Review of Evolutionary Political Economy (2022) 3:73–107
https://doi.org/10.1007/s43253-022-00065-8

ORIGINAL PAPER

Unconventional monetary policies in an agent-based model with mark-to-market standards

Mattia Guerini[1,2,3] · Francesco Lamperti[3,4,5] · Mauro Napoletano[2,3,6,7] · Andrea Roventini[3,4,6] · Tania Treibich[3,6,8]

Received: 28 June 2021 / Accepted: 30 December 2021 / Published online: 30 March 2022

Abstract

We employ an agent-based model to shed light on the macroeconomic effects of accounting principles, unconventional monetary policies, and of their possible interactions. If mark-to-market accounting standards may entail positive feedbacks which amplify economic or financial shocks, unconventional policies may introduce negative feedbacks that might dampen instabilities in financial and real markets. For these reasons, we jointly study these two sets of policies by employing a modified version of the Schumpeter meeting Keynes (K+S) macroeconomic agent-based model. Our results confirm that, due to its pro-cyclical nature, the mark-to-market accounting standard amplifies credit cycles, generating more instability with respect to a simulated economy wherein the historical accounting principle is employed. In contrast, unconventional monetary policy is counter-cyclical and it improves macroeconomic indicators. Finally, we study a scenario wherein mark-to-market accounting and unconventional monetary policy interact. We find that unconventional monetary policy can counterbalance the negative effects brought about by the application of mark-to-market accounting. Our results suggest that unconventional monetary policy instruments should not be considered as temporary interventions to be employed

✉ Mauro Napoletano
mauro.napoletano@univ-cotedazur.fr

1 Department of Economics and Management, University of Brescia, Brescia, Italy

2 GREDEG, CNRS, Université Côte d'Azur, Nice, France

3 Institute of Economics, Scuola Superiore Sant'Anna, Pisa, Italy

4 EMbeDS, Scuola Superiore Sant'Anna, Pisa, Italy

5 RFF-CMCC European Institute on Economics and the Environment, Milan, Italy

6 OFCE, Sciences Po, Paris, France

7 SKEMA Business School, Lille, France

8 School of Business and Economics, Maastricht University, Maastricht, Netherlands

only during crisis periods. They should be part of the toolbox of central banks also in normal times.

Keywords Unconventional monetary policy · Accounting principles · Mark-to-market · Agent-based models

JEL Classification C63 · E58 · G01 · G18

1 Introduction

The evaluation of accounting policies has attracted much less attention in the macroeconomic literature with respect to the one of fiscal and monetary policies. However, in the past, accounting standards have been changed by policymakers with the exact purpose to respond to changes in macroeconomic conditions and financial markets practices. Indeed, accounting policies play a relevant role in macro-financial stabilization as they impact on the size and the structure of the balance sheets of all economic agents (see Bignon et al. 2009).

Before the *Great Depression* and until 1934, private financial and non-financial corporations had a large degree of flexibility when reporting the value of their assets in the official end-of-year statements. This often led to easy and fictitious revaluation of the assets held by firms and banks, making it more difficult for the regulator to identify companies with high insolvency risk. To set a limit to such manipulations, in the early 1940s, *historical value accounting* became the standard.[1] By making the revaluation of assets impossible, the historical value principle also imposed huge constraints on firms.

The evolution of financial markets led to the production of new instruments for which the historical accounting principle seemed to be inappropriate. In particular, the creation of derivative contracts and other complex financial instruments induced the SEC to reconsider the usage of historical value accounting. The risk was that the historical value could have provided a biased measure of the assets' values in derivative contracts. On these grounds, the SEC allowed then financial corporations to adopt the *mark-to-market principle* — also known as *fair value principle* — for the evaluation of futures and other foreign exchange contracts. During the 1980s, the mark-to-market principle was also extended to debt and equity contracts, but only for the banking sector. As these processes continued, by the early 1990s, the mark-to-market accounting replaced historical value accounting as the new standard. As a matter of fact, the Financial Accounting Standards Board (FASB henceforth), which establishes standards in the USA and is recognized globally via the International Accounting Standards Board (IASB) required "all entities to disclose the fair value of financial instruments, both assets and liabilities recognized and not recognized in

[1] The Securities and Exchange Commission (SEC henceforth) forbade the revaluation of assets held in the balance sheets already in 1934. For a complete historical narrative of the accounting principles used in the USA, see SEC (2008).

the statement of financial position, for which it is practicable to estimate fair value" (see FASB 1991).

