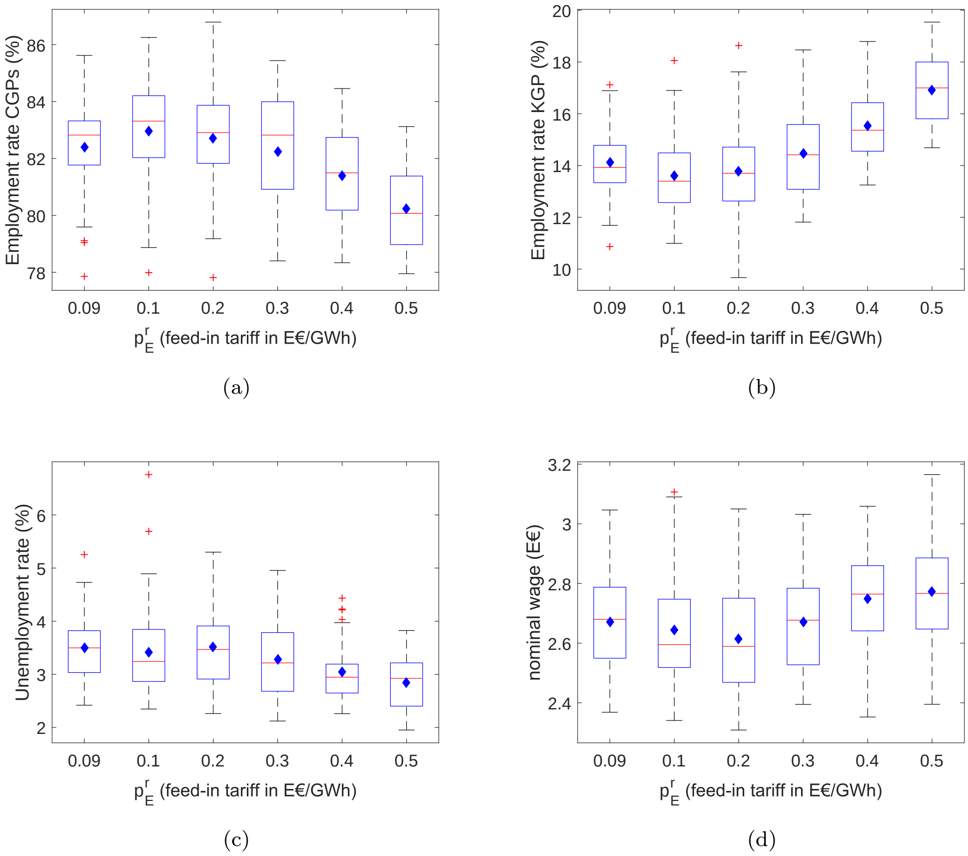


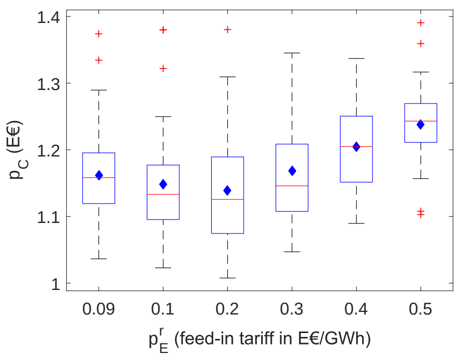
Figure 2: The Figures present a series of boxplots showing, for any value of the feed-in tariff p_E^r considered, the distribution of the employment rate in the consumption goods sector (a), the employment rate in the investment good sector (b), the unemployment rate (c) and the nominal wage level (d) over the 50 seeds of the simulation. The values in the range represented by the boxplots refer to time averages over the entire 20 years long simulation related to any of the 50 seeds.

consumption and capital goods, as observed accordingly in Figure 3. However, unit costs of CGPs depend also on capital goods prices as well as on interest rates, which increase at high p_E^r, see Figure 6, then consumption goods prices increase more than nominal wages, as we can figure out by comparing Figure 2(d) with Figure 3(a), with the result that real wages decrease when the feed-in tariff increases. Therefore, higher consumption goods prices, lower real wages as well as lower supply capacity by the CGPs explain lower consumption levels in the economy. Figure 4 shows the substitution effect between investment and consumption both in terms of average yearly levels (panel a and b) and in terms of average yearly growth rates (panel c and d).

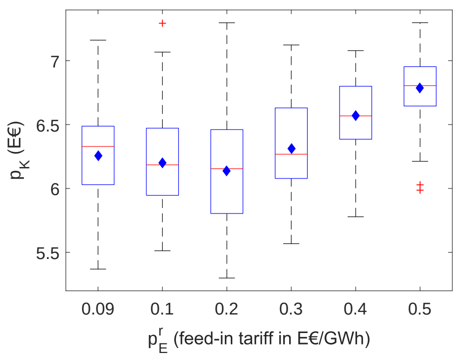
Figure 6 shows how high feed-in tariffs impact interest rates and government finances. The central bank average interest rate increases at higher p_E^r due to the Taylor-rule response to higher consumption goods prices, shown in Figure 3 panel (a) and (c), whereas government finances are affected by the increasing financing costs, see Figure 7, panel (a) and (b), of the feed-in tariff policy. Figure 6 shows that the higher the financing costs, the larger are deficit (panel c) and debt (panel d) to GDP ratios, yet the negative impact is limited and not particularly relevant. On the contrary, the value of the feed-in tariff seems to have a more important impact on the government bond yields. We argue that the impact on bond yields depends both on the larger amount of government debt to be financed and on the higher central bank interest rate for high p_E^r; the first factor implies a higher supply of government bonds in the market, whereas the second one implies that the government bond yields need to increase to make debt instruments preferable as much as liquidity.

Figure 7 reports the boxplots related to the feed-in tariff policy costs with respect to both the nominal GDP (panel a) and the tax revenues (panel b) as well as the oil import costs (panel c) and the overall costs of electricity consumption (panel d), both with respect to nominal GDP. The feed-in tariff policy cost, relative to GDP, clearly increases exponentially with p_E^r in line with the benefits we observe in panel (a) and (b) of Figure 1; while the cost to GDP of oil import and electricity decrease at high feed-in tariffs consistently with the evidence observed in Figure 1 concerning the decrease of the share of non-renewable electricity production (panel b) and of electricity market price (panel c). It is worth noting that, with the present calibration, the order of magnitude of oil import costs (panel c) is much lower than the financing costs of the feed-in tariff policy, being both costs reported with respect to nominal GDP; therefore, the economic benefits (lower imports) of the sustainability transition are lower than its financing costs.

