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Budgetary rigour with stimulus in lean times: Policy advices from an agent-based model

Andrea Teglio[a,c,*], Andrea Mazzocchetti[b], Linda Ponta[b], Marco Raberto[b], Silvano Cincotti[b]

[a] Universitat Jaume I, Campus del Riu Sec, 12071 Castellon, Spain
[b] DIME-CINEF, Università degli Studi di Genova, Via Opera Pia 15, 16145 Genova, Italy
[c] Department of Economics, University Ca' Foscari of Venice, Cannaregio 873, 30121 Venezia, Italy

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ABSTRACT

The 2008 financial crisis, and the subsequent global recession, triggered a wide-spread economic and political debate on the proper policy combination to deal with the crisis and to prevent similar ones in the future. Probably, the main dispute has been around the use of fiscal instruments in order to foster growth while keeping public debt under control. The European Union, for instance, endorsed "austerity" measures for fiscal consolidation but has been sharply criticized by several scholars. This paper aims at contributing to the current debate by presenting the outcomes of a computational study performed with the Eurace agent-based model. We set up an experiment with two base policy scenarios, i.e., stability and growth pact and fiscal compact, incrementally enriching them with complementary policies which relax fiscal rigidity and introduce quantitative easing. Results show that budgetary rigour performs well if and only if some mechanisms of fiscal relaxation and monetary accommodation are considered during bad times; thus confirming in a richer and more realistic model setting the fundamental tenet of Keynesian economics about the importance of sustaining aggregate demand during recessions.

1. Introduction

Following the 2008/2009 financial and economic crisis and the consequent bailout of important financial institutions, most OECD countries experienced large deficits and a significant increase of public debt. The 2010 recovery induced policy makers, in particular in the European Monetary Union where the room of manoeuvre of fiscal policy is conditioned by treaties, to shift the attention from the financial crisis and its causes to the need of fiscal consolidation measures aimed to put public finances on a more "sustainable" path.

In the political and theoretical debate, it became popular the assumption that fiscal consolidation could be very successful in reducing public deficit, in particular due to its claimed expansionary effects. The so-called expansionary austerity hypothesis was supported by both empirical analysis, see e.g. Alesina and Ardagna (2010) and references therein, and theoretical arguments. Under the theoretical perspective, fiscal austerity might have expansionary effects because, if we assume

* Corresponding author.
E-mail addresses: teglio@uji.es (A. Teglio), andrea.mazzocchetti@edu.unige.it (A. Mazzocchetti), linda.ponta@unige.it (L. Ponta), marco.raberto@unige.it (M. Raberto), silvano.cincotti@unige.it (S. Cincotti).

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forward-looking economic agents, today's sacrifices may create expectations of tax reductions, higher disposable income, and lower interest rates[1] in the future, then inducing agents to increase consumption and investment in the short term.

However, economies subject to austerity programs experienced a second severe contraction of economic activity soon after 2010; in addition, bond yields of peripheral Euro-zone countries, skyrocketed to unsustainable levels in 2011. Indeed, beside the literature supporting expansionary austerity, a huge body of both theoretical and empirical work advocating the contrary exists, dating back at least to Keynes' General Theory (1936) and Lerner's functional finance (Lerner and Harris, 1951). In particular, in recent years, in response to the 2008/09 crisis, a number of studies has appeared emphasizing the importance of expansionary fiscal policy during recessions. DeLong and Summers (2012) provide theoretical and empirical evidence about the efficacy of temporary expansionary fiscal policy in severely depressed economies, in both the short and the long term. The argumentation is that the underemployment of production factors as well as low interest rates make the fiscal multiplier substantially greater than in normal times, as also pointed out by Auerbach and Gorodnichenko (2012) and Ferraresi et al. (2014). Furthermore, mitigating present output drops, by means of expansionary fiscal policies, prevents the long-term hysteresis effects of the lower capital accumulation rate and workers' skills on the economy's future potential.

A new term, balance-sheet recession, has also been coined to define the 2008/09 crisis as well as the Japan two last decades of the 90s and 00s (Koo, 2009, 2011, 2014). A balance-sheet recession is the economic crisis that usually follows an asset bubble burst. In this scenario, where the market value of assets collapses while the nominal value of debt remains unchanged, the private sector (households, firms) becomes over-indebted and faces the risk of negative net worth; therefore deleveraging, more than profit maximization, becomes the priority of the private sector, which uses its cash flows to reduce indebtedness instead of financing investments. This deleveraging priority makes also the private sector unwilling to borrow, even at very low interest rates, with financial institutions that are also unwilling to lend, because they need to reduce the risk of their balance sheets. In such a scenario, where private consumption and investment demand decrease, it is therefore argued that the public sector should actually move in the opposite direction, i.e., perform a fiscal stimulus, which would be easily financed due to the excess saving and the low interest rates, with the aim to sustain businesses and households cash flows and to easy balance sheets repair without forcing the economy into depression.

Guajardo et al. (2011), using a different estimation method with respect to the one used by Alesina and Ardagna (2010), find empirical evidence that fiscal consolidation has actually contractionary effects on private domestic demand and GDP, in contrast to the estimates made by Alesina and Ardagna (2010), which the authors show to be biased toward overstating expansionary effects.

De Grauwe and Ji (2012) find evidence that a large part of the surge in the spreads of the peripheral Eurozone countries during 2010/11 was disconnected from fiscal fundamentals and was actually the result of time dependent negative market sentiments caused by the particular situation of government bond markets in a monetary union, where countries, being without their own currency, can be subject to self-fulfilling liquidity crises, which instead are ruled out in countries with full monetary sovereignty. Furthermore, if a country in such a scenario is forced into austerity with the aim to reduce bond spreads, high interest rates, impossibility to devaluate the currency, and fiscal consolidation, may cause a deep recession and transform a liquidity crisis in a solvency crisis.

Depending on the economic conditions and on the institutional setting, fiscal austerity may then turn out to be depressive and self-defeating while fiscal stimulus could actually turn out to be expansionary and self-financing. Several scholars, like Nobel laureates P. Krugman and J. Stiglitz,[2] suggested the use of expansionary fiscal policies along with monetary accommodation in order to fight the crisis (Krugman, 2013).

Based on the current academic and political discussion, we design several policy strategies to be tested and compared in the framework of an enriched version of the agent-based Eurace model (Cincotti et al., 2010, 2012a,b; Raberto et al., 2012; Teglio et al., 2012; Ponta et al., 2018). For this purpose, we argue that the agent-based approach (see e.g. Tesfatsion and Judd, 2006; LeBaron and Tesfatsion, 2008) has some advantage with respect to mainstream approaches in macroeconomics based on dynamic stochastic general equilibrium models. It allows for more realistic agents' behaviour, based on heuristics and behavioural patterns, see e.g. Akerlof, 2002), instead of perfect rationality, and it also allows for non-clearing and decentralized markets, see Raberto et al. (2008a). Furthermore, agent-based modelling allows for out-of-equilibrium aggregate outcomes, emerging from the complex pattern of agents' interaction (Colander et al., 2008; Kirman, 1992).

Among the agent-based macro-models in circulation, see e.g. Ashraf et al. (2014), Delli Gatti et al. (2011), Gabbi et al. (2015), Gualdi et al. (2015), Rengs and Wäckerle (2014), Riccetti et al. (2013), and Wäckerle et al. (2014), it is worth citing the Keynesian model by Dosi et al. (2010), which has been recently used to test different fiscal and monetary policy scenarios (Dosi et al., 2013, 2015). Results show that the introduction of constrained fiscal rules mimicking the stability and growth pact or the fiscal compact worsen the performance of the economy as well as public finances, while the best policy mix able to stabilize macroeconomic fundamentals is the combination of an unconstrained fiscal policy with a dual-mandate monetary policy, targeting both inflation and unemployment. Among other agent-based studies on the recent crisis, Assenza et al. (2015) focus on the emergence of a crisis from micro behavioural interactions, while Klimek et al. (2015) focus on crisis

[1] A related common justification of austerity programs was the risk that bond markets, whenever a government is not sufficiently committed to budget balance, may demand huge spreads for sovereign debt and possibly push a nation into default.

[2] There are many articles around. See for example Stiglitz's "Agenda to save the Euro" and Krugman's "The Depressed Economy Is All About Austerity" http://krugman.blogs.nytimes.com/2013/09/24/the-depressed-economy-is-all-about-austerity/.

resolution mechanisms, finding that there are no economic conditions under which a taxpayer-funded bail-out outperforms the bail-in mechanism with private sector involvement.

In particular, our work shares some similarities with Dosi et al. (2015), because both papers use an agent-based model to contribute to the recent debate about the role of fiscal austerity during economic crises. However, while Dosi's model is more focused on modelling growth and innovation, our model presents a more sophisticated consumption market where demand and supply are entirely endogenous, and a financial market where households can invest their savings. In particular, households can finance firms by purchasing newly-issued stocks and lend to the government by purchasing newly-issued bonds. This last feature has of course a central role when studying the effects of fiscal policy. It is worth noting that the two models, although developed independently and in parallel, reach similar policy conclusions, suggesting the importance of fiscal flexibility during downturns.

In order to investigate the effects of different fiscal policies, we design simulations which diverge only on the edge of a crisis. As shown in Raberto et al. (2012) and Cincotti et al. (2012b), the Eurace model is able to reproduce endogenous business cycles with recessions of different duration and severity. The idea is therefore to let simulations run undifferentiated until a crisis occurs, and to activate the different policy strategies after the first crisis. This setting provides the opportunity to compare, ceteris paribus, how different policies can affect the development of a crisis, measuring some key indicators like the average duration of the crisis, average unemployment, inflation or GDP, among others.

The paper is divided as follows: in the next section we present an overview of Eurace, while in the Appendices we provide more details on the model design and validation. In Section 3 we describe the proposed fiscal and monetary policy scenarios, and in Section 4 we discuss the results of computational experiments. Finally, we draw our main conclusions in Section 5.

2. Overview of the Eurace model

Eurace is an agent-based macroeconomic model and simulator which is under development since 2006. The model is based on the interaction among several classes of economic agents: households, which act as workers, consumers and financial investors; consumption goods producers (CGPs), henceforth firms, producing homogenous consumption goods; a capital goods producer (KGP), producing homogeneous investment goods; commercial banks; a government, and a central bank.

Agents interact through different markets where consumption goods and capital goods, labour and credit are exchanged in a decentralized setting with disperse prices set by suppliers and based on costs. Agents' behaviour is modelled as myopic and characterized by limited information, scarce computational capabilities and adaptive expectations. For instance, CGPs are characterized by a short-term profit objective and make production and investment plans where expected future revenues are based on backward-looking expectations determined by past sales and prices. In particular, production plans depend on past sales and the inventory stock, along the lines of the inventory management literature (Hillier and Lieberman, 1986), while sale prices are determined by a mark-up on costs (wages and debt interests), see e.g. Plott and Sunder (1982), Fabiani et al. (2006). Investment plans depend on the cost of capital goods and the present value[3] of the additional foreseen revenues, but are limited by both by internal[4] and external financing capabilities.[5]

Households set the consumption budget out of their income following a wealth to income target ratio, according to the theory of buffer-stock saving (Carroll, 2001; Deaton, 1992), which states that consumption expenses mainly depend on the need to accumulate a target stock of liquid wealth to be used as a buffer in cases of income downfalls, due to e.g. unemployment. Savings can be allocated in stocks (i.e. the claims on firms/banks equity and future dividends) and government bonds, which are traded in a centralized Walrasian financial market.

Banks have the function to provide short-term loans to firms at an interest rate determined by the cost of central bank loans, i.e. the policy rate, plus a mark-up. It is worth noting that, in line with the working of the banking system in a modern capitalist economy (see e.g. McLeay et al., 2014), banks lending is not limited by the available liquidity and, whenever a bank grants a loan, a corresponding deposit, entitled to the borrower, is created on the liability side of the bank' balance sheet. Furthermore, if it happens that a bank becomes short of liquidity after the settlements of all payments of its clients (households, firms, the capital good producer), the bank gets loans from the central bank which can provide liquidity to the banking system in infinite supply. In line with the post-Keynesian literature, see e.g. Fontana (2003) and Lavoie and Godley (2012), we then follow the endogenous money modelling approach, where loans come before deposits, not viceversa, and, whenever the private sector is willing to borrow more money, banks normally provide more loans and then create endogenously more banking deposits, i.e., new money. Bank lending is however limited by a Basel II-like capital requirement rule; in this respect, each bank assesses the loan risk by considering the financial leverage of the prospective borrower before deciding about a loan request. Finally, a distinctive feature of the Eurace modelling approach is that every agents is modelled through a double-entry balance sheet that includes the details of all assets and liabilities.

[3] According to empirical surveys (Graham and Harvey, 2001, 2002), the net present value is one of the most popular method used by managers to evaluate investments.

[4] Along the lines of Fazzari et al. (2008).

[5] The pecking order theory (Myers and Majluf, 1984) is adopted to determine a hierarchy of financial sources for the firm.

Table 1
Sectorial balance sheet matrix. Subscripts represent the index of the agent to which the stock refers. Uppercase subscripts are used when the stock refers to a whole sector, whereas lowercase subscripts are used when it refers to a single agent (for instance in the case of sums). Finally, superscript characters are introduced when the balance sheet counterpart is more than one single sector.