After the 2007 financial crisis, the mark-to-market principle has been put under serious investigation: the US Congress adopted the Paulson plan in 2008 giving the SEC the power to suspend the application of fair value for public interest or investors' protection reasons. Then in 2009, the European Commission put pressure on the IASB to review the fair value accounting of financial instruments, allowing them to be reclassified using historical cost accounting (see Botzem and Quack 2009). This occurred as there was mounting evidence suggesting that mark-to-market accounting principles might play an important role in the amplification of financial shocks (see Colasse 2010). During the 2008 financial crisis, the values of securities connected to housing markets rapidly fell, leading to a large and rapid devaluation of banks' assets. The adoption of the fair value accounting standard amplified this drop, strongly influencing the ability of many commercial banks to perform their primary lending activity during the crisis. As documented by Heaton et al. (2010), Bhat et al. (2011), and Kolasinski (2011), such a fair value amplification channel had important real consequences as it limited the liquidity in credit and interbank markets. At the time, the recognition of the pro-cyclical effects of accounting standards fueled a debate over potential reforms to avoid similar downturns in the future (Lester and Kothari 2012). Yet, more than a decade later, the mark-to-market accounting principle remains the main evaluation method for financial assets.

Concerning monetary policy, the common wisdom was challenged during the Great Recession when the short-term nominal interest rates hit the zero lower bound (ZLB henceforth) in several countries. Central banks immediately reacted by purchasing toxic assets and eligible non-performing securities directly from the banks or in secondary financial markets, providing financial institutions with a substantial amount of liquidity. Building on these first reactions, all major central banks have designed and introduced a set of policies with the aim of taming the positive feedbacks existing in financial markets: unconventional monetary policies. The main characteristic of such unconventional monetary policies is to target components of the banks' balance sheets. They include lending of last resort operations, large asset purchase agreements, and non-standard supplies of funds.[2] This last set of measures is relatively novel and has been introduced in the central banking toolbox only during the Great Recession.[3] Their major aim is that of dampening the volatility of the components of balance sheets of the banking sector and, therefore, to ensure the flowing of credit from the banking industry to the productive sectors. After the 2008 financial crisis, the European sovereign debt crisis and the COVID-19 recession, it appears that such instruments, designed to be unconventional and methods of last resort, are starting to become conventional ones instead (see Borio and Zabai 2016; Quint and Rabanal 2017). Yet, after more than a decade of use, their effects are far

[2] Among the balance sheet policies, Borio and Zabai (2016) recognize also the possibility of an intervention of the Central Bank onto foreign exchange markets to affect the exchange rate, but this tool is not discussed here.

[3] Note that unconventional monetary policies, of course, have not been introduced only as a corrective response to the positive feedbacks entailed by the mark-to-market accounting policies.

from been fully understood and economic research is in continuous update in this respect (see Kuttner 2018; Rossi 2021; De Santis and Zaghini 2021; Demiralp et al. 2021). What we know is that unconventional monetary policies allowed to stabilize and lower market yields (Krishnamurthy and Vissing-Jorgensen 2011; Duca 2013), to reignite a freezing credit market (Rodnyansky and Darmouni 2017), and to dampen the downward phase of the credit cycle (Bhattarai and Neely 2016).[4]

In this paper, we investigate the interactions between accounting principles and unconventional policies. If the mark-to-market accounting standards may entail positive feedbacks that amplify economic or financial shocks, unconventional monetary policies have been designed to bring about negative feedbacks that might dampen the propagation of shocks. Understanding which of the two effects dominate is of crucial importance in order to shed light of the sources of stability or instability in advanced economies, also in light of the fact that both policies will stay in place in the years to come.

We study our research question extending the well-established Schumpeter meeting Keynes (K+S) macroeconomic agent-based model (see Dosi et al. 2010; Dosi et al. 2013; Dosi et al. 2015) to analyze the transmission mechanisms of mark-to-market accounting for bank assets and lender of last resort policies, as well as their aggregate macroeconomic effects. We find that the fair value accounting standard magnifies credit cycles leading to higher macroeconomic instability. At the opposite, unconventional monetary policies are counter-cyclical and they improve the macroeconomic performance. Finally, when both policies are in place, simulation results show that unconventional monetary tools can counterbalance the negative effects of mark-to-market accounting standards. Overall, our findings suggest that unconventional monetary policy instruments should permanently stay in the toolbox of central banks.

The rest of the paper is organized as follows. Section 2 reviews the empirical and theoretical literature on accounting policies, as well as the literature analyzing the effects of unconventional monetary policies. Section 3 presents the main equations of the model and discusses the novelties with respect to the previous versions of the K+S model. In Section 4, we perform the policy evaluation exercise and present the main results of our analysis. Section 5 concludes.

2 Literature review

In this section, we present the recent empirical and theoretical evidence concerning the effects of accounting and unconventional monetary policies (UMP). Most studies on accounting policies are of qualitative or empirical nature, while the literature on UMP has mostly focused either on case studies or on general equilibrium models.

[4] See also Guerini et al. (2018) for a discussion on the heterogeneous effects of quantitative easing (QE) in the USA and in Europe because of how they combine with other policies, especially fiscal ones.

2.1 Accounting policies

As discussed in the introduction, the adoption of different accounting principles has evolved slowly in the last century, from a purely historical cost-based approach toward an approach on the fair value principle. Indeed, it is only in the 1970s that the mark-to-market accounting practice has begun to be adopted by banks and financial institutions, and it has become dominant since the 1990s (see FASB 1991).