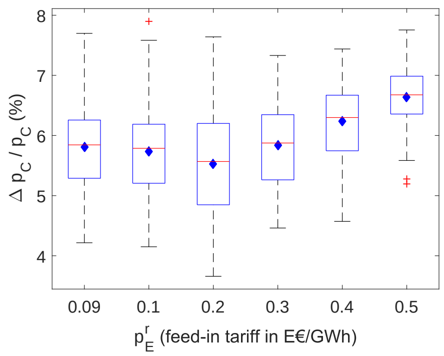
Figures from 8 to 10 present three trajectories over time of relevant variables. This different representation is aimed to provide an understanding of dynamics over time of the Eurace economy. All the three trajectories have been simulated by using the same seed and refer to three different scenarios according to the value of p_E^r, i.e. 0.09 (black-dashed line), 0.3 (blue-dotted line), and 0.5 (green-continuous line). We can observe that the dynamics of the share of renewable energy production capacity, reported in panel (b) of Figure



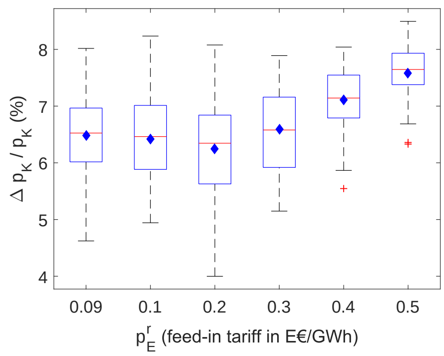
(a)



(b)



(c)



(d)

Figure 3: The Figures present a series of boxplots showing, for any value of the feed-in tariff p^r_E considered, the distribution of the consumption goods price level, p_C (a), the capital good price level, p_K (b), the yearly growth rate of the consumption goods price (c) and the yearly growth rate of the capital good price (d) over the 50 seeds of the simulation. The values in the range represented by the boxplots refer to time averages over the entire 20 years long simulation related to any of the 50 seeds.

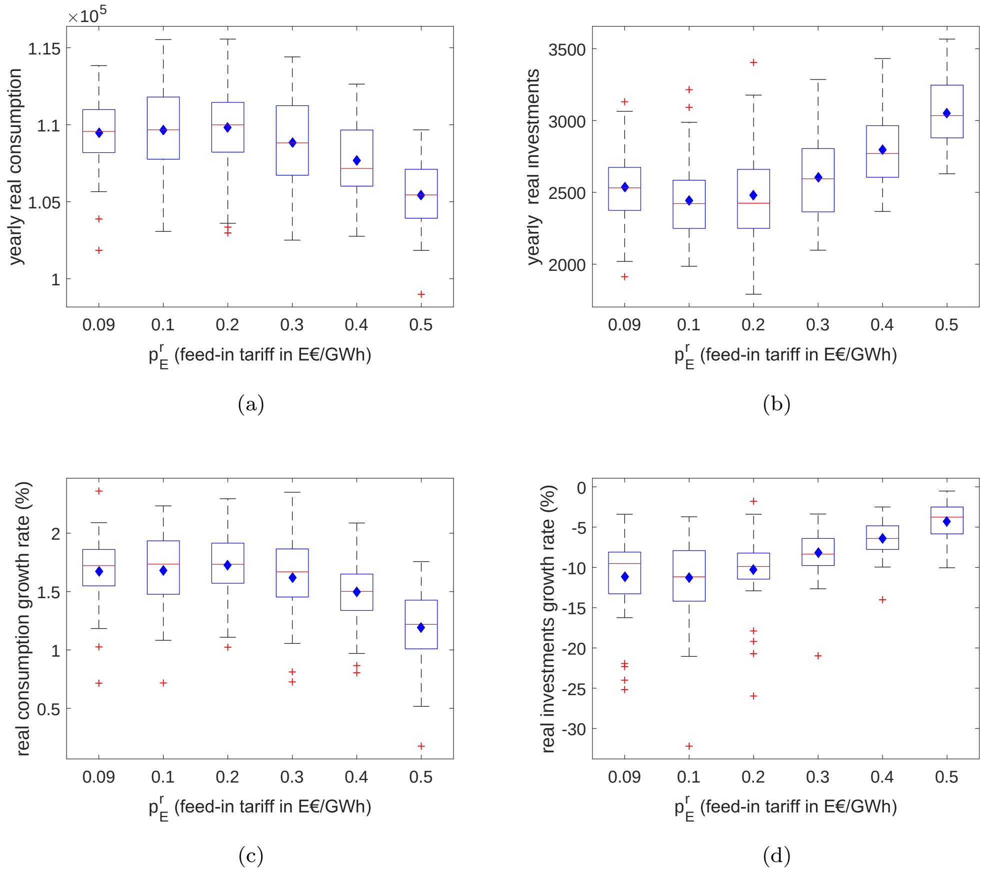
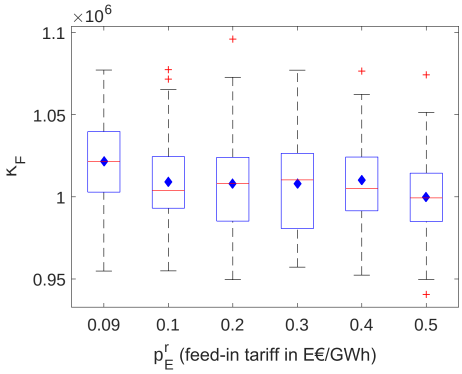
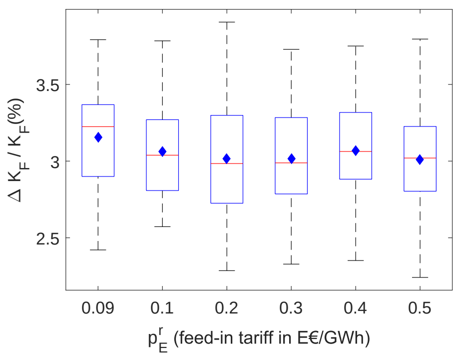