	Households (H)	CGPs (F)	KGP (K)	Banks (B)	Government (G)	Central bank (CB)	Σ
Capital		$+K_F\,p_K$					$+K_F\,p_K$
Inventories		$+I_F\,p_c$					$+I_F\,p_c$
Government bonds	$+n_G^H\ p_G$				$-n_G\,p_G$	$+n_G^{CB}\ p_G$	0
Debt/credit		−Loans		+Loans		$+\text{Loans}_{CB}$	0
				$-\text{Loans}_{CB}$			
Private liquidity	$+M_H$	$+M_F$	$+M_K$	$-D_B$			0
Banks, government liquidity				$+M_B$	$+M_G$	$-D_{CB}$	0
CB liquidity/fiat money						$+\text{M}_{CB}$	$+\text{M}_{CB,0}$
						$-\text{Fiat}_{CB}$	
Traded equity	$+\Sigma_f n_{E_f} p_{E_f}$	$-E_F$					$\Sigma_f n_{E_f} p_{E_f} - E_F$
	$+n_{E_k} p_{E_k}$		$-E_K$				$+n_{E_k} p_{E_k} - E_K$
	$+\Sigma_b n_{E_b} p_{E_b}$			$-E_B$			$+\Sigma_b n_{E_b} p_{E_b} - E_B$
Equity	$-E_H$				$-E_G$	$-E_{CB}$	$-E_H - E_G - E_{CB}$
Σ	0	0	0	0	0	0	0

Table 2
Sectorial transaction flow matrix of agents populating the EURACE economy.

		Households (H)	CGPs (F)	KGP (K)	Banks (B)	Government (G)	Central bank (CB)	Σ
Current account	Consumption	−	+					0
	Wages	+	−	−		−		0
	Transfers	+				−		0
	Investment		−	+				0
	Taxes	−	−	−	−	+		0
	Dividends	+	−	−	−			0
	Coupons	+				−	+	0
	CB coupons payback					+	−	0
	Banks loan interests		−		+			0
	CB loans interests				−		+	0
	CB interests payback				+		−	0
		=	=	=	=	=	=	
	Net cash flow	Savings	Profits	Profits	Profits	Surplus	Seignoirage	0
Capital account	Net cash flow	+Savings	+Profits	+Profits	+Profits	+Surplus	+Seignoirage	0
	Δ Capital		$+\Sigma_f \Delta K_f p_K$	$-\Delta K_K p_K$				0
	Δ Loans		+Δ Loans		−Δ Loans		$-\Delta\ \text{Loans}_{CB}$	0
					$+\Delta\ \text{Loans}_{CB}$			0
	Δ Issue of new shares/bonds	$-\Sigma_f p_{E_f}\,\Delta n_{E_f}$	$+\Sigma_f p_{E_f}\,\Delta n_{E_f}$			$+p_{E_G}\,\Delta n_{E_G}$		0
		$-p_{E_G}\,\Delta n_{E_G}$						0
	Δ Quantitative easing	$+p_{E_G}\,\Delta n_{E_G}^{QE}$					$-p_{E_G}\,\Delta n_{E_G}^{QE}$	0
	Δ private liquidity & Δ Banks' deposits	$-\Delta\ M_H$	$-\Delta\ M_F$	$-\Delta\ M_K$	$+\Delta\ D_B$			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						$+\Delta M_{CB} - \Delta\ \text{Fiat}_{CB}$	0
	Σ	0	0	0	0	0	0	

Following the approach used in Godley and Lavoie (2012), we provide a compact description of the model, which is rather complex, by presenting three significant matrices. Table 1 reports the balance sheet matrix, describing all assets and liabilities for each sector (here a sector has to be seen as a class of agents). Table 2, called transaction flow matrix, shows all the stock and monetary flows among agents. Table 3, called revaluation matrix, reports for each sector the variations in the stock level that are not due to flows but to changes in the stock price. This approach allows to check the consistency at any time step between stocks and flows in the model, both at the level of the single agent and at the aggregate one, in line also with post-Keynesian stock-flow-consistent modelling approach, see e.g. Caverzasi and Godin (2015).

In matrix 1 a plus (minus) sign corresponds to agents' assets (liabilities) and each column can be read as the aggregated balance sheet of a specific sector (e.g. households). Rows show assets and claims of assets among sectors, thus generally adding up to zero. Exceptions are capital and inventories, which are accumulated by CGPs, and households' equity shares, which are issued by CGPs, KGP and banks and do not add up to zero because of the difference between market price and book value.

In Table 2, the current account describes the flows of revenues (plus sign) and payments (minus sign) that agents get and make. Agents are reported in the columns and monetary flows are reported in the rows. The result of agents' sector transactions is the net cash flow. The capital account section of Table 2 describes the balance sheets changes related to each sector.

Table 3
Sectorial revaluation matrix of agents populating the EURACE economy.

	Households (H)	CGPs (F)	KGP (K)	Banks (B)	Government (G)	Central bank (CB)	Σ
Equity$_{t-1}$	$E_{H,t-1}$	$E_{F,t-1}$	$E_{K,t-1}$	$E_{B,t-1}$	$E_{G,t-1}$	$E_{CB,t-1}$	$E_{TOT,t-1}$
Net cash flow	+Savings	+Profits	+Profits	+Profits	+Surplus	+Seignoirage	0
Revaluations/devaluations							
Capital		$+\Sigma_f \Delta p_K K_f$					$+\Sigma_f \Delta p_K K_f$
Inventories		$+\Sigma_f \Delta p_c I_f$					$+\Sigma_f \Delta p_c I_f$
Equity shares	$+\Sigma_f \Delta p_{E_f} n_{E_f}$						$+\Sigma_f \Delta p_{E_f} n_{E_f}$
	$+\Sigma_b \Delta p_{E_b} n_{E_b}$						$+\Sigma_b \Delta p_{E_b} n_{E_b}$
	$+\Delta p_{E_k} n_{E_k}$						$+\Delta p_{E_k} n_{E_k}$
Bonds	$+\Delta p_G n_G^H$				$-\Delta p_G n_G$	$+\Delta p_G n_G^{CB}$	0
	=	=	=	=	=	=	=
Equity	$E_{H,t}$	$E_{F,t}$	$E_{K,t}$	$E_{B,t}$	$E_{G,t}$	$E_{CB,t}$	$E_{TOT,t}$

Special attention deserves the money creation mechanism in the model. The central bank has two channels to introduce new liquidity (or Fiat money) into the system. The first one is via loans provided to banks when they are in liquidity shortage. The second is through quantitative easing operations, i.e., purchase of government bonds in the secondary market. In both cases, the economic agents deposit an amount equal to the new Fiat money in the banking sector (agents who got loans from banks or who sold bonds to the CB), generating additional liquidity that is deposited at the central bank and, in turn, generates new liquidity of the central bank that is always equal to the amount of Fiat money created. This is the reason why in Table 1, the difference between fiat money and central bank liquidity is always constant (and equal to the initial central bank liquidity). It is also worth noting 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 and it decreases when the loan is paid back.

3. Fiscal and monetary policy scenarios

We consider eight combined fiscal and monetary policy scenarios, which can be grouped in two main sets, each characterized by four policies, i.e., a baseline policy scenario plus three additional nested specifications. The two baseline policy scenarios are named fiscal compact (FC) and stability and growth pact (SGP), respectively. The two names refer to the two well-known European treaties[6] designed to ensure that countries in the European Union pursue sound public finances and coordinate their fiscal policies. In particular, the SGP policy scenario sets the public deficit ro GDP ratio as the fundamental policy target, while the FC policy scenario addresses the level of the public debt to GDP ratio. Our definitions do not match exactly the official EU agreements[7] but have merely the purpose to recall in a stylized way the key elements addressed by the corresponding European agreements. In both cases, tax rates on labour and corporate earnings, as well as the value-added tax are the policy instruments considered to get the two targets within pre-determined limits.

For each baseline policy scenario, three further nested policy specifications are then considered during periods of economic crisis, defined here as periods when the unemployment rate is higher than a given threshold. These additional policy specifications, if selected, are effective only during crises, irrespectively from the deficit and debt to GDP levels. The new policies are named as: unemployment escape clause (U), which rules out tax hikes; quantitative easing (QE), consisting in the purchase of government bonds by the central bank in the secondary market; fiscal accommodation (FA), where tax rates are always decreased during crisis periods.

The three different policy specifications outlined above are characterized by increasing strength in counteracting the two baseline scenarios in times of high unemployment. The first choice would be the adoption of the unemployment escape clause (U), avoiding an increase of tax rates even if deficit or debt to GDP ratios are above their thresholds; in addition to this, the policy maker could also pursue unconventional monetary policy measures (QE) with the aim to sustain bond price and then facilitate government debt financing in times of decreasing fiscal revenues; finally, the previous two policies can be complemented by a fiscal accommodation (FA) where tax rates are quickly (on a monthly basis) lowered to increase the purchasing power of the private sector. Given their particular design, the three policies measures are not applied independently to the two baseline scenarios, but are taken into consideration following the particular order of adoption previously outlined.

[6] It is worth noting that the stability and growth pact, born in 1997 and later amended, is embodied in the European law, while the fiscal compact is an intergovernmental treaty, signed in 2012 by 25 EU member states, which introduces a new stricter version of the stability and growth pact.

[7] The stability and growth pact is a set of rules designed to ensure that countries in the European Union pursue sound public finances and coordinate their fiscal policies (http://ec.europa.eu/economy_finance/economic_governance/sgp/index_en.htm). The Treaty on Stability, Coordination and Governance in the Economic and Monetary Union, commonly known as fiscal compact, can be retrieved by request here: http://www.consilium.europa.eu/en/european-council/.

Results related to the two baseline policy scenarios, SGP and FC, as well as the additional specifications, will be presented and discussed. In particular, for both baseline cases, we will then have 3 additional policy scenarios. In the SGP case, they will be named as SGP + U, SGP + U + QE, and SGP + U + QE + FA. We will have analogues scenario names in the FC case.

In the following, we provide the details about the implementation of the two baseline monetary and fiscal policy scenarios:

3.1. *Stability and growth pact (SGP)*

SGP scenario targets a level of yearly deficit to GDP ratio equal to 3 percent. At the beginning of every year, government sets concurrently the level of corporate tax, Value-added tax and labour tax according to the current level of deficit to GDP ratio. Three cases are possible:

1. If the ratio is higher than 3 percent tax rates are increased by 5 percent.
2. If the ratio is negative, i.e. government incomes are higher than expenditures, tax rates are decreased by 5 percent.
3. If the ratio is included between 0 and 3 percent, tax rates remain unchanged.

3.2. *Fiscal compact (FC)*

The policy target set in FC scenario is given by a level of debt to GDP ratio equal to 60 percent. At the beginning of every year, government computes the ratio between debt, that corresponds to the value of the outstanding bonds, and GDP. Depending on the level of debt to GDP ratio compared to the target, two main cases are possible:

1. If debt to GDP ratio is lower than 60 percent, tax rates are set according to the following rule:
   - If deficit to GDP ratio is greater than 0, tax rates are increased by 5 percent.
   - If deficit to GDP ratio is lower than 0, tax rates are decreased by 5 percent.
2. If debt to GDP ratio is higher than 60 percent, government computes the twentieth part of the value exceeding the threshold, i.e.

$$ET = \frac{(Debt/GDP) - 0.6}{20}$$

   In terms of fiscal policy, the effects are twofold:
   - Tax rates are increased by 5 percent if the deficit to GDP ratio is greater than *ET* and decreased otherwise.
   - Government repurchases bonds in the secondary market for a value equal to *ET* if its payment account is positive.

In the following, we provide the details about the implementation of the three additional policy specifications:

3.3. *Unemployment escape clause (U)*

At beginning of the year, if the average unemployment rate of the previous year or the current unemployment rate is greater than 10 percent, unemployment escape clause is activated and tax rates are left unchanged despite the level of deficit to GDP ratio and the debt to GDP ratio in SGP and FC basis scenarios, respectively.

3.4. *Quantitative easing (QE)*

The quantitative easing mechanism is modelled by allowing the central bank to buy government bonds in the financial market. This mechanism activates on the top of the standard Taylor rule, which sets the policy rate. QE is activated when the current unemployment rate is higher than 10 percent. The quantity of bonds to be purchased daily is set as:

$$\frac{n_G/10}{240}$$

i.e., the 10 percent of the total outstanding bonds n_G. The quantity is computed on daily basis, being 240 the number of days in a year, because the central bank enters the bonds market every day, in order to smooth the purchase across one year.

3.5. *Fiscal accommodation (FA)*

Fiscal accommodation is activated on a monthly basis, if the current unemployment rate exceeds the threshold of 10 percent. Being a monthly policy, tax rates decreases are computed as the twelfth part of the yearly tax rates changes, set to 5 percent.

4. Simulation results

One of the most relevant features of the Eurace model is the emergence of endogenous business cycles and crises, depending on boom-bust credit cycles. The mechanisms of generation and propagation of such crises have been discussed in previous papers, see e.g. Cincotti et al. (2010), Raberto et al. (2012) or Teglio et al. (2012), and we will recall them when needed. In this section we discuss the effectiveness of the different fiscal and monetary policies, outlined in Section 3, in preventing or mitigating the endogenous economic crises arising in the Eurace model.

The methodology of our study is based on Monte Carlo computational experiments, consisting in running simulations with different seeds of the pseudorandom number generator for each policy scenario. We consider eight policy scenarios, as explained in Section 3, and fifty seeds per scenario, for a total of four hundred simulations. Simulations are performed *ceteris paribus*, meaning that all the parameters of the economic system are identical across the different policy scenarios, with the exception of the specific parameters characterizing the policy scenario. Simulations run for a time span of twenty five years but they are indistinguishable during the first nine years, when every case runs under the stability and growth pact policy (SGP). Simulations are allowed to diverge at the beginning of year nine, when the distinction among the different policies is enabled. In this way, simulations have a common transition phase, which we discard in the analysis, and a second differentiated period that originates from the same initial conditions. Therefore, for every given seed, divergence among simulated time series is caused only by the different policy settings.