The motivations underlying such a transition can be found in economic theory and in particular, in the efficient market hypothesis (EMH) by Fama (1970). According to the EMH, the market price is the best measure of the fundamental economic value of any asset, because it correctly aggregates all the private information. Hence, if the EMH holds true, there is a strong justification for a regulator to impose banks and financial institution to report the mark-to-market values of all the assets they are holding in their portfolios. This would indeed provide a more precise economic evaluation of the controlled institution, which can in turn be better regulated (see Heaton et al. 2010). Though still dominant, the EMH has been challenged by theoretical as well as empirical arguments (see Shiller 2003; Lo 2004, 2017, for a review).

The fair value principle has also shortcomings, which have been highlighted by the empirical literature using quantitative data or case studies (see Landsman 2006). First of all, it is difficult to estimate a fair value for all the securities whose markets are illiquid and for which traded volumes are relatively low. Second, if the market price is a bad proxy of the underlying fundamental economic value — i.e., in all the occasions where the EMH does not hold true — the regulators might take biased regulatory decisions. Third, the mark-to-market suffers some implementation issues, as it involves large accounting discretion and possibility of manipulation compared to historical cost-based practices (see Landsman 2006). Finally, the real effects of the mark-to-market usage might also be heterogeneous due to different regulatory and institutional arrangements (see La Porta et al. 1998).

The empirical literature has also investigated whether the fair value might provide some useful information to investors. Barth (1994) shows that the correlation between the reported fair value and the share price has increased over time implying that — under the assumption that prices reflect fundamental values — the fair value measurement error has been decreasing. Barth et al. (1995) confirm the previous evidence but find additionally that fair value evaluations are much more volatile than historical cost-based measures and that the incremental volatility is not reflected in the share price volatility. In general, the evidence from the 1980 to 1990 period finds that the fair value has improved its performance as an accurate measure of economic fundamentals over time. However, in that period, markets were fairly liquid and no large financial crisis was observed. In a more recent work, Bhat et al. (2011) show that mark-to-market might be uninformative when markets are illiquid and when there are periods of distress.

Furthermore, Bignon et al. (2009) claim that mark-to-market-based accounting generates fundamental problems because of the complementarity of assets, which possibly generates increasing returns and forces internal accountants to select a specific valuation model when determining the assets' value. However, different valuation models might generate large differences in the final price of the assets (defined as the *reliability problem*). Moreover, the existence of excessive financial market volatility (i.e., with the failure of the EMH) creates additional valuation risks and possibly reduces the capacity of investments (defined as the *financial volatility problem*). Finally, Boyer (2007) confirms that, by mixing present profit with unrealized capital gains and losses, mark-to-market accounting generates discrepancies between the creation value and the liquidation value of assets. All in all, according to Boyer (2007), the fair value introduces an accounting accelerator on top of the typical financial accelerator already at work in credit markets (see, e.g., Bernanke et al. 1994).

2.2 Unconventional monetary policies

Identifying causal relations for unconventional monetary policies (UMPs) by means of the commonly used time-series approaches is an extremely difficult task. Most of these "policy shocks" occurred in the same period and they typically have been endogenous replies to the global financial crisis more than exogenous marginal changes. Notwithstanding this inner difficulty, most of the research investigating the effects of unconventional monetary measures has been carried out via empirical exercises (see Bhattarai and Neely 2016). To cope with the abovementioned intrinsic difficulties, research in this domain has generally performed event studies, therefore focusing on a specific central bank announcement or intervention. These studies have typically employed short-term and high-frequency datasets with the aim of evaluating the effects of the policy under investigation on the domestic short- and long-term yields. Using this approach, Krishnamurthy and Vissing-Jorgensen (2011), Gagnon et al. (2011), Christensen and Rudebusch (2012), and Duca (2013) provide converging evidence validating the hypothesis that large asset purchase programs have reduced long-term interest rates, preventing high liquidity premiums from depressing financial institutions and financial markets. Swanson (2017) instead compares the effects brought about respectively by forward guidance and large-scale asset purchases in the ZLB period, i.e., 2009–2015. This work finds that while the forward guidance is more effective in the short run, large-scale asset purchases are a more preferable instrument for the control of medium-/long-term yields and for reducing interest rate uncertainty. In a different fashion, the work by Altavilla and Giannone (2017) employs a survey of individual professional forecasters to evaluate the effects of announcements of the purchase of government bonds by the Central Bank on the expectations of domestic returns. The study shows that the announcement of accommodative monetary policies significantly dropped the expectations on bonds' yields for at least 1 year. Different in spirit is also the work by Gorodnichenko and Ray (2017), which focuses on the identification of the transmission mechanisms of unconventional monetary policies. They show that such policies affect market segmentation and they are effective policy tools to modify the interest rate structure and to create interest rate differentials between asset classes during crises periods. The authors also argue that UMP might be less effective in normal times.[5] All in all, the evidence supports that most of the proposed unconventional policies have had a positive effect on financial stability, by reducing both short- and long-term yields and by increasing the liquidity of the financial system.[6]