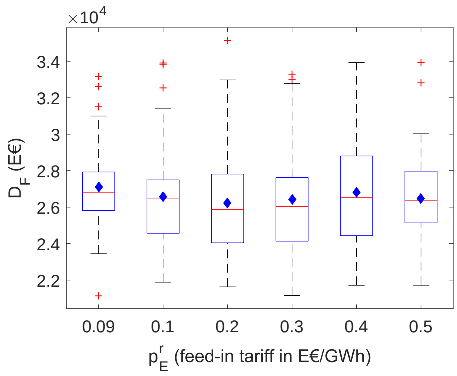
Figure 4: The Figures present a series of boxplots showing, for any value of the feed-in tariff p_E^r considered, the distribution of the real consumption level (a), the real investment level (b), the real consumption yearly growth rate (c) and the real investment yearly growth rate (d) over the 50 seeds of the simulation. The values in the range represented by the boxplots refer to time averages over the entire 20 years long simulation related to any of the 50 seeds.



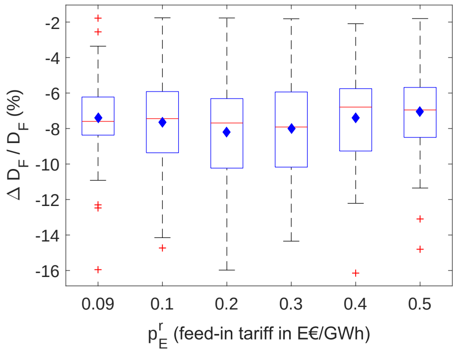
(a)



(b)



(c)



(d)

Figure 5: The Figures present a series of boxplots showing, for any value of the feed-in tariff p_E^r considered, the distribution of the firms' aggregate capital stock, K_F (a), the firms' aggregate capital stock yearly growth rate (b), the firms' aggregate debt, D_F (c) and the yearly growth rate of the firms' aggregate debt (d) over the 50 seeds of the simulation. The values in the range represented by the boxplots refer to time averages over the entire 20 years long simulation related to any of the 50 seeds.

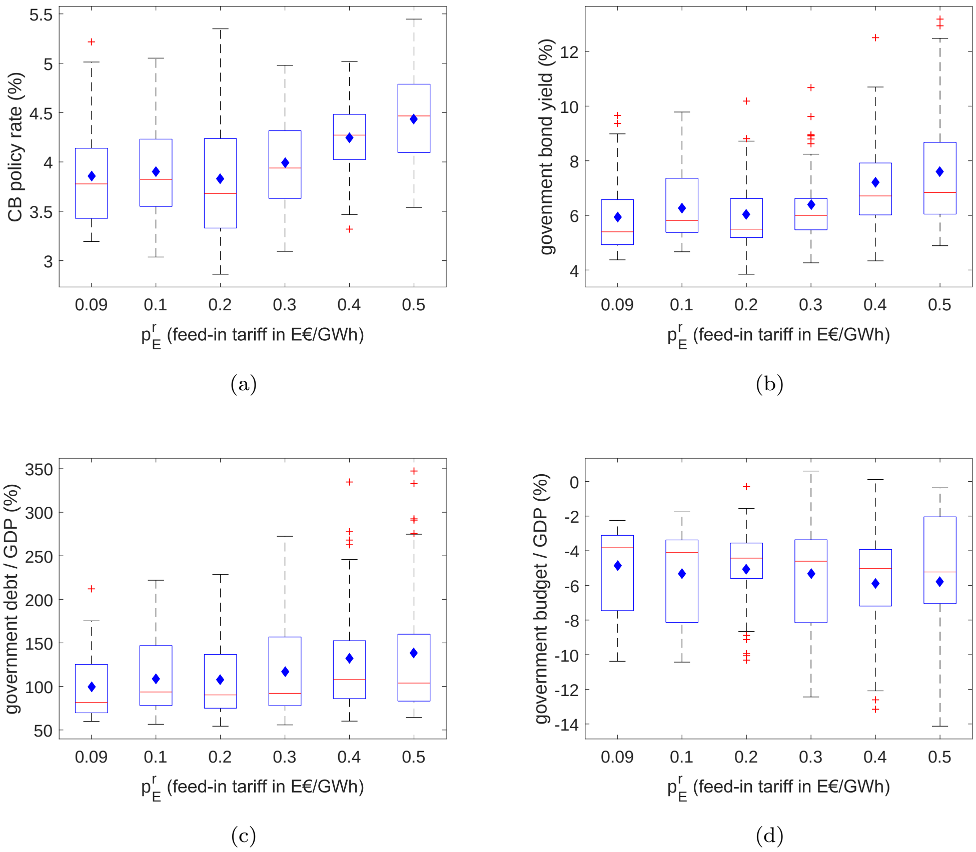
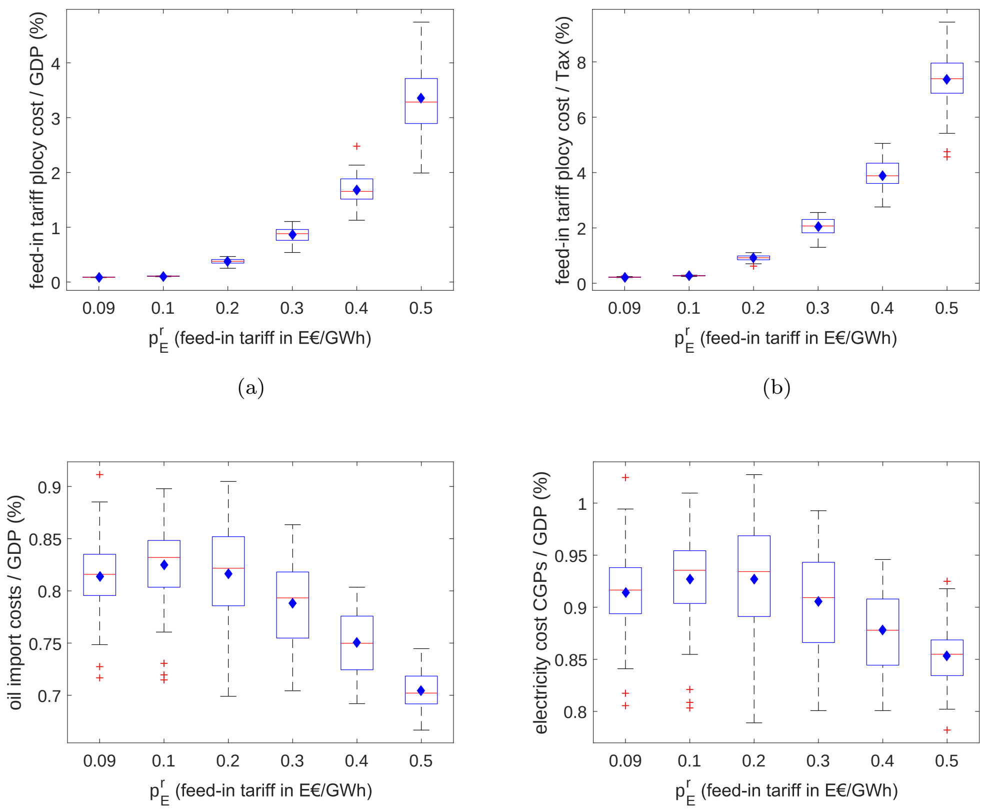