The presentation of results is organized to show both the performance of the different policies during crisis periods and the overall performance of each policy during the entire time span. On the one hand, we focus the attention on what happens during a crisis and why some policies perform better than others; on the other hand, we want to show the behaviour of some crucial variables (e.g., public budget related variables) in the long run.

Simulations have been performed with the following settings: 5000 Households, 100 Consumption Goods Producers, 5 Banks, 1 Capital Good Producer, 1 Government and 1 Central Bank.

In the following sections, results are presented from a qualitative and quantitative point of view, with the intention to examine and disclose the economic mechanisms that explain the obtained results. For every policy scenario, several tables report the ensemble averages of many relevant economic variables. Ensemble averages have been computed over the different seeds of the pseudo-random number generator; the relatively low standard errors, as reported within brackets in the tables, indicate that the ensemble averages provide reliable indications and that increasing further the number of seeds would not provide new meaningful information.

4.1. Genesis of a crisis

The Eurace model is characterized by endogenous business cycles and endogenous crises, as described for instance in Raberto et al. (2012). Gross domestic product shows three stylized behaviours: a trend growth, alternate periods of growth and recession (business cycles), and sudden output falls that are usually followed by subsequent recoveries.

The underlying rate of GDP growth is given by capital accumulation by firms. Change in technology and human capital are not considered in this work, as our focus is on the short and medium run out-of-equilibrium dynamics, when firms are endowed with an amount of physical capital that can be increased. We are not interested here in the hypothetical steady state where firms invest only to replace depreciated capital. The origin of a typical crisis in the model can be summarized as follows. When the economy is in a boom period, characterized by high growth rate and nearly full employment, the increment of unit costs, due to the strong pressure on wages, as well as high aggregated demand, causes an increase in the level of prices. Consequently, the central bank inflation targeting policy rule raises the base interest rate, increasing interest payments by firms. Fig. 1 illustrates this mechanism for a representative simulation[8] of the model, for 4 selected policies. Fig. 2 shows that the economic boom is driven by a credit expansion starting at year 9, slowing down in the second half of the 11th year, and growing again during year 12. Let us focus now on the fiscal compact scenario (FC) (we will compare the different policies later). Fig. 3 shows a double dip recession starting in the second half of the 11th year and becoming a severe crisis at the beginning of year 13, after a temporary phase of economic recovery.

During the inflation of the credit bubble, the financial stability of the economic system is significantly weakened; firms' financial indicators deteriorate (see Fig. 4). The interest bill paid by firms becomes very high with respect to revenues, causing an increasing insolvency risk for firms. The bubble burst is actually triggered by insolvency bankruptcies of firms that are large enough to hurt banks' equity, see Figs.[9] 6 and 2 (top panel). In turn, banks' equity contraction, due to the minimum capital requirements regulatory provisions, causes a credit crunch that affects firms' possibilities to refinance their debt, thus leading to a vicious cycle that severely hits economic activity through illiquidity bankruptcy chains, see Fig. 5.

[8] The representative simulation is given by a particular choice of the seed of the pseudo-random number generator. The four policy scenarios represented in the figures obviously refer to the same seed.

[9] Note that we are still focusing only on the fiscal compact case, i.e. the continuous black line.

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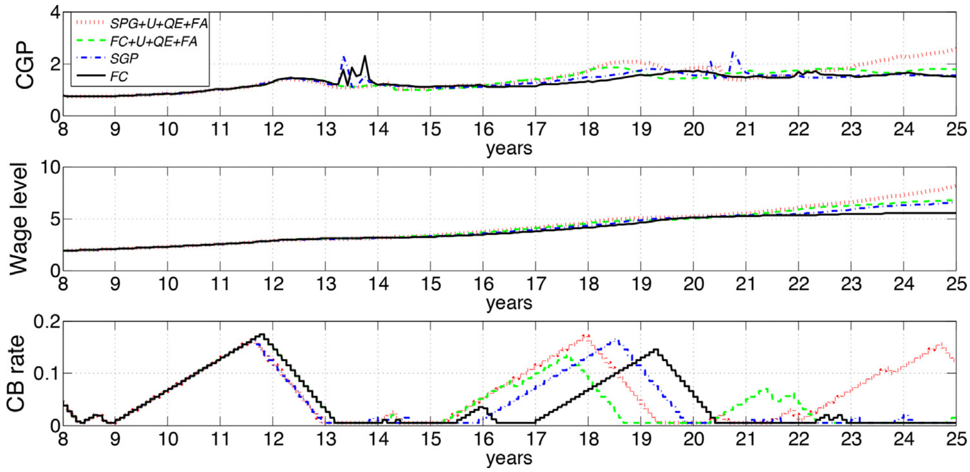

Fig. 1. Monthly consumption good price (top panel), wage level (middle panel) and central bank interest rate (bottom panel) for four different fiscal and monetary policy scenarios.

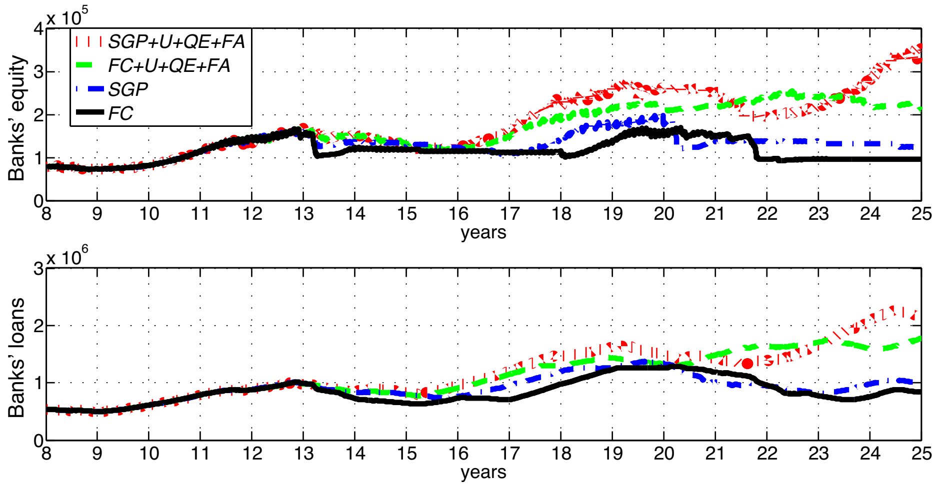

Fig. 2. Monthly banks' equity (top panel) and banks' loans (bottom panel) for four different fiscal and monetary policy scenarios.

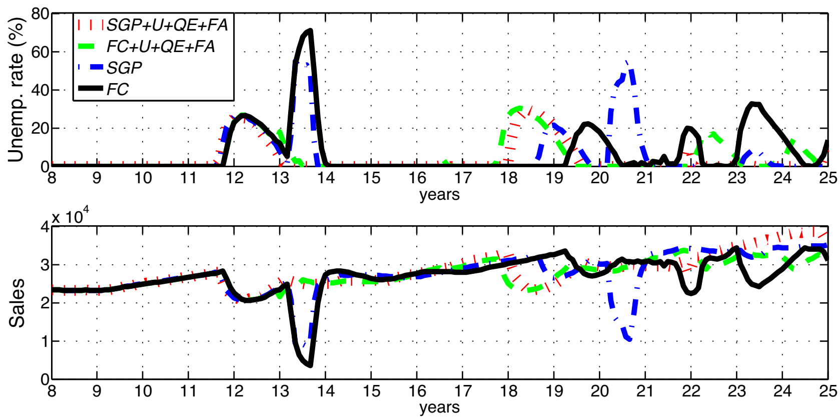

Fig. 3. Monthly unemployment rate (top panel) and sales (bottom panel) for four different fiscal and monetary policy scenarios.

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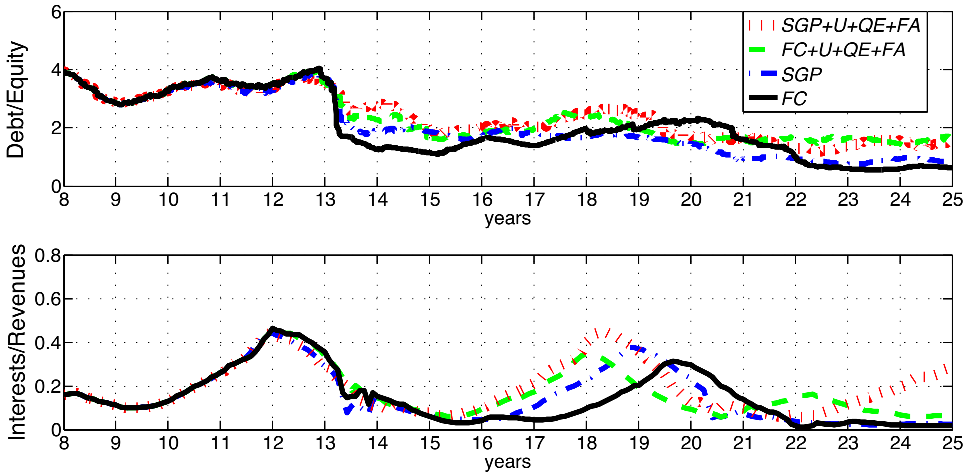

Fig. 4. Monthly firms' debt to equity ratio (top panel) and interests to revenues ratio (bottom panel) for four different fiscal and monetary policy scenarios.

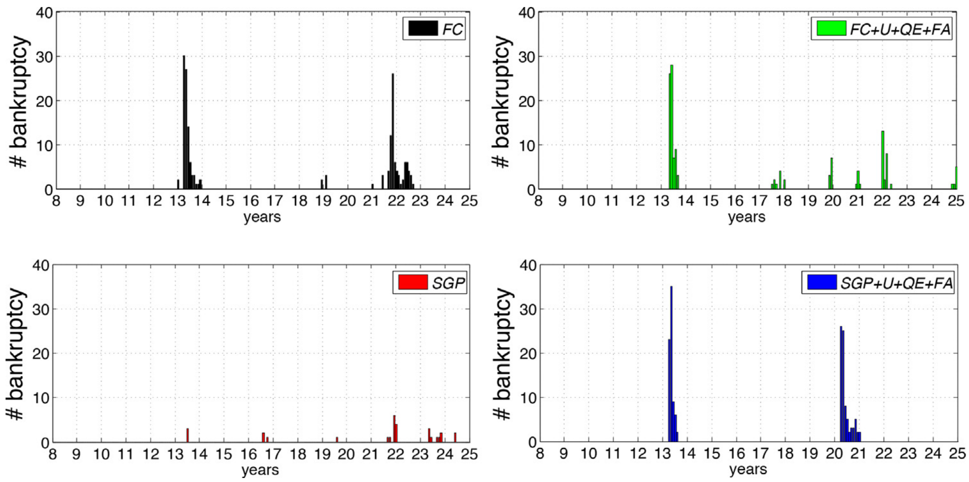

Fig. 5. Monthly number of illiquidity bankruptcies for four different fiscal and monetary policy scenarios.

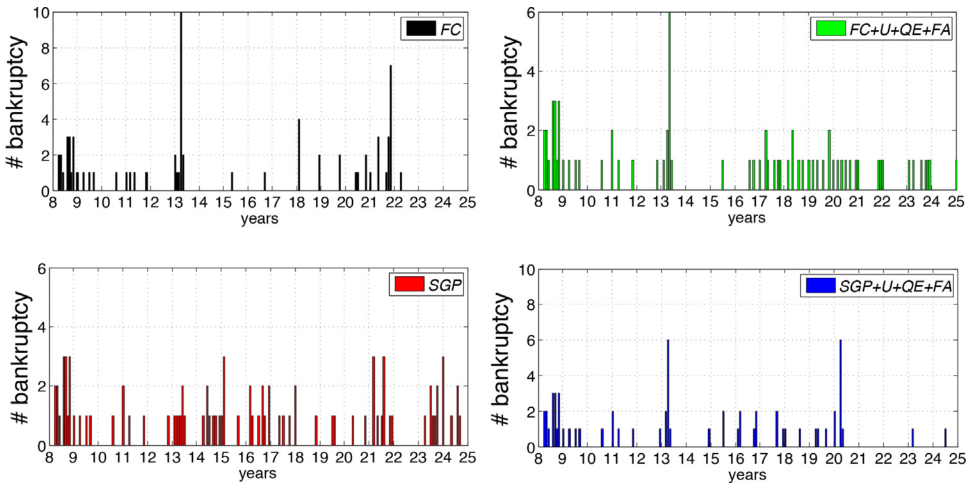

Fig. 6. Monthly number of insolvency bankruptcies for four different fiscal and monetary policy scenarios.

Table 4
Fiscal policy and public accounts: yearly statistics (%).