At the same time, much less is known about the impact of unconventional monetary policies on the real economy. In general, the empirical evidence seems to support the fact that the adopted measures have also generated positive real outcomes (see, e.g., Bhattarai and Neely 2016). For example, there is a consensus on the positive impact of UMPs on output and inflation, although studies disagree on the magnitude of such effect. Kapetanios et al. (2012), Baumeister and Benati (2013), and Gambacorta et al. (2014) employ panel and/or threshold vector autoregressive models and find that a positive increase in inflation (estimates range between 0.5 and 2%) as well as in output (estimates range between 0.9 and 3.6%) is generated by the introduction of unconventional monetary policies. However, possibly due to the difficulty of identifying clean transmission mechanisms, many economists contest these results. Borio and Zabai (2016) suggest indeed that there might be a leak in the transmission of the unconventional monetary policy measures from the financial to the real sector and that these short-term positive effects might vanish in the long run, when the cost-benefit of the measures deteriorates. Rogoff (2017) claims instead that "many economists are rightly concerned that unconventional monetary policy tools are poor substitutes for conventional interest rate policy and might well have more side-effects," implying that there is a possibility that these new tools are only imperfectly capable of managing private demand, inflation, and output.[7]

The mechanisms linking UMPs to output and inflation have also been investigated through theoretical studies employing either general equilibrium or agent-based models. Let us here begin with the results stemming from the large-scale DSGE model that has been used at the Federal Reserve for assessing the impact of UMPs.[8] Using this model, Chung et al. (2011) show that the FED's asset purchase program may have contributed to a reduction of the 10-years treasury yield, an increase of the core inflation as well as a decrease in the unemployment rate. Oddly enough, using the same model, Engen et al. (2015) find instead that the bonds purchasing programs had no effects on output, inflation, and unemployment in the initial post-crisis years (i.e., in 2009 and 2010) but have sped up the pace of recovery from 2011 onward. Confirming the results in Altavilla and Giannone (2017), Engen et al. (2015) also put forward that the most important channel of transmission has been through changes

[5] As Gorodnichenko and Ray (2017) put it, with some oversimplifications: "purchases of assets in a particular segment move prices more strongly in that segment." Note that this result is in line with the findings of Krishnamurthy and Vissing-Jorgensen (2011).

[6] For a critical review of the literature, see also Martin and Milas (2012), who claim that only the very first wave of UMPs, carried out through the acquisition of asset-backed securities rather than bonds, succeeded in decreasing the interest rates and that the effects on the real economy are instead in general very mild.

[7] This is however in contrast with the results by Peersman (2011) who finds that the transmission channels of balance sheet policies are similar to those of the standard interest rates policies.

[8] For more information on the baseline FRB/US model, see https://www.federalreserve.gov/econres/us-models-about.htm.

in expectations in the private sector where agents "began to learn that monetary policy was going to remain substantially more accommodative than usual over a longer period of time" (p. 26). Results similar to those of Engen et al. (2015) have also been obtained in Chen et al. (2012) by means of a medium-scale DSGE model estimated with Bayesian techniques on US data. Their findings confirm that there have been only modest effects of UMP on GDP growth and inflation in the short run, but that output might be positively affected in the long run. More recently, Farmer and Zabczyk (2016) have investigated the effects of maturity extension programs in a general equilibrium model with limited asset market participation. Their findings suggest that such a policy is Pareto-improving as it stabilizes non-fundamental fluctuations in the stock market. Finally, after 10 years of adoption of UMPs all around the world, a recent paper by Quint and Rabanal (2017) has used a DSGE model to investigate the possibility of using such policy tools also during more tranquil periods and not only during large recessions that hit the ZLB — transforming them de facto into "conventional" tools. They find that these instruments can be useful also in normal times only if the economy is affected by shocks of financial origin; they are instead ineffective in normal times in the case of demand or supply shocks.

In the macroeconomic agent-based camp (Gaffard and Napoletano 2012; Fagiolo and Roventini 2017; Dawid and Delli Gatti 2018; Dosi and Roventini 2019), to our knowledge, the unique agent-based model directly investigating the transmission mechanisms and the effects of asset purchasing programs is the one by Cincotti et al. (2010). In their model, an unconventional monetary policy coupled with a counter-cyclical fiscal policy delivers a better macroeconomic performance vis-à-vis a tight fiscal policy and no central bank intervention in the bond market. However, unconventional monetary policy might also generate higher inflation rates and be responsible for a higher volatility of output over the long run. Assenza et al. (2017) have instead introduced a stylized unconventional monetary policy exercise in an agent-based model of the business cycle by means of a cash-in-hand policy — which is closer in spirit to helicopter money, or to a fiscal plan. Their findings suggest that the cash-in-hand policy is dominated by a standard Taylor rule. Finally, Schasfoort et al. (2017) have focused on the transmission mechanisms of different forms of monetary policy, finding that the interest rate policy might be a blunt tool for the control of inflation.