Figure 6: The Figures present a series of boxplots showing, for any value of the feed-in tariff p^r_E considered, the distribution of the CB policy rate (a), the government bond yield (b), both on a yearly basis, the government debt to GDP (c) and the government budget to GDP (d) over the 50 seeds of the simulation. The values in the range represented by the boxplots refer to time averages over the entire 20 years long simulation related to any of the 50 seeds.



(a) (b) (c) (d)

Figure 7: The Figures present a series of boxplots showing, for any value of the feed-in tariff p_E^r considered, the distribution of the cost of the feed-in-tariff mechanism to GDP (a), to tax revenues (b), oil import costs to GDP (c) and electricity cost of firm to GDP (d) over the 50 seeds of the simulation. The values in the range represented by the boxplots refer to time averages over the entire 20 years long simulation related to any of the 50 seeds.

8, is characterized by both big jumps and a relatively steady growth. In particular, accordingly with the investment decision rule based on the NPV, see Equation 4, jumps occur whenever interest rates, reported in panel (d) of Figure 10, are very low or close to zero, see e.g. years 9 and 13 in the blue dotted-line scenario and years 9, 15, 19 in the green continuous-line one. Concerning economic variables, we observe an increasing difference between the three scenarios, in particular in the second half of the simulation time span, i.e. when the difference in the renewable production capacity becomes relevant. The black dashed-line scenario is affected by a severe endogenous crisis around year 11, see the unemployment rate (Figure 9a) and consumption (Figures 10d,10b), that causes a huge reduction of investments. The crisis in the black dashed-line scenario is so severe that causes a drop even in the productive capital stock of firms, because of a very low investment rate combined with the bankruptcy of many firms that stay out of production for months. This crisis has also the effect of cooling down the dynamics of all relevant prices, i.e. nominal wage (Figure 9b), consumption and capital goods prices (Figures 10a and 10c). On the contrary, in the green continuous-line scenario investments are generally maintained at higher rates, certainly also because of solar panel production, that helps to keep the economy in good shape avoiding a prolonged unemployment crisis from year 11 to 16, as in the black dashed-line scenario. Lower unemployment on average in the green continuous-line scenario is the cause of steeper nominal wage dynamics in the second half of the simulation time span (Figure 9b) and, being wages the most relevant costs for both capital and consumption goods producers, this in turn is the cause of a higher increase of capital and consumption goods prices in the green scenario (Figure 10a and 10c)). Finally, Figure 10 shows the long-run trade-off between the production of investment goods (panel b), partly characterized by solar panels, and the one of consumption goods (panel d), already observed in the previous box plots, see Figure 4. Moreover, Figure 9c, shows that investments in renewable production capacity occurs to some extent also at the expense of capital accumulation in the economy among consumption goods producers, as the capital endowment of firms in the green continuous-line scenario is constantly lower than in the black dashed-line case and very similar to the blue dotted-line scenario.