FC	*SGP*	*U*	*QE*	*FA*	Tax rates	Debt/GDP	Deficit/GDP	Bond yield
√					22.22 (0.40)	99 (3)	1.21 (0.44)	8.40 (0.27)
√		√			20.29 (0.37)	110 (4)	3.23 (0.46)	9.33 (0.39)
√		√	√		21.03 (0.32)	105 (4)	2.11 (0.45)	8.42 (0.32)
√		√	√	√	19.64 (0.30)	121 (7)	4.27 (0.58)	9.44 (0.46)
	√				20.22 (0.34)	117 (6)	2.85 (0.33)	12.42 (0.45)
	√	√			18.74 (0.32)	140 (8)	5.07 (0.41)	15.02 (0.74)
	√	√	√		19.48 (0.28)	131 (7)	3.77 (0.39)	13.19 (0.54)
	√	√	√	√	18.29 (0.30)	163 (11)	6.92 (0.58)	14.41 (0.70)

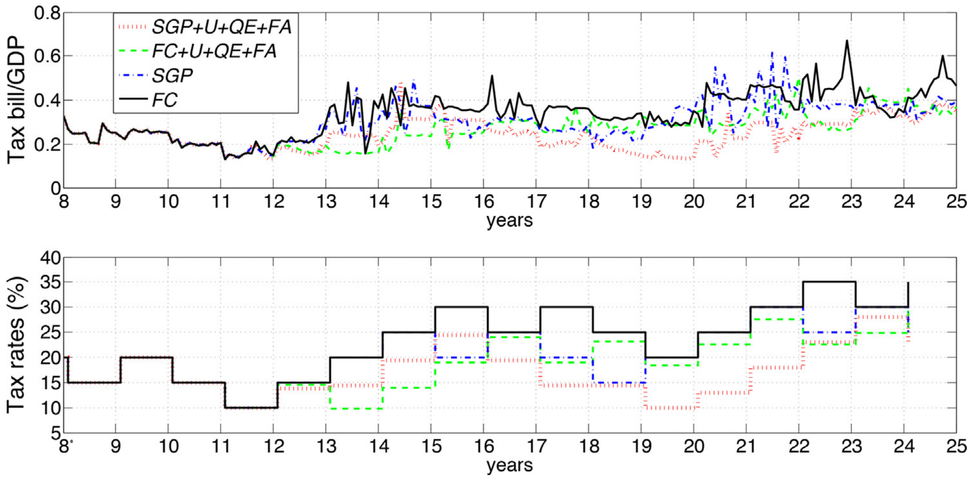

Fig. 7. Monthly tax bill/GDP (top panel) and tax rates (bottom panel) for four different fiscal and monetary policy scenarios.

4.2. *Dealing with the crisis: a comparison of fiscal policies*

In Section 3 we presented the set of eight policies we are considering in the model. Two fiscal policies, called "fiscal compact" (FC) and "stability and growth pact" (SGP), are used as standard scenarios. SGP means targeting a 3% deficit over GDP ratio, whereas FC adds the constraint on government debt, which should not exceed 60% of GDP. Moreover, the standard scenarios are incrementally enriched with three complementary policies which relax fiscal rigidity. The first policy is the "unemployment escape clause" (U), stating that while the unemployment rate is above a given threshold of 10%, budget constraints on public deficit and debt are suspended. In the second complementary policy, the central bank is allowed to buy government bonds in the secondary market (QE). Finally, the "fiscal accommodation" policy (FA) adds a tax rate reduction to the U + QE policy.

As a result we have eight different policy combinations, which are reported in the left side of our tables (see for instance Table 4). On the other hand, time series plots present only four of the eight total policies. This choice is motivated by a readability issue and by the fact that plots are mainly intended to visualize and interpret the economic mechanisms that lead to the aggregated results presented in the tables. The four policies shown in the time series plots are the basic ones of FC "fiscal compact" and SGP "stability and growth pact", along with their most expansionary versions, i.e. characterized by the addition of the unemployment escape clause (U), quantitative easing (QE), and fiscal accommodation (FA). The rationale here is to show the "extreme" cases, remanding to the tables for the intermediate ones.

Before the discussion on the effects of fiscal policy, let us briefly resume the main mechanisms through which taxation affects spending patterns and agents' behaviours in the model. Increasing the tax rate on households' labour and capital income affects the available net income, as in Eq. (A.13), therefore decreasing consumption and aggregate demand. Eq. (A.14) shows that consumption follows a buffer stock saving rule that targets a fixed wealth-to-income ratio. Taxes on firms' corporate earning decrease firms' financial resources, forcing them to resort to borrowing money from banks or issuing new stocks. The value-added tax raises the market price of final goods, decreasing the real demand of goods by households in the short run, with non-trivial effects in the medium run. Finally, higher corporate taxes for both firms and banks generally decrease households' dividends, and then households' disposable income through the capital income channel.

Let us focus on the crisis that goes from the second half of year 11 to the end of year 13. Fig. 3 clearly shows that counterbalancing a strict fiscal policy during recessions is crucial in order to avoid severe crises. In the case of the expansionary versions of the two basic policies, the deep crisis of year 13 is prevented. Fig. 7 shows how the government avoids raising taxes in order to fulfil its budget commitments. Tax rates are kept low and the tax bill over GDP also remains low. However, looking at Fig. 8 showing the yearly government budget and deficit over GDP, it emerges that deficit and debt do not

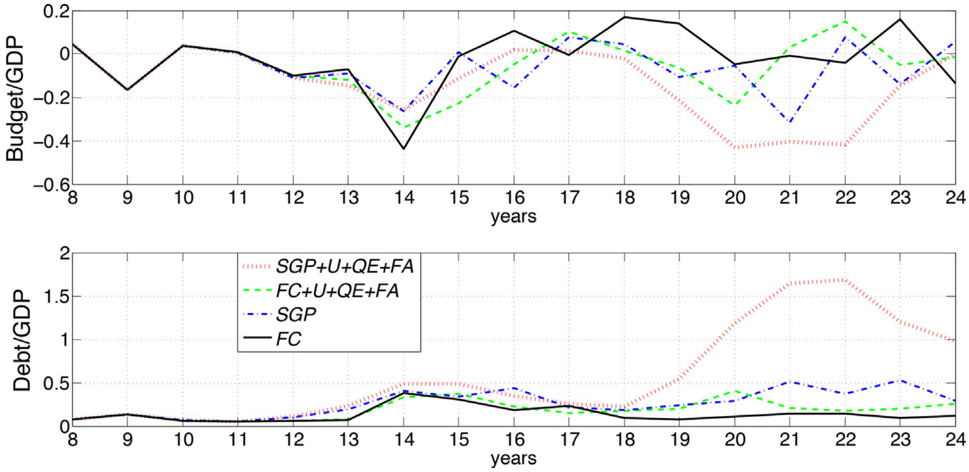

Fig. 8. Monthly budget to GDP ratio (top panel) and debt to GDP ratio (bottom panel) for four different fiscal and monetary policy scenarios.

significantly increase during the crisis. This is true in particular for the case of the expansionary version of the fiscal compact (when a strict fiscal compact scenario is relaxed during high unemployment periods). The main point suggested here is that, during a crisis, the potential loss in GDP caused by a rigid “austerity” policy is higher than the raise in deficit or debt caused by the temporary relaxing of such rigid measures. In other words it suggests that the fiscal multiplier is sufficiently high during recessions to recommend expansionary policies stimulating aggregate demand. Fig. 1 shows that, during the crisis, the interest rate is very similar among all policy scenarios. Actually, the monetary policy is set by the Taylor rule in all cases and, when unemployment starts growing, the central bank decreases the interest rate to foster new investments. Nevertheless, if we observe banks and firms data in Figs. 2 and 4, we see remarkable differences. The deleveraging process characterized by both a sudden reduction of firms' debt and a crash of banks' equity is clearly reduced in the case of fiscal stimulus. Sustaining aggregate demand during the crisis has a chain of positive effects in the short-medium run; first, it prevents sales crush, supporting firms' cash flows and their internal financing, thus decreasing bankruptcies risk; then, it defends banks from the swift equity losses caused by bankruptcies, allowing them to continue lending also after year 13. On the contrary, it is interesting to notice the long lasting negative effect on lending caused by strict fiscal policies in Fig. 2, where (for FC and SGP policy scenarios) loans are strongly reduced and go back to pre-crisis levels only after almost five years (year 18). This is due to a vicious cycle where banks are not able to lend and to make enough profits to increase their equity capital (by retaining earnings). Furthermore, Basel II regulation does not allow banks with low equity capital to lend and therefore to improve their financial statement, leading to a long lasting stalemate in the economy.

4.3. Fiscal scenarios from a wider perspective

Results presented in the previous section convey a clear message: relaxing fiscal policy during a crisis is beneficial for the economy. The government should have as a primary objective during a crisis the reduction of unemployment by sustaining aggregate demand. Both in the case of “fiscal compact” and “stability and growth pact” regimes, a fiscal expansion has a positive impact during a crisis. This is what we observe in our results and what has been illustrated in some representative figures. Of course, we need also to consider the other side of the coin, by looking at public accounts.

Moreover, we need to generalize our results showing some robustness across the stochastic shocks to the model, or more precisely the different seeds used to simulate it. In this regard, we present a set of tables showing the ensemble averages of several economic indicators, computed over fifty different seeds. We also report in Figs. 10 and 11 the boxplots of some of the main variables presented in the tables.

The tables consider the complete set of the eight scenarios and allow us for some more detailed comments on the incremental design of policy strategies. In this respect, having many scenarios to compare, let us briefly outline a general discussion frame. The first comparison should be between “stability and growth pact” (SGP) and “fiscal compact” (FC), i.e., between a pure deficit targeting constraint and a stricter one involving also debt restrictions. Then, we consider the cumulative effect of the additional policies introduced in the previous sections, i.e., “unemployment escape clause” (U), “quantitative easing” (QE) and “fiscal accommodation” (FA). Furthermore, we will present and analyze both the outcomes of the model obtained from the entire simulation time span and the specific results concerning periods of crisis.

Tables 5 and 6 show the ensemble average values of some indicators characterizing periods of crisis. In particular they show the average number of occurrences of at least two consecutive months with unemployment higher than[10] 10% (Table 5)

[10] We use this condition as a proxy of a crisis.

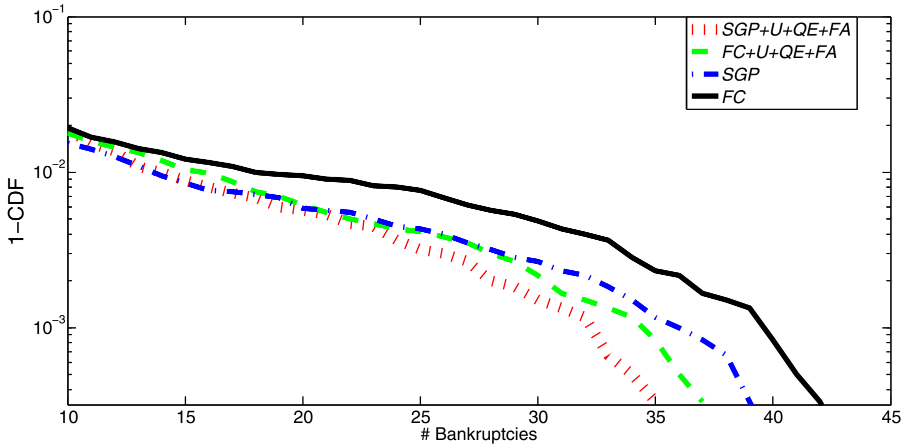

Fig. 9. Inverse cumulative distribution of firms' bankruptcies during a bimester.

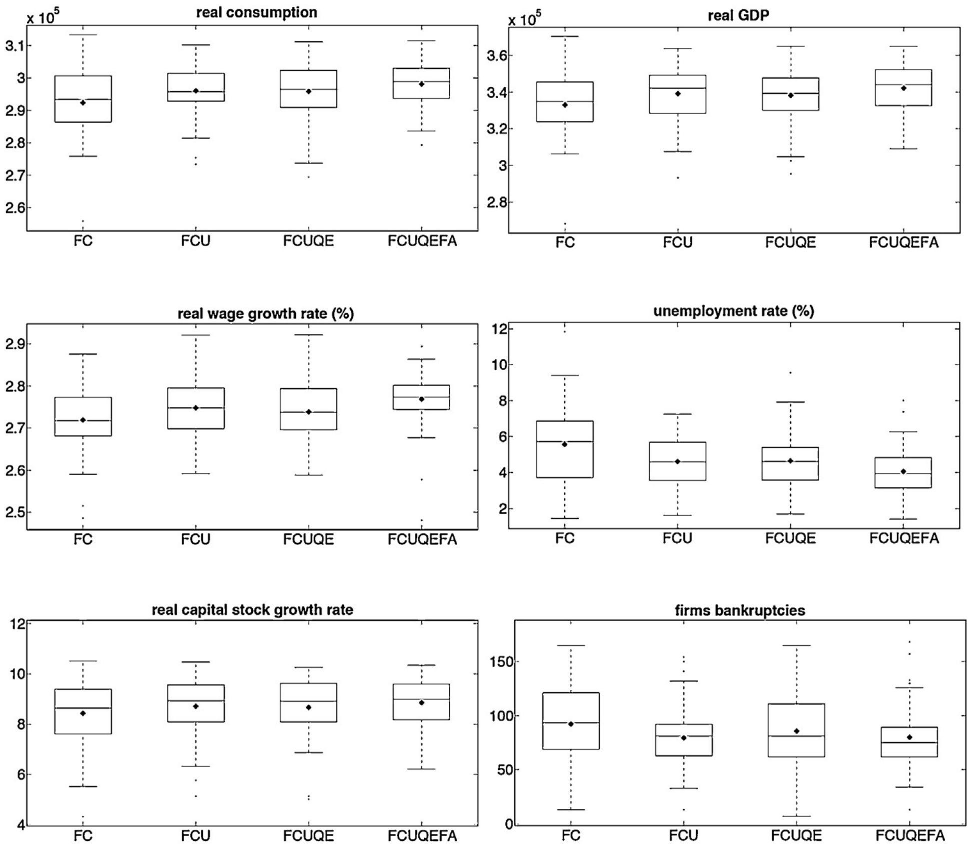

Fig. 10. Boxplot and mean of real consumption (top-left panel), real GDP (top-right panel), real wage growth rate (middle-left panel), unemployment rate (middle-right panel), real capital stock growth rate (bottom-left panel), inflation rate (bottom-right panel) for four different fiscal and monetary policy scenarios.

or 20% (Table 6). The two tables also show the average duration of a crisis, measured in consecutive months, and the probability for a firm to go bankrupt during this period. Finally, the maximum unemployment rate during the crisis period is shown.