3 The model

The model presented here builds upon the *Schumpeter meeting Keynes* family of macroeconomic agent-based models. In particular, in this work, we take the Dosi et al. (2015) version as the starting point.[9]

The model comprises heterogeneous consumption-good firms, which produce a homogeneous good using labor and capital and invest in productivity-enhancing

[9] For the sake of brevity, the bulk of the K+S model is presented in Appendix 1. In this section, we only provide a brief description of the main mechanisms at work and we describe in detail the new equations introduced to tackle the research questions outlined in Section 1.

machines with the aim of outperforming their competitors. Machines are instead produced and delivered by heterogeneous capital-good firms, which use only labor as inputs in order to produce and carry out (innovative and imitative) R&D activity. Heterogeneous banks are also present to support, by means of credit, the consumption-good firms in their investment projects. A government and a central bank complete the model. The government carries out fiscal policy. The central bank sets the interest rate using the Taylor rule which can comprise either a single or a dual mandate. Concerning the accounting principles, in all previous versions of the K+S models, the balance sheet assets are evaluated at their historical value.

In this paper, we introduce new policy exercises, taking into account some of the evolutions that have been taking place over the past two decades in the accounting and monetary policy domains. Concerning the former, we introduce the mark-to-market accounting principle as an alternative to the historical accounting (see Section 3.1). With respect to the latter, we implement lender of last resort operations as a proxy for the very first version of unconventional monetary policies put in place by US FED in 2008 (see Section 3.2). In order to include these elements, modifications to the credit market, to the balance sheets of the banking sector, and to the government's behavior as well as to the central bank's behavior have been necessary. Together with the newly implemented policies, they constitute the modeling contribution of this paper.

3.1 Mark-to-market accounting

As already mentioned in the introductory section, fair value accounting and historical value accounting are two opposite extremes. In reality, neither of the two can be considered as true and accurate. In our model, they must be interpreted as archetypes of the guiding principles toward which a policymaker might lean. Their main difference resides in the fact that, in order to evaluate changes in the financial conditions of a financial institution, the former method looks at current variations in the market value of specific balance sheet items, while the latter only measures the original value of the asset, at the moment it has been acquired.

Since the FASB (1991) directives, companies operating in the financial sector are required to report the fair value of the debt and equity securities that they hold in the asset side of their balance sheet. However, the usage of the mark-to-market principle implies that banks adjust the values of their assets as soon as some of their (direct) borrowers default on their loans during the year or if these borrowers become riskier. This is true also for financial institutions holding government debt: when government bonds become riskier, so that they cannot be considered as *safe assets* (see Caballero et al. 2017; Caballero and Farhi 2018), under a mark-to-market accounting regime banks will consider the higher likelihood of default of the government and depreciate the government-issued securities they hold.

The introduction of such a mechanism in our model possibly unleashes a positive feedback mechanism between government and commercial banks' performance. If the government accumulates debt at a faster pace than the GDP growth, the debt-to-GDP ratio increases and government bonds become riskier. From the perspective of a private bank with public bonds in its balance sheet, this represents a devaluation of the government securities, i.e., a reduction of its asset size. It is therefore subject to an equivalent fall in its equity and, in turn, an increase in leverage. Finally, via the macroprudential policy framework, the worsening of a bank's balance sheet reduces the maximum amount of credit that this bank is willing to lend. At the end of the chain, this process negatively impacts on the investment possibilities of the consumption-good firms. The opposite holds true if the public debt-to-GDP ratio decreases. In such a situation, bonds are revalued upward, banks' assets get inflated, credit supply flourishes, and a larger amount of credit can be lent to the consumption-good firms for the acquisition of new machines.

This channel of revaluation and devaluation was totally absent in the previous versions of the model. The unique mechanism through which the value of the banking sector could have impacted the real sector was related to the implementation of a capital adequacy macroprudential framework (or bad loans channel). In particular, whenever a consumption-good firm defaults on its debt, the lending bank suffers an equity loss of equivalent size. This decreases the maximum amount of credit it can supply. The negative credit shock therefore originates in the real side of the economy. The introduction of the fair value accounting principle, instead, includes the possibility of a pure financial shock. As already commented, this channel generates a positive feedback between the risk of default of a government and the credit market.

We implement the mark-to-market principle only for one item on the asset side of the banking industry, i.e., government bonds. The supply of public bonds in the K+S model is determined endogenously. The bonds supply for a period t should cover government deficit. In particular, the government deficit Def_t and the supply of new bonds B_t^S write:

$$\begin{aligned} Def_t &= Debt_t^{cost} + G_t^{bailout} + G_t - Tax_t \\ B_t^S &= \max\{Def_t, 0\} \end{aligned} \tag{1}$$

where $Debt_t^{cost}$ represents interest payments on the stock of government debt, $G_t^{bailout}$ measures the cost of bank bailouts in the period, and G_t and Tax_t are, respectively, the fiscal transfers to unemployed workers and the taxes gathered on firms' and banks' profits. Notice that the Government has to issue new bonds only if $Def_t > 0$. In such a case, the newly issued bonds are directly purchased by the banks given their share in the economy-wide supply of credit:

$$B_{h,t}^D = f_{h,t} B_t^S, \tag{2}$$

where $f_{h,t} = \frac{TC_{h,t}}{\sum_b TC_{b,t}}$ measures the share of bonds bought by bank h in period t and $TC_{h,t}$ is the total credit it could supply. Equation 2 also sets the banks' demands for government bonds. However, to effectively purchase the value $B_{h,t}^D$, it is also necessary that bank h has enough liquid resources. As a matter of fact, an illiquid bank with a level of cash lower than $B_{h,t}^D$ will not be able to purchase the desired amount of government securities. We assume that in this case the central bank acts as a lender of last resort, buying the residual bonds on the primary market (i.e., monetary financing). This practice was once used by many national central banks, but is nowadays forbidden either by law (e.g., Article 123 of the Treaty on the Functioning of the European Union — TFEU — for what concerns the European Central Bank) or with the aim of granting sufficient independence to the central bank (e.g., Bank of

England and Federal Reserve).[10] Overall, this mechanism of bond demand and supply allows us to clear the market for government securities in every period t.

Once the bonds market is closed, the newly issued government bonds appear in the asset side of the banks' balance sheet and in the liability side of the government's one. Under a historical value accounting regime, the nominal value of these bonds is discounted only by the constant risk-free interest rate:

$$B_{h,t}^{hist} = \frac{B_{h,t}}{1 + r^{bonds}}. \tag{3}$$

where r^{bonds} represents the constant, risk-free, interest rate. Under the fair value accounting regime instead, the discount factor of the government bonds is updated in every period. In this model, we do not introduce a secondary market for government bonds, but we assume that the fair value discount factor is a function of (i) the government debt-to-GDP ratio and (ii) the share of public debt held by the central bank. These indicators measure respectively the solvency of the government and the liquidity of the banking sector.[11] The mark-to-market rate therefore writes:

$$r_t^{mtm} = r^{bonds} + \varpi_1 \frac{Debt_t}{GDP_t} + \varpi_2 \frac{B_{cb,t}}{Debt_t}. \tag{4}$$

As already anticipated, the mark-to-market revaluation coefficient positively depends on the government insolvency risk, as measured by $\frac{Debt_t}{GDP_t}$, and on the liquidity risk of the banking industry, measured by $\frac{B_{cb,t}}{Debt_t}$. The parameters ϖ_1 and ϖ_2 weight the relative importance of the two indicators. Thus, at the end of the period, when compiling the balance sheet of bank h, the value of the government bonds under the mark-to-market accounting regime reads:

$$B_{h,t}^{mtm} = \frac{B_{h,t}}{1 + r_t^{mtm}}. \tag{5}$$

Notice that in the K+S model, nothing prevents the government from building up a "negative stock of debt," i.e., to accumulate reserves by running subsequent surpluses. Indeed, at the beginning of the simulation, the government debt is equal to zero. If the economy reaches full employment, the government is likely to run a surplus as unemployment subsidies expenditures are zero, the probability of bailing-out a bankrupted bank is low, and the profits of banks and firms increase (which boosts tax collection). In these conditions, the government is likely to accumulate a buffer of liquid reserves. From the mark-to-market accounting perspective, this implies

[10] Notwithstanding all these limitations, some form of monetary financing has been envisaged in April 2020, after the shock caused by the COVID-19 pandemic, at the Bank of England. In particular, the BoE has temporarily, and by a relatively small amount, increased the Ways and Means Account of the government. See https://www.ft.com/content/664c575b-0f54-44e5-ab78-2fd30ef213cb.

[11] We assume that $\varpi_2 > 0$ because a high value in the last term of Eq. 4 implies that the banks did not have the sufficient amount of liquidity to purchase all bonds. We argue that this has a positive impact on perceived risk. However, an alternative interpretation would be possible if one assumes, using a forward-looking perspective, that a large share of public debt held by the central bank signals a hawkish attitude by the central bank also in the future, which would strongly intervene in the bonds market. This would decrease the rate r^{mtm} and would require that $\varpi_2 < 0$.

that also upward revaluations of government bonds are possible, if the government buffer becomes sufficiently large. A downward revaluation of assets occurs instead whenever the government debt-to-GDP ratio is strictly positive.

3.2 Unconventional monetary policy

The second policy instrument that we introduce in this paper is a form of unconventional monetary policy. As we already mentioned, we do not aim to model a secondary market for government securities, nor do we introduce a *securitization* process — which would involve the collection of different bad loans into new assets, tradable on specific financial markets, as in Mazzocchetti et al. (2018). The unconventional monetary policy in our model closely resembles the implementation of the very first measures adopted at the early stage of the financial crisis by the US Federal Reserve, back in 2008.[12] At that time, the FED bought a selection of "toxic assets" from banks in order to clean their balance sheets and provide liquidity relief. With respect to the previous versions of the K+S model, we therefore endow the central bank with the power of directly intervening on the balance sheets of financial institutions by purchasing their bad debt, which in our model is a form of toxic securities. The final aim of such a policy is to sustain credit supply to firms and to avoid banking crises. Indeed, the main activity of the banking sector in the model is to provide credit to consumption-good firms (see also Appendix 1) when their internal financial resources are insufficient to fund their production or investment plans. Such a credit activity endogenously generates a financial cycle (see Dosi et al. 2015). However, some firms might become insolvent due to competitive pressure or wrong investments and may go bankrupt. When this occurs, the bank that lent money to the bankrupt firm records a non-performing loan (a bad debt) in its balance sheet. In normal situations, such an asset shall be scratched from the balance sheet generating a net equity loss for the bank. This, in turn, negatively impacts on the credit capacity of the bank as described by:

$$TC_{h,t} = \frac{NW_{h,t-1}}{\tau^b(1 + \beta BadDebt_{h,t-1})} \tag{6}$$

where $NW_{h,t-1}$ represents previous period bank equity, $\tau^B \in [0, 1]$ is a parameter fixed by the regulatory authority, $BadDebt_{h,t-1}$ is the amount of non-performing loans in the previous period, and β is a parameter measuring the banks' sensitivity to her financial fragility, as measured by the stock of bad debts.

Increasing bad debts restricts credit supply as shown by Eq. 6. The unconventional monetary policy dampens this effect as the cost of bad debt is shared between the bank and the central bank, which intervenes by injecting liquid resources (i.e., cash) into the bank's balance sheet, by purchasing a fraction of the bad debt and partially offsetting the fall in equity. Formally, the UMP policy writes:

$$UMP_{h,t} = \alpha_{ump} BadDebt_{h,t} \tag{7}$$

[12]Notice that our policy exercise can be considered as a UMP setting but it is quite different from the quantitative easing as implemented, among the others, by the ECB after 2015.

where $UMP_{h,t}$ is the amount of resources that the central bank injects into the balance sheet of bank h to buy a fraction $\alpha_{ump} \in [0, 1]$ of its stock of bad debt. The parameter α_{ump} measures the aggressiveness of the UMP policy: the higher is the coefficient α_{ump}, the larger is the intervention of the central bank, and the lower is the effect that a bankruptcy in the consumption-good sector exerts on banks' credit supply. In practice, the central bank exogenously generates new liquidity, by partially bearing the cost of bank losses and by increasing the size of its own balance sheet. This mechanism dampens the oscillations generated by the credit cycle and contributes to avoid a credit market freeze.

Aside from the unconventional tools, the central bank performs monetary policy following a Taylor rule of the form:

$$r_t^{cb} = r^T + \gamma_\pi(\pi_t - \pi^T) + \gamma_U(U_t - U^T), \quad \gamma_\pi > 1, \quad \gamma_U \geq 0 \tag{8}$$

where π_t represents current inflation, U_t the current unemployment level, and variables with apex T are target levels. The parameters γ_π and γ_U measure the aggressiveness of the central bank toward the two targets of low inflation gap and/or low unemployment gap. In the benchmark parametrization, the central bank pursues a pure inflation-targeting policy, i.e., $\gamma_U = 0$ where the Taylor principle is satisfied ($\gamma_\pi > 1$). Furthermore, to keep into account also the dual mandate policy of the Federal Reserve, we also simulate scenarios wherein $\gamma_U > 1$. In particular, we study a dual mandate scenario where the central bank assigns the same importance to inflation and unemployment stabilization.

4 Results

The analysis of the model is performed by means of Monte Carlo simulations. The values of the main parameters characterizing the model's equations can be found in Appendix Table 4. We run a set of pseudo independent simulations to wash away the cross-simulation variability and to evaluate the statistical significance of our claims.[13]

Before moving to the discussion of the policy exercises, we check the validity of the model using an indirect inference approach (see Windrum et al. 2007; Fagiolo et al. 2019), by investigating the power of the model to jointly replicate a list of stylized facts in the baseline scenario, characterized by the usage of the historical value accounting principle, a single mandate Taylor rule, and the absence of unconventional monetary policy. In Table 1, we present the main summary statistics. We observe that for all variables we obtain reasonable statistics, with volatility rankings comparable to empirically observed ones in the USA. The replication of stylized facts is also carried out more in depth in Appendix 3, where we show that the model is able

[13] All the results presented below refer to averages across 50 Monte Carlo runs. Since most of the variables under investigation are ergodic (see Guerini and Moneta 2017), 50 Monte Carlo runs, each composed of 500 time periods, generate 25,000 observations for each variable which are sufficient to obtain reliable statistics (Vandin et al. 2020). Within each scenario and among the 50 Monte Carlo runs, the sole source of variation is given by the pseudo random number generator. Between the 50 batch runs in different scenarios, instead, the pseudo random number generator is held constant and we only change either the parameters or the behavioral rules, according to the equations specified in Section 3.