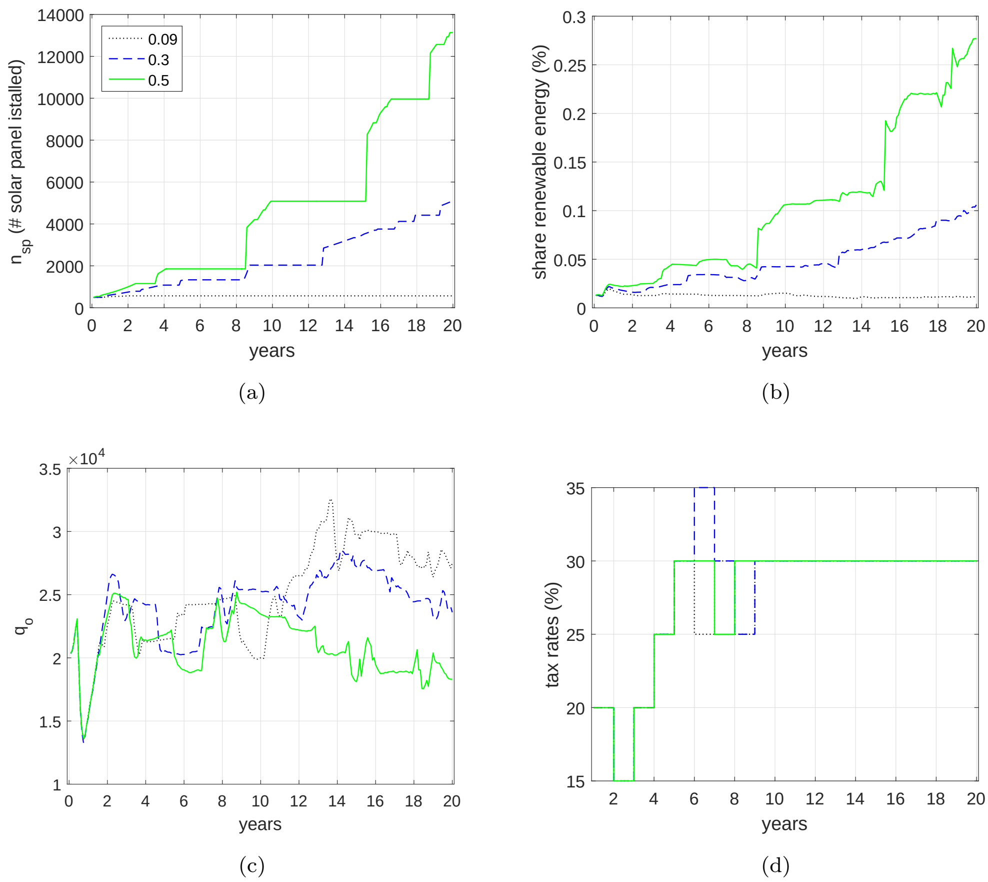
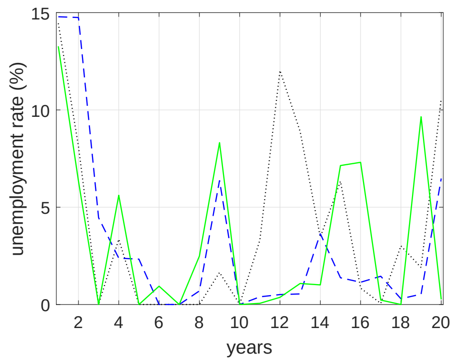
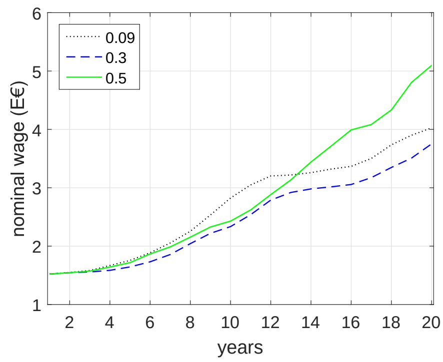


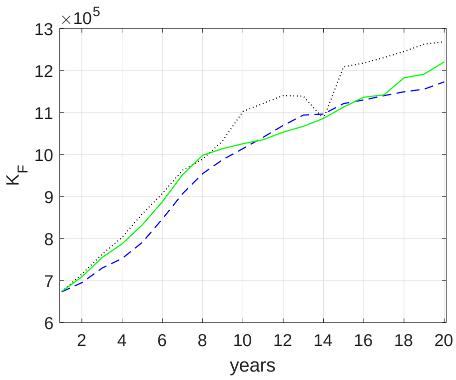
Figure 8: The figures show the number of solar panels installed (a), the share of the renewable energy (b), the oil amount consumed monthly by the PP (c) and the tax rate (d) during the entire 20 years long simulation. The 3 different colours correspond to the 3 values of the guaranteed electricity price p_E^r. In particular the black, blue, green lines represent $p_E^r = 0.09, 0.3, 0.5$, respectively.



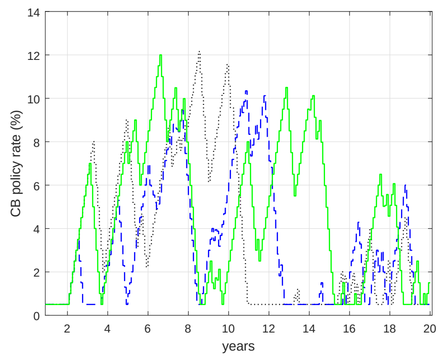
(a)



(b)



(c)



(d)

Figure 9: The figures show the unemployment rate (%) (a), the average nominal wage level (b), the firms' aggregate capital stock (c) and the CB policy rate (%) (d) during the entire 20 years long simulation. The 3 different colours correspond to the 3 values of the guaranteed electricity price p_E^r. In particular the black, blue, green lines represent $p_E^r = 0.09, 0.3, 0.5$, respectively.