Furthermore, Fig. 9 shows the inverse cumulative distribution function of bankruptcies during a bimester for different policy scenarios (considering all seeds). It has to be read as the probability of having more that a given number of bankruptcies during two consecutive months. Results clearly suggest that, when no fiscal relief mechanism is applied during crises, bankruptcies are more likely to happen and the economy is more unstable.

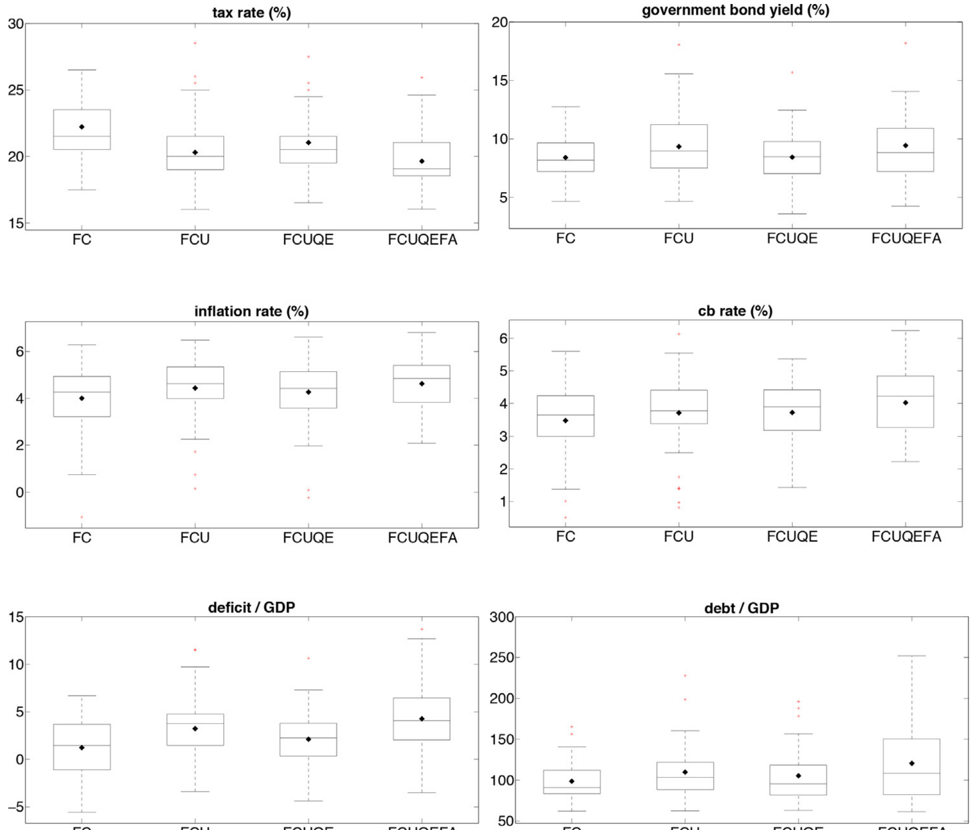

Fig. 11. Boxplot and mean of tax rate (top-left panel), government bond yield (top-right panel), inflation rate (middle-left panel), CB rate (middle-right panel), deficit to GDP ratio (bottom-left panel), debt to GDP ratio (bottom-right panel) for four different fiscal and monetary policy scenarios.

Table 5
Crisis analysis. # Depressions is the number of episodes with, at least, two consecutive months where unemployment rate is higher than 10%. Duration is the average number of months that characterize depressions. Bankruptcy prob.(%) represents firms' bankruptcy probability during depressions.

FC	*SGP*	*U*	*QE*	*FA*	# Depressions	Duration	Bankruptcy prob.(%)
√					1.6 (0.2)	18.7 (1.4)	39.64 (5.73)
√		√			1.2 (0.2)	15.4 (0.8)	19.86 (4.40)
√		√	√		1.3 (0.1)	14.8 (0.9)	29.16 (5.20)
√		√	√	√	0.9 (0.1)	12.9 (0.7)	22.28 (4.44)
	√				1.0 (0.1)	14.0 (1.5)	25.18 (4.61)
	√	√			0.9 (0.1)	14.0 (0.9)	18.32 (3.60)
	√	√	√		1.0 (0.1)	14.1 (1.0)	23.02 (5.01)
	√	√	√	√	0.9 (0.1)	12.8 (0.8)	22.68 (5.31)

Table 6
Crisis analysis. # Depressions is the number of episodes with, at least, two consecutive months where unemployment rate is higher than 20%. Duration is the average number of months that characterize depressions. Bankruptcy prob.(%) represents firms' bankruptcy probability during depressions. Max unemployment represents the unemployment rate peak for each scenario.

FC	*SGP*	*U*	*QE*	*FA*	# Depression	Duration	Bankruptcy prob.(%)	Max unempl.
√					0.8 (0.1)	9.5 (0.6)	33.78 (5.56)	39.57 (2.17)
√		√			0.5 (0.1)	8.0 (0.6)	15.76 (4.10)	33.55 (1.75)
√		√	√		0.4 (0.1)	8.8 (0.5)	21.30 (4.72)	35.11 (1.95)
√		√	√	√	0.3 (0.1)	6.9 (0.4)	14.12 (4.17)	31.13 (1.20)
	√				0.5 (0.1)	9.4 (0.5)	19.98 (4.36)	33.69 (1.83)
	√	√			0.5 (0.1)	8.9 (0.6)	11.42 (3.04)	29.37 (0.91)
	√	√	√		0.5 (0.1)	8.2 (0.5)	15.00 (4.07)	32.10 (1.60)
	√	√	√	√	0.3 (0.1)	7.0 (0.5)	17.02 (4.65)	31.87 (1.71)

Table 7
Prices: yearly growth rates (%) and central bank rate (%).

FC	*SGP*	*U*	*QE*	*FA*	Money wage	Price	Real wage	CB rate
√					6.47 (0.21)	4.01 (0.20)	1.94 (0.12)	3.48 (0.15)
√		√			6.90 (0.17)	4.44 (0.19)	2.17 (0.09)	3.71 (0.16)
√		√	√		6.81 (0.15)	4.26 (0.20)	2.18 (0.10)	3.73 (0.14)
√		√	√	√	7.24 (0.10)	4.63 (0.16)	2.35 (0.11)	4.03 (0.13)
	√				7.14 (0.16)	4.64 (0.19)	2.17 (0.12)	3.72 (0.12)
	√	√			7.28 (0.14)	4.79 (0.15)	2.26 (0.12)	3.96 (0.13)
	√	√	√		7.29 (0.12)	4.95 (0.17)	2.02 (0.10)	3.93 (0.11)
	√	√	√	√	7.35 (0.11)	4.68 (0.16)	2.42 (0.11)	4.23 (0.13)

Table 8
Real variables yearly growth rates (%).

FC	*SGP*	*U*	*QE*	*FA*	Consumption	GDP	Unemployment	Capital stock
√					1.71 (0.13)	2.19 (0.18)	5.57 (0.29)	8.43 (0.19)
√		√			2.03 (0.10)	2.73 (0.15)	4.60 (0.20)	8.71 (0.16)
√		√	√		2.04 (0.09)	2.63 (0.16)	4.64 (0.21)	8.66 (0.16)
√		√	√	√	2.08 (0.10)	2.86 (0.15)	4.06 (0.19)	8.85 (0.14)
	√				2.12 (0.10)	2.83 (0.13)	4.33 (0.25)	9.07 (0.18)
	√	√			2.16 (0.08)	2.95 (0.10)	3.90 (0.18)	9.10 (0.17)
	√	√	√		1.95 (0.09)	2.75 (0.14)	4.30 (0.21)	9.06 (0.17)
	√	√	√	√	2.11 (0.10)	2.88 (0.14)	3.99 (0.21)	8.88 (0.17)

Table 9
Credit variables yearly growth rates (%).

FC	*SGP*	*U*	*QE*	*FA*	Loans	Deposits	Equity
√					5.73 (0.38)	4.41 (0.43)	4.97 (0.08)
√		√			6.84 (0.32)	6.12 (0.34)	6.38 (0.07)
√		√	√		6.40 (0.33)	5.55 (0.36)	5.78 (0.07)
√		√	√	√	7.05 (0.21)	6.80 (0.22)	6.44 (0.04)
	√				7.27 (0.31)	6.61 (0.37)	7.00 (0.06)
	√	√			7.66 (0.23)	7.50 (0.25)	7.37 (0.06)
	√	√	√		7.63 (0.27)	7.28 (0.25)	7.21 (0.06)
	√	√	√	√	7.28 (0.24)	7.65 (0.23)	6.91 (0.06)

With a pure “fiscal compact” strategy the probability of having a very severe crisis, i.e., characterized by unemployment higher than 20 % during a simulation, is 80% (see Table 6) and the average duration of the crisis is nine month and a half. The bankruptcy probability for a firm is 33% and the maximum unemployment rate is almost 40% during the crisis. The situation with a pure “stability and growth pact” strategy is less catastrophic but still severe, with a 50% crisis probability per simulation and a 20% bankruptcy probability for a firm during a crisis. On the other hand, the beneficial effect of relaxing the fiscal constraint during crises appears quite distinctly from the data. In particular, in the FC case, when we simply allow for the unemployment escape clause, all the crisis indicators perform much better. Similar results hold for the SGP case both in Tables 5 and 6.

Going more into the detail, the activation of the unemployment escape clause, which rescinds the fiscal constraint above a given threshold of unemployment rate, has always a positive effect on the economy during crises, as Tables 5 and 6 clearly show. Concerning the overall economic performance, the general macroeconomic indicators are also notably improved by activating the escape clause, as shown in Table 8. This is of course related to the higher stability of the economic system during crises, which allows for a better performance of the economy. This higher stability of the economy allows for an increased effectiveness of the credit sector, which is able to provide more credit to firms, as already shown in Fig. 2, and confirmed in Table 9. The countercyclical policies improve therefore both the credit provision and the equity of the banking sector (Table 9). As expected, looking at public finances in Table 4, we observe both in the FC+U and SGP+U cases an increase both in public debt and deficit over GDP and in the bond yield. However, over 25 years, public finances do not seem to be under strain, especially in the FC+U case, where deficit is around 3% of the GDP and debt is at 110%.

The next incremental policy step concerns the introduction of the quantitative easing mechanism. In the QE case, when the unemployment escape clause is activated, the central bank is allowed to buy government bonds in the secondary market. QE has a positive effect in keeping low the government bond yield, due to central bank’s demand for bonds, and in slightly improving public finances. The level of prices is scarcely affected, probably because QE is activated only during crises when the unemployment rate is high, wages do not raise, and firms have room to increase production by hiring new workers with little effect on wages and prices (Table 7). However, the QE monetary expansion does not help the economy in a substantial way. Both during crises and during the overall 25 years of simulation, all economic indicators get marginally worse. Both in case of FC and SGP with QE, bankruptcy probability and maximum unemployment rate raise during crisis periods, and the average 25 years GDP growth also declines with respect to the unemployment escape clause case.

The slightly poorer economic performance of quantitative easing improves substantially when coupled with a reduction of taxes during high unemployment periods. This scenario is represented in the tables by activating the fiscal accommodation option FA. The combination of QE and FA seems to give good results, especially in the case of an underlying fiscal compact scenario (FC). The average number of crises during the simulation time span drops consistently (below 1 in Table 5 and around 0.3 in Table 6, with both the underlying FC and SGP cases), as it does the average duration of the crisis, showing the minimum values both under FC and SGP. The long-run economic indicators are also very good in both cases, showing a low unemployment rate combined with a high GDP growth rate (Table 8). Government data show of course a drastic decrease in the overall tax rate, due to reduction of fiscal pressure during crisis periods, along with a deterioration of government finances. Comparing the two fiscal regimes of FC and SGP, the state of public accounts seems more sustainable in case of fiscal compact, where deficit is 4.27% of the GDP and debt is slightly higher that 120%. On the other hand, when the underlying SGP fiscal regime is adopted, public accounts reach a more critical level with debt over 160% and deficit close to 7% of the GDP.

5. Concluding remarks

This paper investigates the effects of different fiscal and monetary policy combinations by simulating an evolutionary agent-based economy. Particular attention is devoted to the study of the economy on the edge of a crisis, in order to understand the policy mixture that can be more helpful both in the short run, to overcome the crisis, and in the long run, to have a sustainable growth path and debt.

For this purpose we considered two base policies whose aim is to keep public budget under control (i.e., fiscal compact and stability and growth pact), integrating them with fiscal and monetary stimulus during recessions. Our results show that targeting debt or deficit over GDP ratios, irrespective of the existing economic conditions, leads to very poor outcomes and high instability. Expansionary fiscal policies during recessions are very helpful to reduce both the number and the duration of crises. Therefore we find that counter-cyclical fiscal policies, supported by adequate monetary policies, are recommended in order to enhance growth and stability. The rationale behind these results is the need to counterbalance credit driven business cycles which can lead to boom and bust dynamics if neglected. These results are in line with the Keynesian lesson, emphasizing the importance of government intervention during recessions to stimulate aggregate demand.

The policy recommendation, embedded in the current economic debate, is therefore to keep under control public and private debt during goods times, acting with counter-cyclical and macro-prudential policies (see also Teglio et al. (2012) about the key role of private debt regulation). This is the main way to prevent an excessive leverage with potential instability and bubbles. Besides, expansionary fiscal policy and monetary accommodation should be vigorously used during bad times in order to offset the loss in unemployment and aggregate demand. It's worth remarking that the duality of this policy is important because budgetary rigour during good times will help to avoid the explosion of public debt which could hurt the economy in the long run.