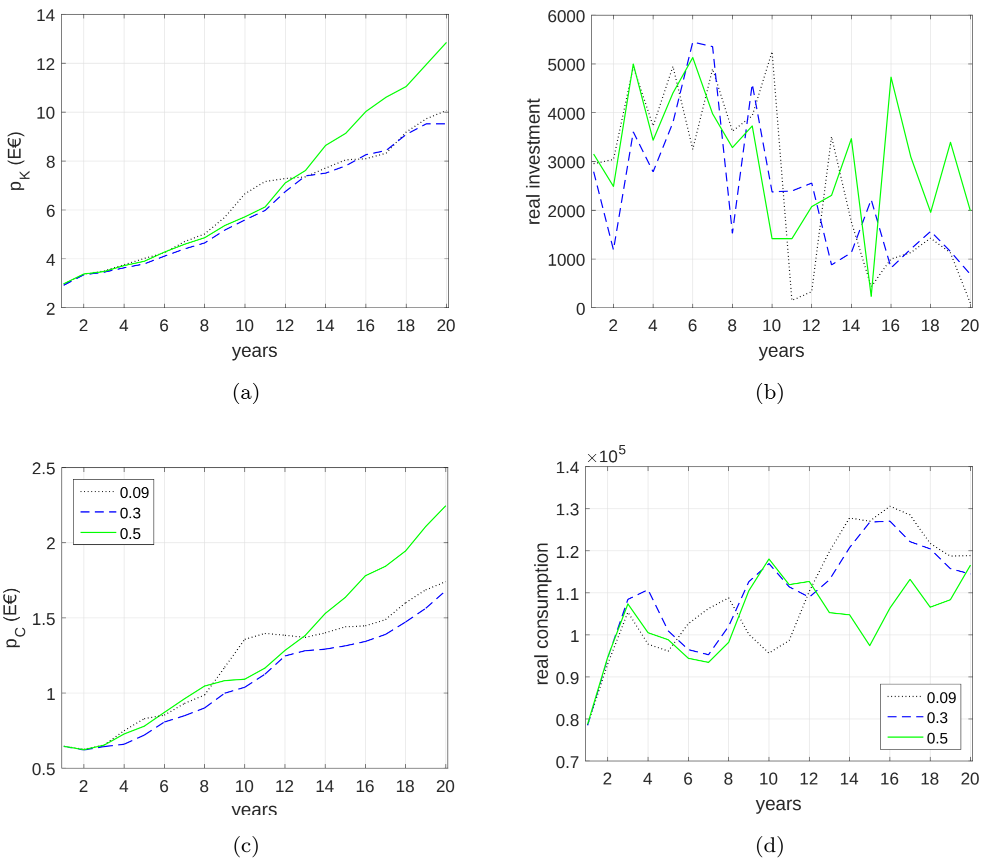


Figure 10: The figures show the capital good price (a), the real investment (b), the consumption goods price (c) and the real consumption (d) during the entire 20 years long simulation. The 3 different colours correspond to the 3 values of the guaranteed electricity price p_E^r. In particular the black, blue, green lines represent $p_E^r = 0.09, 0.3, 0.5$, respectively.

4. Concluding remarks

This study presented a set of computational experiments based on the Eurace agent-based macroeconomic model and simulator. The Eurace model has been enriched with new features to allow the investigation of the transition towards a sustainable energy production paradigm. The work focuses on a policy proposal aimed to foster the transformation of the present economic system, where energy production is mainly based on fossil-fuels, to an alternative one based on renewable energy. In particular, we study the effectiveness and the impact on the economy of a feed-in tariff policy aiming at incentivizing the production of energy by means of a renewable source, e.g. solar energy. In this perspective, a new energy sector has been designed into the Eurace model, by including an electricity market, power producers (renewable and fossil-fuel based) and a more complete version of the capital goods producer, which employs labour force to produce both investment goods for firms and solar panels for the renewable power producer.

Computational results clearly show a significant impact of the feed-in-tariff mechanism, which successfully incentivizes the production of solar panels and increases the share of renewable energy consumed in the Eurace economy. Furthermore, the costs of financing the transition to renewable energy does not seriously affect neither the economic performance, if measured by unemployment rates, which actually slightly reduce, nor government finances, which are only moderately affected. This is an important and positive result that was not obvious a priori, also considering that the fiscal costs of the policy result to be much higher than the economic benefits of lower fossil fuel import costs for the economy, according to a realistic calibration based on the present fossil fuels import bill of an advanced economy.
On the other hand, we observe that, the stronger the feed-in tariff policy is, the higher is the weight of the investment sector in the economy, due to the needed production of renewable energy technology, at the expenses of the production of consumption goods. This important outcome implies a reduced purchasing power of consumption goods by households, and then lower living standards, if measured only according to the perspective of a consumerist society. However, if factors like better employment rates and the reduced GHG emissions are also taken into account, along with consumption, by an appropriate preference function, the final outcome on well-being should be probably deemed as favourable.

Future research will investigate and compare different policy options for the financing of the feed-in tariff mechanism, with particular attention to the issuing of green bonds and the adoption of targeted unconventional monetary policies, such as the green quantitative easing.

Acknowledgment

The authors acknowledge EU-FP7 collaborative project SYMPHONY[9] under grant no. 611875. Moreover, the authors thank Franziska Schuetze from Global Climate Forum for useful discussions.

[9]www.projectsymphony.eu

Appendix

This appendix provides a compact model description that emphasizes the adopted stock-flow-consistent modelling approach along the lines introduced by Godley and Lavoie (2012) and common also within post-Keynesian economics, see also Caverzasi and Godin (2015). The following tables outline the stocks (balance sheet entries) and flows (income statement entries) characterizing Eurace agents. A detailed description of agents behavioural rules in the production and consumption sectors is reported in Teglio et al. (2015), whereas Ozel et al. (2016) describes the structural and behavioural features of the housing market. Finally, it is worth noting that the stock-flow-consistent modelling approach provides a set of relevant theoretical identities at the agent, sector, and aggregate level, whose subsistence need to be numerically verified during the simulation, thus providing a very important diagnostic and validation tool for the model and its implementation.

In the following, four tables (matrices) are presented showing:

- the agent class balance sheet (Table 2), i.e., the asset and liability entries of each particular agent type;
- the sectorial balance sheet (Table 3), i.e., the assets and liabilities aggregated over a sector (all agents belonging to the same class), which sum to zero with their counterparts in other sectors;
- the cash flow matrix (Table 4), i.e. the monetary flows among sectors, both in the current and capital account;
- the revaluation matrix (Table 5), which provides the information about sectors' net worth (equity) changes between periods.

It is worth noting that in the sectorial balance sheet (Table 3), columns report the aggregated balance sheet of each sector, whereas along the rows we can identify the relations among sectors by spotting the liabilities (with minus sign) in one sector and the corresponding claims, i.e. assets (with plus sign), in another sector, thus generally summing up to zero. Exceptions are: the capital goods accumulated by firms and by the renewable power producer; inventories; housing units and equity shares[10] owned by households.
Furthermore, in the last column of the sectorial balance sheet (Table 3). the difference between central bank liquidity (an asset) and central bank fiat money (a liability) is named $M_{CB,0}$, to emphasize that this difference is equal to the initial central bank liquidity and then is constant over the simulation. Fiat money is the money created by the central bank to provide loans to commercial banks, when they are in liquidity shortage, or to buy government bonds in the secondary market, through quantitative easing operations. Households, that sell government bonds to the central bank, deposit the sale proceeds at their own banks,

[10]We assume that equity shares in households portfolio do not sum up to zero with the corresponding equity counterpart in the issuer balance sheet because of the usual difference between market price and book value.

while the money lend to banks by the central bank is lent to households or firms, then in turn deposited again in the banking sector. Therefore, in both cases, the liquidity of the banking sector is increased by an amount equal to the new Fiat money created. Banks deposit their liquidity at the central bank, then increasing its liquidity by an amount always equal to the Fiat money originally created. It is worth noting however that the money supply in the economy can variate independently from the fiat money created by the central bank, because it endogenously raises every time a bank grants a new loan or mortgage and it decreases when the loan or mortgage is paid back.