Finally, we would like to mention the model enrichments we are currently developing. First, the inclusion of a housing market with bail-in bail-out mechanism for defaulting banks. Second, the addition of more sophisticated and realistic financial instruments mimicking the securitization mechanism. Third, a multi-country environment with different institutional architectures.

Acknowledgments

The authors acknowledge EU-FP7 collaborative project SYMPHONY[11] under Grant No. 611875. Andrea Teglio also acknowledges project ECO2015-68469-R funded by the Spanish Ministry of Research.

Appendix A. The model

Eurace agents

In the appendix, we describe in details agents' decision making and interactions through different market settings. Agents' state variables are the balance sheet entries described in Table 1; in the following, we report the equations characterizing agents' behaviour and decision making. Agents' formation of expected values, wishes or plans about key economic variables are also reported and denoted with the superscript *e*, while wishes or plan are marked by an hat on the variable symbol. Tables A.10–A.14 include agents' parameters set for the simulations' initialization, used to produce the presented results.

Scheduling

The elementary simulation time step can be considered a calendar day; however, most agents' decisions and economic events occur at a weekly, monthly, or even yearly periodicity, and are asynchronous. For instance, trading of stocks and government bonds is active every day; consumption budget decisions are made monthly by households but purchases are made on weekly basis; firms' decision about production planning, new hirings, pricing, investments and financing are

[11] www.projectsymphony.eu.

Table A.10

Firm parameters		
Symbol	Name	Value
λ	Previous month production weight	0.5
γ	Total factor productivity	1.5
α	Output elasticities of labor	0.662
β	Output elasticities of capital	0.338
ξ_K	Capital goods constant monthly depreciation rate	0.005
ξ_w	Monthly wage percentage increase	0.01
μ_C	Fixed mark up	0.1
ξ_d	Fraction of net earnings paid as dividends	0.75
ω_π	Central bank inflation target weight	0.5

Table A.11

Bank parameters		
Symbol	Name	Value
ψ	Capital adequacy ratio	0.10
T_ℓ	Loan duration (months)	24
δ_ℓ	Monthly fraction of debt repayment	$1/T_\ell$

Table A.12

Household parameters		
Symbol	Name	Value
ξ_C	Adjustment speed of consumption	0.01
λ_C	Target ratio of liquid wealth to net income	70
π_H	Probability of financial asset portfolio allocation	0.1
δ_w	Constant rate of reservation wage decrease	0.01

Table A.13

Central bank parameters		
Symbol	Name	Value
r^*	Assumed real interest rate	0.02
$\hat{\pi}_C$	Inflation target	0.02
$\hat{\upsilon}_N$	Unemployment target	0.0
ω_π	Inflation weight	0.2
ω_υ	Unemployment weight	0.2

Table A.14

Government parameters		
Symbol	Name	Value
r_G	Fixed nominal yearly rate on bonds	0.02
δ_U	Fraction of last wage setting the unemployment benefit	0.7
δ_T	Fraction of the average wage level setting the transfer payment	0.5
δ_G	Fraction of public employees among household population	0.2

characterized by a monthly periodicity but are asynchronous, i.e., each firm makes its monthly production/investments decisions at a particular day, henceforth activation day, of the calendar month.[12]

Finally, decisions by policy makers can be taken on a monthly or yearly basis. In particular, the policy rate is set by the central bank at the beginning of each calendar month, at the same time the government sets the amount of bonds to issue during the month to address its liquidity needs; tax rates instead are usually adjusted on a yearly basis according to the predefined fiscal policy.

Consumption goods producers (firms)

[12] A calendar month is defined as a set of 20 days.

We provide below a sequential list of the key decision variables each consumption goods producer, henceforth firm f, plans or decides once a month, at its particular activation day:

- the expected demand of consumption goods $q^e_{C_f}$ it will face, based on a linear interpolation of past T_C monthly sales;
- the desired level of inventories $\hat{I}_f$ to meet expected demand $q^e_{C_f}$;
- the production needs $\overline{q}_{C_f}$ necessary to accumulate the desired level of inventories $\hat{I}_f$, i.e., $\overline{q}_{C_f} = \max[0, \hat{I}_f - I_f]$;
- the production plan $\hat{q}_{C_f}$ as a linear combination[13] of production needs $\overline{q}_{C_f}$ and previous month production q_{C_f}, i.e., $\hat{q}_{C_f} = (1-\lambda)\overline{q}_{C_f} + \lambda q_{C_f}$;
- the labor force $\hat{N}_f$ needed and the amount of physical capital $\hat{K}_f$ needed to meet the desired production plan, given the present endowment of capital goods K_f, the present number of employees N_f, and the Cobb-Douglas production technology, as follows:

$$\hat{N}_f = \left(\frac{\hat{q}_{C_f}}{\gamma (K_f)^\beta}\right)^{1/\alpha}; \tag{A.1}$$

$$\hat{K}_f = \left(\frac{\hat{q}_{C_f}}{\gamma (N_f)^\alpha}\right)^{1/\beta}; \tag{A.2}$$

where γ is the total factor productivity, while α and β are the output elasticities of labor and capital, respectively;
- the labor demand N^d_f given by the difference, if not negative, between the needed labor force $\hat{N}_f$ and the present number of employees N_f;
- the planned investment in new capital goods $\Delta\hat{K}_f$, which is bounded by the difference $\hat{K}_f - K_f$ and maximizes the present value of the foreseen additional revenues $p^e_{C_m} \Delta_m q_{C_f}$, originated by the investment at any next month m, after deducting the investment costs at the capital goods price p_K, as follows:

$$\Delta\hat{K}_f = \underset{\Delta\hat{K}_f \le (\hat{K}_f - K_f)}{\arg\max} \left(-p_K \Delta\hat{K}_f + \sum_m \frac{p^e_{C_m} \Delta_m q_{C_f}}{(1+\tau_C)\left(1+\frac{r_{K_f}}{12}\right)^m} \right); \tag{A.3}$$

where τ_C is the value added tax on consumption, $p^e_{C_m}$ is the expected price level at any future month m and $\Delta_m q_{C_f}$ is the additional output given by the planned investment. The latter two quantities are estimated as follows:

$$p^e_{C_m} = p_C \left(1 + \frac{\pi^e_C}{12}\right)^m; \tag{A.4}$$

$$\Delta_m q_{C_f} = \gamma N^\alpha_f (K_f + (1-\xi_K)^m \Delta\hat{K}_f)^\beta - \gamma N^\alpha_f K^\beta_f; \tag{A.5}$$

where π^e_C is the expected yearly inflation rate[14] and ξ_K is the capital goods constant monthly depreciation rate.[15] Finally, r_{K_f} is the yearly average cost of capital of firm f; for the sake of simplicity, this cost is estimated by averaging the cost of different loans. It is worth commenting the asymmetry in the way demand for capital and labour is determined. In particular, labour demand fully depends on the one-step forward expected demand of consumption goods, see Eq. (A.1); on the contrary, expected sales matter only to set the maximum bound for the desired capital endowment of the firm, given the present level of employment, see Eq. (A.1). Given this bound, investment demand is determined by the discounted long-term expected cash flows (see Eq. (A.3)) and takes into account the capital goods price as well as financing costs. This sort of asymmetry in input demand determination has been modeled to take into account the different way the two production inputs are usually managed by firms in reality, and accordingly in Eurace. In particular, labour can be considered as a flow variable for the firm, whereas physical capital is a stock variable and indeed is one of the balance sheet entries of the firm. In more practical terms, the firm is usually able to change its labour input quite easily; in particular, firms can fire employees at no cost and are able to hire new workers without particular difficulty considering the usual unemployment levels. On the contrary, capital goods when acquired by a firm become specialized to the firm itself and cannot be resold to other producers. In other terms, investment is irreversible and, even if in principle firms could not fully employ their plants (but this possibility is not considered in our model), the full cost of cumulated investments is still borne by firm's

[13] This provision is aimed to smooth the production plan over time and then reduce oscillations in input demand.

[14] Expected inflation π^e_C is estimated as a weighted average between the declared central bank inflation target $\hat{\pi}_{CB}$ and the present yearly realized inflation rate π_C, i.e., $\pi^e = \omega_\pi \hat{\pi}_{CB} + (1-\omega_\pi)\pi_C$, where the weight parameter ω_π can be considered as a sort of trust of private agents on the central bank policy action.

[15] Due to capital depreciation, the cash flows given by the additional revenues of investments decrease exponentially over time and therefore the sum of Eq. (A.3) is truncated when the addend is lower than a positive very small threshold.

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finances. These considerations are the rationale that supports setting labour demand, i.e. demand for a flexible input, based on short-term sales expectations, and setting capital goods demand, i.e. demand for irreversible investments, based on the cost opportunity of capital, yet with the limit determined by expected sales.

- the total liquidity needs $\hat{M}_f$ given by the foreseen cost of planned capital goods investments $p_K \Delta\hat{K}_f$, planned labor costs $w_f \hat{N}_f$, debt interests $\mathcal{I}_f$ and the installment $\delta_D D_f$ of debt repayment, taxes[16] $\mathcal{T}_f$ and the foreseen dividend payout $n_{E_f} d_f$, i.e.,

$$\hat{M}_f = p_K \Delta\hat{K}_f + w\hat{N}_f + \mathcal{I}_f + \delta_\ell D_f + \mathcal{T}_f + n_{E_f} d_f; \tag{A.6}$$

  where δ_ℓ is the monthly fraction of debt repayment[17] and, considering the yearly interest rate r_{f,b_i} paid by firm f on its ith debt of amount D_{f,b_i} to bank b, monthly debt interests payments are given by: $\mathcal{I}_f = \sum_{b,i} \frac{r_{f,b_i}}{12} D_{f,b_i}$;
- the amount of new loan $\hat{\ell}_f$ requested to the banking system, given by the difference, if not negative, between $\hat{M}_f$ and present liquidity M_f;
- if rationed in the credit market, i.e., the new loan ℓ_f received is lower than $\hat{\ell}_f$, the amount of new shares Δn_{E_f} to issue in the stock market, given by:

$$\Delta n_{E_f} = \frac{\hat{M}_f - \ell_f - M_f}{p_{E_f}}; \tag{A.7}$$

  where p_{E_f} is the present stock price;
- if rationed also in the stock market, the reduction of the costs under its control, in order to make the total financial needs consistent with the available liquidity. First, the total dividend payout is reduced up to zero, then, if still not sufficient, the investment plan is sized down and, eventually, the production plan as well.[18]

As soon as the decisions above are taken, the firm pays its financial commitments, namely, debt interests and debt installments, taxes on corporate earnings, the value added tax and dividends to shareholders. Then, in the same activation day, the firm enters factors (labor and capital goods) markets to fulfill its production and investment plans, also considering possible revisions downward due to rationing in the credit and stock markets. In particular, if the number of employees is higher than needed, the firm fires workers in excess, otherwise it starts the first labor market session to hire new additional employees. If the firm is unable to hire all the needed new employees, it increases its wage offer by a fixed percentage ξ_w and starts a second market session. If rationed again, it increases again its wage offer but exits the labor market ending up with a number of employees N_f lower than the planned one. Monthly wages are paid in advance at the end of the labor market sessions.[19] Then, the firm purchases the amount of new capital goods according to fulfill its investment plan. New capital goods are immediately delivered and summed up to the existing capital endowment. We assume that firms are never rationed in the capital goods market. Finally, firms execute the production process that, following the Cobb-Douglas technology, delivers immediately an amount of new consumption goods q_{C_f} given by the new levels of labor N_f and capital K_f, as follows:

$$q_{C_f} = \gamma N_f^\alpha K_f^\beta. \tag{A.8}$$

The new produced goods are summed to present inventories and made available for sale to households during the 20 business days following firms' activation days. Finally, the new sale price p_{C_f} is set based on a fixed mark-up μ_C on the overall unit costs c_{u_f}, i.e.,

$$p_{C_f} = (1 + \mu_C) c_{u_f}; \tag{A.9}$$

where overall unit costs are a weighted average of inventories' unit costs $c_{u_f}^{(I)}$ and new produced goods unit costs $c_{u_f}^{(q)}$, given by labor costs and the interest bill, as follows:

$$c_{u_f} = \frac{I_f\, c_{u_f}^{(I)} + q_{C_f} c_{u_f}^{(q)}}{I_f + q_{C_f}} \qquad c_{u_f}^{(q)} = \frac{w_f N_f + \mathcal{I}_f}{q_{C_f}}. \tag{A.10}$$

[16] $\mathcal{T}_f$ include taxes on corporate earnings and the value added tax (VAT) paid by consumers. VAT is collected by firms and transferred by them to the government.
[17] See Table A.11.
[18] If the available liquidity is not even sufficient to meet compulsory payments, i.e. debt service and taxes, then the firm enters a process called illiquidity bankruptcy, where it fires all its employees and stay inactive till it is able to raise the necessary funds in the stock market. It is worth remembering that the model foresees also a more severe case called insolvency bankruptcy, which is triggered whenever the equity of the firm becomes negative and therefore involves also a debt restructuring process with a consequent loan and equity write-off for lending banks.
[19] Further details about the Eurace labor market are provided in Dawid et al. (2014).