Furthermore, the monetary flows among sectors are presented in the cash flow matrix (Table 4), where the current account reports aggregate revenues (plus sign) and payments (minus sign) among sectors, therefore summing to zero along the rows. The capital account reports the endogenous money creation / destruction operations by means of borrowing/debt repayment by private agents with banks as well as fiat money creation / destruction by the central bank by means of the standing facility with banks or government bonds purchase (quantitative easing). These operations, along with the current account net cash flows, determines the liquidity change of a sector.

Finally, the revaluation matrix (Table 5) provides the information about changes in sectors' net worth (equity) between periods. In particular, agents' net worth dynamics depends on net cash flows in the current account, physical capital depreciation and price changes in financial (stocks and bonds) and real (housing units, capital goods and inventories of consumption goods) assets.

Table 2: Agent class balance sheets

Agent class	**Assets**	**Liabilities**
Household *abbrev.*: HH *index*: $h = 1, \dots, N_{Hous}$	Liquidity: M_h Stock portfolio: $\Sigma_b n_{E_{h,b}} p_{E_b} +$ $\Sigma_f n_{E_{h,f}} p_{E_f} +$ $n_{E_{h,K}} p_{E_K} +$ $n_{E_{h,PP}} p_{E_{PP}} +$ $n_{E_{h,RP}} p_{E_{RP}}$ Gov Bonds: $n_{h,G}\ p_G$ Housing units: X_h	Mortgages: U_h Equity: E_h
Consumption Goods Producer *abbrev.*: CGP *index*: $f = 1, \dots, N_{Firm}$	Liquidity: M_f Capital goods: K_f Inventories: I_f	Debt: $D_f = \sum_b \ell_{f,b}$ Equity: E_f
Capital Goods Producer *abbrev.*: KGP	Liquidity: M_K Inventories: I_K	Equity: E_K
Power Producer *abbrev.*: PP	Liquidity: M_{PP}	Equity: E_{PP}
Power Producer Renewable *abbrev.*: RP	Liquidity, M_{RP} Solar panels, n_{sp}	Equity, E_{RP}
Bank *abbrev.*: B *index*: $b = 1, \dots, N_{Bank}$	Liquidity: M_b Loans: $\mathcal{L}_b = \sum_f \ell_{b,f}$ Mortgages: $U_b = \sum_h U_{b,h}$	Deposits : $\mathcal{D}_b = \sum_h M_{b,h} + \sum_f M_{b,f} + M_{b,K}$ CB standing facility: $D_b = \ell_{b,CB}$ Equity: E_b
Government *abbrev.*: G	Liquidity: M_G	Outstanding government bonds value : $D_G = n_G\ p_G$ Equity: E_G
Central Bank *abbrev.*: CB	Liquidity: M_{CB} Loans to banks: $\mathcal{L}_{CB} = \sum_b \ell_{CB,b}$ Gov Bonds: $n_{CB,G}\ p_G$	Outstanding fiat money: Fiat_{CB} Deposits: $\mathcal{D}_{CB} = \sum_b M_b + M_G$ Equity: E_{CB}
Foreign Economy *abbrev.*: FE	Liquidity, M_{FE}	Equity, E_{FE}

Table 2. Balance sheets of any agent class characterizing the Eurace economy. Balance sheet entries in the table have a subscript character, that is the index of an agent in the class to which the variable refers. In some cases, we can find two subscript characters, where the second one refers to the index of an agent in another class where there is the balance-sheet counterpart. For instance, D_f refers to the total debt of firm f, i.e. a liability, and $\mathcal{L}_b$ refers to the aggregate loans of bank b, i.e. an asset. $\ell_{f,b}$ (or $\ell_{b,f}$) refer to the loans granted by banks b to firms f. Of course, $\sum_b \mathcal{L}_b = \sum_f \ell_{b,f}$ represents an aggregate balance sheet identity, that is verified along the entire simulation. $n_{E_{h,x}}$ represent the number of outstanding equity shares of agents x held by households h. The market price of the equity shares is given by p_{E_x}. The stock portfolio's value of household h is then computed as: $\sum_x n_{E_{h,x}} p_{E_x}$. Government bonds' number and market price are given by n_G and p_G, respectively.

	Sectors								
	Non-Financial Private Agents (NFPAs)					Banks	Policy Makers		Σ
	HHs	**CGPs**	**KGP**	**PP**	**RP**	**Bs**	**G**	**CB**	
Tangible Capital	$+X_H\ p_X$	$+K_F\ p_K$			$+n_{sp}\ p_{sp}$				$+X_h\ p_X\ +K_F\ p_K\ +n_{sp}\ p_{sp}$
Inventories		$+I_F\ p_C$	$+I_K\ p_K$						$+I_F\ p_C\ +I_K\ p_K$
Debt(-) / Credit(+)	$-U_H$	$-D_F$				$+D_F$ $+U_H$ $-\ell_{CB}$		$+\ell_{CB}$	0
Liquidity:									
NFPA	$+M_H$	$+M_F$	$+M_K$	$+M_{PP}$	$+M_{RP}$	-D_B			0
Banks/Gov						$+M_B$	$+M_G$	- D_{CB}	0
Central Bank								$+\mathrm{M}_{CB}$ $-\mathrm{Fiat}_{CB}$	$+\mathrm{M}_{CB,0}$
Gov Bonds	$+n_G^H\ p_G$						$-n_G\ p_G$	$+n_G^{CB}\ p_G$	0
Equity Shares (+) / Net worth (-)	$+\Sigma_f n_{E_f} p_{E_f}$ $+n_{E_k} p_{E_k}$ $+n_{E_{PP}} p_{E_{PP}}$ $+n_{E_{RP}} p_{E_{RP}}$ $+\Sigma_b n_{E_b} p_{E_b}$ $-E_H$	$-E_F$	$-E_K$	$-E_{PP}$	$-E_{RP}$	$-E_B$	$-E_G$	$-E_{CB}$	$+\Sigma_f n_{E_f} p_{E_f} - E_F$ $+n_{E_k} p_{E_k} - E_K$ $n_{E_{PP}} p_{E_{PP}} - E_{PP}$ $n_{E_{RP}} p_{E_{RP}} - E_{RP}$ $+\Sigma_b n_{E_b} p_{E_b} - E_B$ $-E_H - E_G - E_{CB}$
Σ	0	0	0	0	0	0	0	0	0

Table 3: Sectorial balance sheet matrix. Subscripts represent the index of the agent or of the sector (i.e. the set of all agents of the same class) to which the stock refers. Uppercase indexes are used when the stock refers to the whole sector, e.g. F refers to the sector of all CGPs and to the aggregate value of a particular stock in the sector, whereas lowercase subscripts are used when it refers to the single agent (for instance in the case of sums). Finally, superscript characters are introduced in the case of government bonds units n_G, i.e. n_G^H and n_G^{CB}, and $Loans_B$, i.e. $Loans_B^F$ and $Loans_B^{RP}$, because the balance sheet counterpart (in the asset side) is hold by two sectors, i.e. households and central bank in the case of government bonds units and consumption good producers and renewable power producer in the case of loans.