After twenty days, the day before a new activation day occurs, each firm calculates its monthly income statement along with monthly interests, taxes and net earnings; then computes the share of dividend payout as a fraction ξ_d of net earnings, if positive, and updates its balance sheet.[20]

Capital goods producer

There is just one type of technology for capital goods. Capital goods are produced on request and therefore do not generate inventories. Energy and raw materials are the only factor of production and are assumed to be imported from abroad. The price of capital goods is set according to a mark-up on input prices, which are exogenously given. Profits of investment good producers are distributed in equal shares among all households. Thus, the amount paid by consumption goods producers for investment goods is partially (the part related to mark-up) channelled back into the economy. In the experiments performed in this study, however, in order to separate the effects of the different fiscal policies from the exogenous dynamics of raw materials and energy, the price of these commodities has been conventionally set to zero, and the price of capital goods is set to a constant value. The model can therefore be considered as a closed economy where the revenues of the capital goods producer coincide with its profits and are fully channelled back into Eurace economy through dividends and tax payments.

Banks

Banks are always active on a daily basis being ready to receive loans requests from firms. As outlined in the previous paragraph, each firm sends a loan request at its activation day and firms' activation days are uniformly distributed over the calendar month. Whenever a bank receive a loan request $\hat{\ell}_f$ by a firm *f*, the request is evaluated and a loan eventually offered according to the following steps:

- the bank assesses the risk of the new loan; first, it estimates the default probability π_{D_f} of the prospective borrower, based on its leverage, along the lines of the Moody's KMV model (Saunders and Allen, 2010); then, it assesses the risk weight $\omega_{\hat{\ell}_f}$ of the new loan through an ad-hoc cubic function approximating[21] the so-called Basel II internal ratings approach, i.e.,

$$\pi_{D_f} = \frac{D_f + \hat{\ell}_f}{D_f + \hat{\ell}_f + E_f} \qquad \omega_{\hat{\ell}_f} = 2.5(\pi_{D_f})^3. \tag{A.11}$$

  The rationale is that the lower the capital base of the borrower with respect to its debt, the higher the likelihood of default is, and then the loan's risk, because of possible equity losses due to negative earnings;
- the bank *b* checks if its risk-weighted loan portfolio including the new prospective loan, weighted by its risk, still fulfils regulatory capital requirements, i.e. if the following condition holds:

$$E_b \geq \Psi \left(\sum_i \omega_{\ell_i} \ell_i + \omega_{\hat{\ell}_f} \hat{\ell}_f \right); \tag{A.12}$$

  where Ψ is the so called capital adequacy ratio, i.e. a policy parameter, ranging from 0 to 1, set by the regulatory provisions for the banking system;
- the bank *b* rejects the loan requests or otherwise it offers to firm *f* a loan amount $\ell_{b,f} \leq \hat{\ell}_f$ to the extent the capital requirement condition of Eq. (A.12) is satisfied; the new loan is offered for a duration of T_ℓ months at a yearly interest rate $r_{b,f}$ given by central bank rate plus a stochastic mark-up depending of the loan risk ω_{ℓ_f}.

The borrowing firm ranks the loan offers received according to their interest rates and accepts the loan offers with the lowest rates up to the amount of money requested.

At the end of any calendar month, each bank computes its income statement along with income taxes and net earnings, then decides the dividends payout, to be paid each first day of the calendar month, then updates its balance sheet. All net earnings, if positive, are paid out as dividends, unless the bank had to decline loan requests because of the capital adequacy ratio constraint. In this case, the bank retains all net earnings to increase its equity base.

Households

Households are always ready on a daily basis to make a financial trade and to look for a new job, if unemployed. In particular, at any daily simulation step, each household has a given exogenously probability π_H to change the allocation of its financial portfolio. In this case, the household forms beliefs about the expected returns of all financial assets (firms' shares and government bonds) according to a weighted average of fundamentalist, random and chartist prototype expected returns, then she/he computes the new "optimal" asset allocation according to a preference structure based on the myopic loss aversion hypothesis of prospect theory (Kahneman and Tversky, 1979; Benartzi and Thaler, 1995); finally, the household

[20] In particular, each firm updates the value of its net worth or equity. If the equity becomes negative the firm is declared insolvent and enters a special process termed insolvency bankruptcy, where the its fires all its employees, undergoes a restructuring of its debt with a related loan write-off and a corresponding equity loss on creditor banks' balance sheets, and stays inactive for a period of time after which it enters again the market with a healthy balance sheet. Physical capital of insolvent firms is therefore not lost but remains inactive for a while.

[21] According to the graphical representation reported in Yeh et al. (2005).

issues buy and sell orders to get the desired optimal allocation. Full details about households' financial beliefs and preference and the working of the financial market are provided in Raberto et al. (2008b), Teglio et al. (2009).

After financial market transactions are over, unemployed households enter the labor market to evaluate pending job offers. Here, households are randomly queued to apply to the set of available jobs characterized by the highest wages, provided that they are higher than their reservation wage.[22] If a household is not successful in getting a new job, her/his reservation wage is decreased by a constant rate δ_w and the household re-evaluates again pending job offers. If the job search is again unsuccessful, household's reservation wage is again decreased by the same rate δ_w and she/he leaves the labor market till next daily simulation step. Further details about the Eurace labor market are provided in Dawid et al. (2014).

Employed households receive their salary from their employers (the firms) on a monthly basis but at different days which coincide with firms' activation days, i.e. the dates when they have been hired. Salaries w_f are identical among the employees of the same firm f but differ across firms, according to the labor market outcome, because firms raise their wage offer whenever they are unable to find the needed employees. Households employed in the public sector receive from the government a public wage w_g, which is set equal to the average wage in the private sector in the last 12 months. Unemployed households receive on a monthly basis an unemployment benefit[23] from the government; the benefit is paid the same day of the month the household is fired. The day of the month a households receive the salary or the unemployment benefit, it gets also a transfer payment[24] y_{T_h} from the government and computes and pays taxes on both the labor income y_{L_h} (the salary or the unemployment benefit) and the capital income, given by the stocks' dividends y_{E_h} and bonds' coupons y_{B_h} received during the previous 20 days. The same day the household receives its labor/unemployment benefit income, it also determines its monthly consumption budget $\mathcal{C}_h$, which is modelled according to the theory of buffer-stock saving behavior (Carroll, 2001; Deaton, 1992), stating that households consume more or less than their net income with the aim to get a target ratio λ_C of liquid wealth[25] W_h to total net income $y_{h,\text{net}}$. In particular, being the total net income $y_{h,\text{net}}$ given by:

$$y_{h,\text{net}} = (1-\tau_N)y_{L_h} + (1-\tau_K)(y_{E_h} + y_{B_h}), \tag{A.13}$$

where τ_N and τ_K are the tax rates on labor and capital income, respectively, the monthly consumption budget $\mathcal{C}_h$ is determined by:

$$\mathcal{C}_h = y_{h,\text{net}} + \xi_C(W_f - \lambda_C y_{h,\text{net}}), \tag{A.14}$$

where ξ_C gives the speed of adjustment of consumption to meet the desired wealth to income target ratio. Therefore, households consume more (less) than their net income if their liquid wealth if higher (lower) than a multiple λ_C of their net income.

In particular, households' decision about the product to buy is driven by purchasing probabilities based on the values they attach to the different choices. Choice probabilities depend only on prices, as consumption goods are homogenous and therefore no quality differences is considered. Then, based on goods' prices, households use a logit model and calculate the purchasing probability, which is higher if the price is lower. Once the household has selected a good, he spends his entire weekly budget for that good. If the desired quantity is not fully available he spends as much as possible on that good, then selecting another one. If he is rationed again, he transfers the remaining budget to the following week.

Central bank

The central bank is in charge of monetary policy, which consists of two main tasks: to provide liquidity in infinite supply to banks, whenever they need it, and to set the monthly policy rate r_{CB}, which is the cost banks pay when borrowing liquidity. In particular, at the beginning of each month, the central bank collects the information about the latest values of inflation and unemployment in the Eurace economy and sets the policy rate r_{CB} for the incoming month as follows:

$$r_{CB} = \pi_C + r^* + \omega_\pi(\pi_C - \hat{\pi}_C) + \omega_\upsilon(\hat{\upsilon}_N - \upsilon_N), \tag{A.15}$$

where π_C is the last realized value of the inflation rate, measured in a yearly moving window, r^* is the assumed real interest rate, $\hat{\pi}_C$ is the inflation target, $\hat{\upsilon}_N$ is the unemployment target, and υ_N is the previous month unemployment rate.

It is worth noting that Eq. (A.15) resembles the well known Taylor rule (Taylor, 1993), but departs from the standard one for including a sort of unemployment gap, i.e., $(\hat{\upsilon}_N - \upsilon_N)$, instead of the usual output gap. The reason of this choice is practical as it is not obvious, in particular in an agent-based model, how the output gap could be measured. However, the two measures are clearly strongly interconnected and the unemployment gap used in Eq. (A.15) is certainly a satisfactory indicator of economic recession.

Government

The government is in charge of both fiscal and welfare policies. The revenues of the government come from taxes that are applied to four sources: corporate earnings, consumption, capital income (dividends and bond coupons) and labour income (wages and unemployment benefits). Taxes are collected on a monthly basis, while the four related tax rates are usually revised yearly, depending on the particular fiscal policy adopted, as outline in Section 3.

[22] The reservation wage is set equal to the last received wage and is therefore heterogeneous among households.
[23] The unemployment benefit is set at a fraction δ_U of the last salary received by the households.
[24] The transfer payment is set to a fraction δ_T of the average wage paid by firms.
[25] The liquid wealth is given by liquidity plus the market value of the stocks and government bonds portfolio.

Governments expenditures include the labor cost of public sector employees,[26] unemployment benefits, transfers and government bond coupons.

On a monthly basis, if in short of liquidity, the government decides to issues new bonds, which are directly sold in the bond market at a discounted price with respect to the market price p_G, and then purchased by households.

Government bonds are perpetuities that pay a monthly fixed coupon that depends on the bond nominal value $\hat{p}_G$ and the fixed nominal yearly interest rate r_G. Government bond market price depends on households' trading behavior, which, like in the stock market case, is characterized by a mix of chartists, random and fundamentalist typical patterns. In particular, in the case of bonds, the fundamental price is determined by discounting the supposedly risk-free future bond coupons with the central bank policy rate.

Appendix B. Validation

Initialization and input validation

The initialization of the Eurace model complies with two main requirements: stock-flow consistency and input validation.

The dynamic stock-flow consistency of agents' balance sheets is a crucial feature of the Eurace model, and at time zero all the balance sheets should be accurately initialized in a consistent way. In addition, the initialization phase allows us to provide the model with parameters and initial values gathered from the literature or from empirical evidence. In particular we initialize the model with correct economic ratios, derived from real world data.

In order to achieve these objectives we developed a specific software that is able to carry out the initialization automatically. We define in this software all the cross-relations between the balance sheet items of the economic agents and we control for the consistency of the process. We start the initialization by setting at 1 the initial value of the nominal monthly wage, and we use it as a reference for all other variables. For example, from household's wage we derive its total initial wealth, according to standard wealth-to-income ratios. Then we allocate households' wealth among liquidity, bank deposits and financial assets (stocks and bonds), again according to realistic economic ratios. On the other side, households deposits provide the value of banks liabilities, allowing us to correctly initialize the other items of bank's balance sheets. The same happens with the equity of the firms, derived by households shares, which allow us to initialize firms balance sheets, including their capital stock, which in turn can be used to initialize loans on banks asset side. This dynamic initialization process allows us to have a consistent model at the beginning of the simulation, where initial conditions have been chosen in order to keep realistic proportions among the different items of agents' balance sheets, and to correctly size stocks and flows dimensions. It is worth noting that agents' balance sheets elements are highly interconnected, and that a correct process drastically reduces the degrees of freedom of the whole initialization procedure.

Concerning some examples of the economic ratios for initialization, the debt-to-equity ratio of firms is initialized at 2, which is a realistic value for industrial companies. Risk (weighted) assets to equity ratio for banks is set to 5. The wealth-to-income ratio for households is set around 70, with 30% of households financial wealth allocated into banks deposits, and the remaining 70% into financial assets. The initial value of public debt is set to a value that, assuming a 10% unemployment rate and the initial productive capacity of firms, would set the debt-to-GDP ratio around to 100%, which is in line with the Eurozone.

This approach is actually part of an ex-ante validation method, called "input validation" (Cirillo and Gallegati, 2012), where model's fitness is ensured by setting parameter values and variables ratios according to empirical analysis of actual data. The other pillar of input validation consists in designing realistic behavioral and institutional features, as we have shown in the previous appendix. Therefore, we do not use any indirect calibration, according to Windrum et al. (2007), but we adopt a hyper-realistic approach by trying to feed the model ex-ante with empirical parameter values.

Empirical validation

In this section, we analyze the outcomes of the model in order to check if they match some relevant macroeconomic stylized facts.

The tables presented in the paper show that the magnitude of the endogenously generated economic indicators are quite realistic. In Table 4 we find that values of debt/gdp for the different policy cases range from 99% to 160%, levels of deficit/gdp range from 1% to 7%, and level of bond yields from 8% to 14%. These numerical values of highly aggregated and entirely endogenous indicators are surprisingly accurate, and should be interpreted as symptom of the fitness of the model. We should also cite the unemployment rate that in general ranges from 3.99% to 5.57% (Table 8), reaching peaks that range from 29% to 40% during crises (Table 6). In general, the outcomes of the model are realistic and this is not inferable by the micro specification of the model, because it is the result of a complex process of interaction.

We also present a brief analysis of some main stylized facts that can be found for instance in Uribe and Schmitt-Grohe (2017), Watson and Stock (1999), Napoletano et al. (2006). Fig. B.12 and Table B.15 show that the model matches the standard facts about volatility of investments and consumption. We use here the relative standard deviation (RSD) as a measure of volatility. Table B.16 shows the correlation structure of the real GDP. We observe that GDP is positively correlated with investments and consumption, and it is anti-correlated with the unemployment rate. GDP also shows a positive correlation

[26] The number of public employees is set at a fixed percentage δ_G of the total household population.