		HHs	CGPs	KGP	PP	RP	Bs	G	CB	FE	Σ
Current Account	Consumption goods	−	+								0
	Investment goods		−	+		−					0
	Electricity		−		+	+					0
	Oil				−					+	0
	Wages	+	−	−				−			0
	Transfers	+						−			0
	Taxes	−	−	−	−		−	+			0
	Dividends	+	−	−	−		−				0
	Coupons	+						−	+		0
	CB coupons payback							+	−		0
	Banks loan interests		−				+				0
	Banks mortgage interests	−					+				0
	CB loans interests						−		+		0
	CB interests payback							+	−		0
		=	=	=	=	=	=	=	=	=	
	Net cash flow	Savings	Profits	Profits	Profits	Profits	Profits	Surplus	Seignoirage	Surplus	0
Capital Account	Net cash flow	+Savings	+Profits	+Profits	+Profits	+Profits	+Profits	+Surplus	+Seignoirage	+Surplus	0
	Δ Loans		$+\Delta D_F$				$-\Delta D_F$ $+\mathcal{L}_{CB}$		$-\Delta\mathcal{L}_{CB}$		0
	Δ Mortgages	$+U_H$					- U_H				0
	Δ Issue of new shares / bonds	$-\Sigma_f p_{E_f} \Delta n_{E_f}$ $-p_G \Delta n_G$	$+\Sigma_f p_{E_f} \Delta n_{E_f}$					$+p_G \Delta n_G$			0
	Δ Quantitative easing	$+p_G \Delta n_G^{QE}$							$-p_G \Delta n_G^{QE}$		0
	Δ Private Liquidity & Δ Banks' deposits	$-\Delta\ M_H$	$-\Delta\ M_F$	$-\Delta\ M_K$	$-\Delta\ M_{PP}$	$-\Delta\ M_{RP}$	$+\Delta\ D_B$				0
	Δ Banks / Public Liquidity & Δ Central bank deposits						$-\Delta\ M_B$	$-\Delta\ M_G$	$+\Delta\ D_{CB}$		0
	Δ CB Liquidity / Δ Fiat Money								$-\Delta\ M_{CB}$ $+\Delta\ \mathrm{Fiat}_{CB}$		0
	Σ	0	0	0	0	0	0	0	0	0	

Table 4: **Sectorial transaction flow matrix of agents populating the EURACE economy**. Note that HH stands fo Households, CGP stands for Consumption Goods Producer, KGP stands for Capital Goods Producer, PP stands for Power Producer, Gov stands for Government and CB stands for Central Bank.

		HHs	CGPs	KGP	PP	RP	Bs	G	CB	FE	Σ
Equity$_{t-1}$		$E_{H,t-1}$	$E_{F,t-1}$	$E_{K,t-1}$	$E_{PP,t-1}$	$E_{RP,t-1}$	$E_{B,t-1}$	$E_{G,t-1}$	$E_{CB,t-1}$	$E_{FE,t-1}$	$E_{TOT,t-1}$
Net cash flow		+Savings	+Profits	+Profits	+Profits	+Profits	+Profits	+Surplus	+Seignoirage	+Profits	0
Revaluations/ Devaluations											
	Housing units	$+\Sigma_h X_h \Delta p_X$									$+\Sigma_h X_h \Delta p_X$
	Capital		$+\Sigma_f K_f \Delta p_K$ $-\Sigma_f \xi_K K_f p_K$			$+ n_{sp} \Delta p_K$					$+\Sigma_f K_f \Delta p_K$ $-\Sigma_f \xi_K K_f p_K$ $+n_{sp} \Delta p_K$
	Inventories		$+\Sigma_f I_f \Delta p_c$	$+I_K \Delta p_K$							$+\Sigma_f I_f \Delta p_c$ $+I_K \Delta p_K$
	Equity shares	$+\Sigma_f n_{E_f} \Delta p_{E_f}$ $+\Sigma_b n_{E_b} \Delta p_{E_b}$ $+n_{E_K} \Delta p_{E_K}$ $+n_{E_{PP}} \Delta p_{E_{PP}}$ $+n_{E_{RP}} \Delta p_{E_{RP}}$									$+\Sigma_f n_{E_f} \Delta p_{E_f}$ $+\Sigma_b n_{E_b} \Delta p_{E_b}$ $+n_{E_K} \Delta p_{E_K}$ $+n_{E_{PP}} \Delta p_{E_{PP}}$ $+n_{E_{RP}} \Delta p_{E_{RP}}$
	Bonds	$+n_G^H \Delta p_G$							$+n_G^{CB} \Delta p_G$		$+n_G^H \Delta p_G$ $+n_G^{CB} \Delta p_G$
		=	=	=	=	=	=	=	=	=	=
Equity		$E_{H,t}$	$E_{F,t}$	$E_{K,t}$	$E_{PP,t}$	$E_{RP,t}$	$E_{B,t}$	$E_{G,t}$	$E_{CB,t}$	$E_{FE,t}$	$E_{TOT,t}$

Table 5: Sectorial revaluation matrix. The matrix provides information about changes in sectors net worth (equity) between periods. Net worth changes depend on net cash flows in the current account, physical capital depreciation (at rate ξ_K) and price changes in real and financial assets. It is worth noting that net worth of the issuers of financial assets (firms and the government) are not subject to asset price changes.

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