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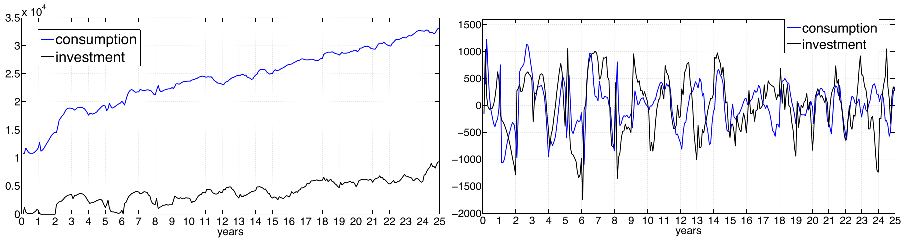

Fig. B.12. Average level of consumption and investment (left panel) and hp filtered series of consumption and investment (right panel) across 50 seeds.

Table B.15
Means and relative standard deviation (RSD) of yearly level of real GDP, consumption and investment, computed over 50 seeds; Standard error in parenthesis. Average growth rates of real GDP, consumption and investment across 50 seeds, with standard deviation, standard error (SE) and relative standard deviation (RSD).

Series	Levels		Growth rates			
	Mean	RSD	Mean	St. deviation	SE	RSD
GDP	$3.4693e^{+04}$ (171.86)	0.3557 (0.0027)	0.0485	0.0060	0.0008	0.1237
Consumption	$2.4105e^{+04}$ (84.87)	0.2449 (0.0024)	0.0426	0.0035	0.0005	0.0824
Investment	$3.8289e^{+03}$ (75.71)	0.9956 (0.0056)	0.0994	0.0565	0.0080	0.5684

Table B.16
Cross-correlation of hp filtered series vs real GDP. Standard errors of Monte Carlo simulations in parentheses.

Filtered series	$t-4$	$t-3$	$t-2$	$t-1$	t	$t+1$	$t+2$	$t+3$	$t+4$
GDP	0.1308	0.3382	0.5685	0.7989	1.0000	0.7989	0.5685	0.3382	0.1308
	(0.0148)	(0.0130)	(0.0099)	(0.0070)	(0.0000)	(0.0070)	(0.0099)	(0.0130)	(0.0148)
Consumption	0.1906	0.3391	0.5178	0.6806	0.6480	0.4524	0.2428	0.0527	−0.1134
	(0.0180)	(0.0167)	(0.0163)	(0.0158)	(0.0172)	(0.0179)	(0.0144)	(0.0107)	(0.0121)
Investment	0.0564	0.2327	0.4210	0.6216	0.8934	0.7480	0.5782	0.4013	0.2406
	(0.0148)	(0.0149)	(0.0144)	(0.0135)	(0.0096)	(0.0119)	(0.0129)	(0.0135)	(0.0127)
Loans	0.6187	0.5816	0.4956	0.3564	0.1500	−0.0891	−0.2876	−0.4404	−0.5462
	(0.0109)	(0.0107)	(0.0107)	(0.0105)	(0.0100)	(0.0104)	(0.0106)	(0.0103)	(0.0098)
Unemployment	−0.1628	−0.2016	−0.2292	−0.2422	−0.2344	−0.1829	−0.1085	−0.0334	0.0341
	(0.0107)	(0.0115)	(0.0131)	(0.0151)	(0.0166)	(0.0155)	(0.0116)	(0.0077)	(0.0069)
Bankruptcies	0.0997	0.1003	0.1040	0.0730	−0.0726	−0.1566	−0.1708	−0.1739	−0.1594
	(0.0122)	(0.0121)	(0.0120)	(0.0104)	(0.0124)	(0.0182)	(0.0219)	(0.0220)	(0.0193)

Table B.17
Cross-correlation of the main financial variables. Standard errors of Monte Carlo simulations in parentheses.

Filtered series	$t-4$	$t-3$	$t-2$	$t-1$	t	$t+1$	$t+2$	$t+3$	$t+4$
Stock vs	−0.2341	−0.2753	−0.2739	−0.2305	−0.1701	−0.1077	−0.0569	−0.0245	−0.0046
Bond price	(0.0180)	(0.0184)	(0.0226)	(0.0293)	(0.0364)	(0.0409)	(0.0417)	(0.0393)	(0.0346)
cb rate vs	0.2303	0.2159	0.1897	0.1528	0.1031	0.0378	−0.0145	−0.0526	−0.0764
Bond yield	(0.0109)	(0.0108)	(0.0102)	(0.0093)	(0.0080)	(0.0069)	(0.0067)	(0.0072)	(0.0080)
Stock returns vs	0.1152	0.0949	0.0680	0.0381	0.0214	0.0169	0.0174	0.0219	0.0246
GDP gr. rate	(0.0158)	(0.0166)	(0.0171)	(0.0174)	(0.0170)	(0.0159)	(0.0143)	(0.0128)	(0.0117)
Gov. debt vs	0.5880	0.5907	0.5938	0.5974	0.6013	0.5921	0.5825	0.5727	0.5623
Bond yield	(0.0340)	(0.0348)	(0.0357)	(0.0366)	(0.0375)	(0.0375)	(0.0375)	(0.0376)	(0.0376)

with loans to firms, which are leading the business cycle expansion, while it shows an anti-correlation with firms' defaults, which are following a cycle contraction. This results are in line with stylized facts on the credit cycle (see for instance Cappiello et al. (2010)).

We also show some facts related to the financial variables of the model in Table B.17. The central bank policy rate is positively correlated with the bond yield, leading its variations. Stock prices are anti-correlated with bond prices, and a fall of the stock price index seems to lead an increase in the bond price.

As expected, bond yields are also correlated with government debt, as new bond issuing in general decreases bonds' price. Results also show a weak correlation between GDP growth rate and stock returns, where stock returns tend to anticipate GDP growth (although the relation between economic growth and equity returns is not easy to disentangle; see for instance Ritter (2005)).

Finally, Fig. B.13 shows the most relevant cross-correlations included in the tables.

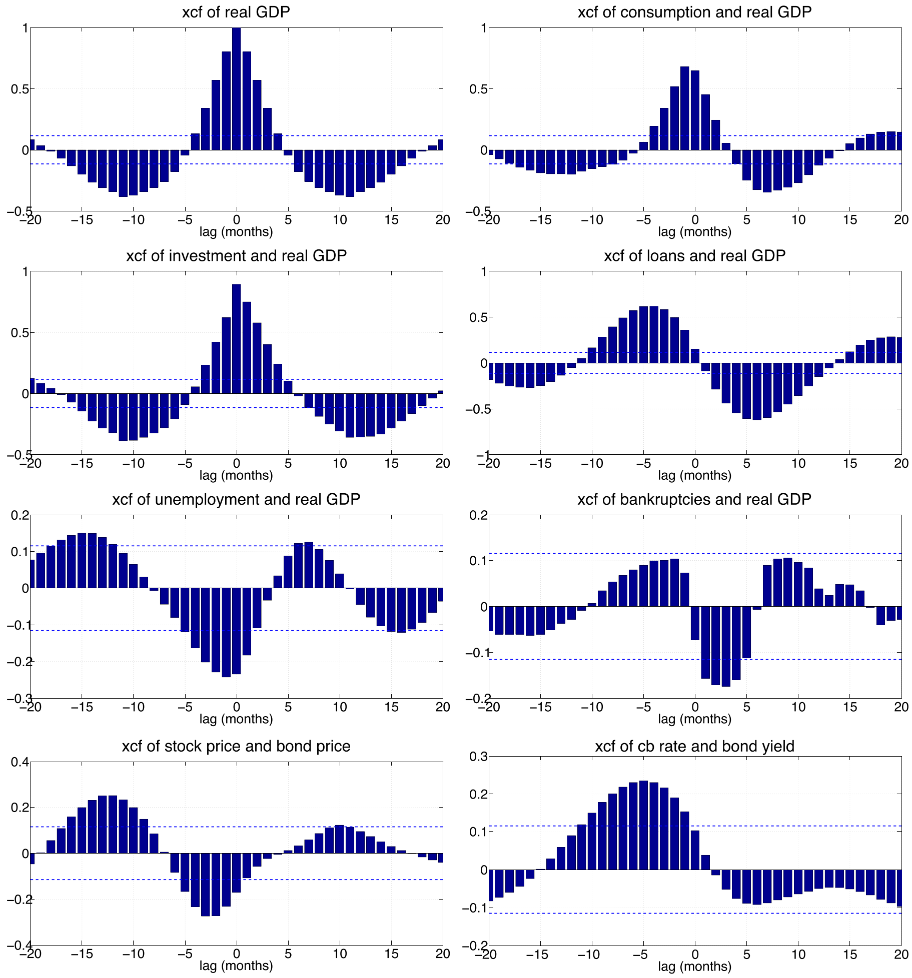

Fig. B.13. Cross-correlations. Time series considered are monthly and hp filtered.

Table B.18
Tax multiplier means. Standard errors of Monte Carlo simulations in parentheses.

Policy	Tax multiplier			
	3 months	6 months	9 months	12 months
SGP	−1.38 (0.02)	−1.54 (0.03)	−0.52 (0.02)	0.04 (0.03)
SGP + U + QE + FA	−1.87 (0.08)	−2.78 (0.12)	−2.11 (0.15)	−1.69 (0.14)
SGP + U + QE + FA (recessions)	−3.26 (0.20)	−5.36 (0.26)	−3.87 (0.30)	−2.72 (0.28)

Computing fiscal multipliers

We compute a tax multiplier and a public transfers multiplier. The tax multiplier is computed analyzing the time series produced by the main experiment of the paper. We observe the percentage variation in the tax rate (in general, and during crises) and we compute the related variation in GDP growth in the subsequent four quarters. The transfers multiplier is computed by running a new experiment, where we consider positive and negative shocks to the public transfers (one every two years) and we compute the related variation in the GDP in the subsequent six quarters.

Tax multipliers shown in Table B.18 represent an ensemble average of 50 different seeds. The time series of GDP and taxes include the last fifteen years of simulation, from year 9 to year 24. For this analysis, two policy scenarios are included, i.e. *SGP* and *SGP + U + QE + FA*. In *SGP* scenario, tax rates are only revised every first day of the year. Therefore, we have determined the fiscal multiplier by considering the yearly changes in tax rate (when it occurs) and the following growth rates of the detrended GDP monthly series. However, in *SGP + U + QE + FA* scenario, tax rates are revised both with a fixed yearly frequency and during recessions. Hence, in the computation of the tax multiplier for the *SGP + U + QE + FA* scenario, we take into account all the tax rate changes. Moreover, we have also computed the tax multiplier related only to the tax rate changes occurring during recessions.

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Table B.19
Transfers multiplier means. Standard errors of Monte Carlo simulations in parentheses.

Shock	Transfers multiplier computed using levels					
	3 months	6 months	9 months	12 months	15 months	18 months
Positive	1.39 (0.06)	1.10 (0.03)	0.80 (0.01)	0.50 (0.02)	0.44 (0.01)	0.39 (0.01)
Negative	0.32 (0.08)	0.32 (0.05)	0.25 (0.03)	0.12 (0.02)	0.03 (0.02)	0.03 (0.16)

The multiplier values are negative, unveiling and inverse relation between taxation and GDP. Furthermore, in the $SGP+U+QE+FA$ scenario, the multiplier is lower, showing that effects of tax rate changes during recession are stronger than in the baseline scenario. It is interesting to notice that the effect of the tax reduction is higher in the first six months and then decreases to close-to-zero value in the case of the Stability and Growth Pact policy. We see a similar declining pattern in the case of active fiscal policy during recessions, but the multiplier seems more persistent, indicating an higher utility of these policies during crises.

In order to calculate the public transfers multiplier, we run a new set of simulations characterized by exogenous shocks on the transfers. In the model, public transfers are computed yearly as a fixed fraction of the average wage and paid monthly to households. We set six biennials exogenous shocks, half of them being positive and half negative. The intensity of the shocks is given by a percent change of the fixed fraction used to compute transfers. The public transfers multiplier is then calculated whenever a shock occurs and it is given by the ratio of the changes in the GDP levels over the change of public transfers levels. Table B.19 shows the averages of transfer multipliers, classified into positive and negative shocks.

The value of the transfers multiplier is positive, suggesting that positive (negative) shocks to the public transfers result in a change of GDP levels of the same sign. The sign and values of multiplier is in line with the existing literature. Batini et al. (2014) provide a survey on the literature on fiscal multipliers, both from theoretical and empirical perspective. Generally, fiscal multipliers have values between 0 and 1, but they can also exceed 1 in different cases. Moreover, the table shows that the effects of transfers is higher in case of positive shocks rather than negative ones. This could be due also to the positive GDP growth trend in our artificial economies. We can notice, again, that the value of the multiplier is declining with time.

Although there is little consensus in the literature on the size of the multipliers and on the methodology to compute them, our results fit with the majority of empirical and modeling works' finding. For instance, Riera-Crichton et al. (2016) show that value of tax rate multiplier is negative, with a value between 0.66 and 3.69, depending on the horizons considered. Several studies agree on the state-dependence of fiscal multipliers, see e.g. Auerbach and Gorodnichenko (2012) for empirical results. Napoletano et al. (2015) design an agent-based model in order to study the fiscal multiplier evolution over the business cycle, finding that the size of the multiplier is time-varying and it is determined by the persistence of credit rationing in the economy. These findings are in line with our experiments, as shown in Tables B.18 and B.19.

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