Table 1 Summary statistics of selected variables in the baseline scenario

Variable	Mean	Std. dev.
GDP growth	0.0301	0.0013
Cons. growth	0.0301	0.0013
Inv. growth	0.0293	0.0021
Unemployment rate	0.0786	0.1389
Inflation rate	0.0334	0.0061
Crisis likelihood	0.0463	0.0166
GDP volatility	0.0372	0.0046
Cons. volatility	0.0248	0.0077
Inv. volatility	0.4664	0.1107

Crisis likelihood is measured as the percentage of periods in which GDP growth is below -3%. All volatilities are measured as a standard deviation

to replicate the most relevant macro and micro properties. In particular, at the macro level, we observe (i) a self-sustained long-run endogenous growth with (ii) short-run business cycles; (iii) fat-tailed GDP growth rate distribution, and a set of statics well in tune with those obtained from real-world data, namely (iv) relative volatilities of GDP, consumption, and investment; (v) auto- and cross-correlations between GDP, consumption and investment; (vi) dynamic cross-correlations of private debt and total deposits with GDP; and (vii) dynamic auto- and cross-correlations between private debt and amount of bad debt. At the micro level, instead, the model is able to reproduce (i) right-skewed fat-tailed distribution of firms size in both sectors, (ii) Laplace distribution of the growth rates of firms in both sectors, (iii) persistent productivity growth rates of firms in both the capital-good and consumption-good sectors, and (iv) lumpy firms' investment patterns.

After the successful empirical validation of the model, we move to policy exercises. In particular, we are interested in evaluating the effects of the mark-to-market accounting standard, of the unconventional monetary policy, and of a dual mandate Taylor rule on the real side of the economy. With these objectives in mind, Tables 2 and 3 summarize the main results. The values in the two tables display the ratios between the average values of each variable computed in a policy scenario with respect to those obtained in the benchmark one. For each ratio, we also report the p-value associated to the t-test whose null hypothesis claims that *the ratio between the two considered scenarios is not different from 1*. Therefore, a failure to reject the null hypothesis would imply that, for the variable under consideration, the two scenarios there compared provide indistinguishable results. If the variable has a positive economic connotation — e.g., GDP growth — a ratio significantly larger (smaller) than one would imply that the first scenario outperforms (is outperformed by) the second in the pairwise comparison. The opposite holds true for an economic variable inversely related to macroeconomic performance — e.g., unemployment.

Table 2 Comparison of different policies

Variable	GDP	Consumption	Investment	Unemployment	Inflation
MtM vs. Base					
ratio	0.954	0.955	1.023	1.439	1.060
p-value	0.029	0.032	0.116	0.009	0.215
UMP vs. Base					
ratio	1.017	1.017	1.055	1.052	1.110
p-value	0.041	0.035	0.002	0.591	0.024
MtM + UMP vs. Base					
ratio	1.017	1.017	1.040	1.103	1.088
p-value	0.021	0.016	0.011	0.324	0.044
MtM + UMP vs. MtM					
ratio	1.101	1.098	1.011	0.986	1.058
p-value	0.006	0.006	0.531	0.867	0.064
MtM + UMP vs. UMP					
ratio	1.000	1.000	0.988	1.154	0.995
p-value	0.937	0.931	0.149	0.076	0.735
DM + MtM vs. DM					
ratio	1.031	1.031	1.001	1.352	1.020
p-value	0.251	0.243	0.911	0.216	0.289
DM + UMP vs. DM					
ratio	1.046	1.046	1.022	1.037	1.016
p-value	0.075	0.068	0.043	0.597	0.389
DM + MtM + UMP vs. DM					
ratio	1.050	1.050	1.027	1.055	1.016
p-value	0.061	0.057	0.024	0.462	0.439
DM + MtM + UMP vs. DM + MtM					
ratio	1.023	1.023	1.023	1.037	0.999
p-value	0.054	0.051	0.029	0.490	0.916
DM + MtM + UMP vs. DM + UMP					
ratio	1.004	1.003	1.005	1.028	1.001
p-value	0.302	0.333	0.453	0.471	0.932
DM vs. Base					
ratio	0.990	0.990	1.045	1.999	1.066
p-value	0.528	0.519	0.007	0.071	0.117
DM + MtM vs. MtM					
ratio	1.086	1.083	1.015	1.446	1.054
p-value	0.014	0.015	0.376	0.166	0.123
DM + UMP vs. UMP					
ratio	1.003	1.003	1.008	1.171	0.983
p-value	0.504	0.429	0.397	0.026	0.238

Table 2 (continued)

Variable	GDP	Consumption	Investment	Unemployment	Inflation
DM + MtM + UMP vs. MtM + UMP					
ratio	1.006	1.006	1.026	1.149	0.993
p-value	0.148	0.133	0.014	0.056	0.633

Average ratios across scenarios. *Base*, baseline with single mandate monetary policy. *MtM*, mark-to-market accounting policy. *UMP*, unconventional monetary policy. *DM*, dual mandate monetary policy

4.1 Standalone policy exercises

We begin by evaluating the effects of different accounting regimes on macroeconomic performance. For this purpose, the mark-to-market scenario (MtM) is compared against the baseline one, where historical value accounting is employed — see the first section in Tables 2 and 3. Let us recall that the accounting policy directly impacts upon the balance sheets of the banks, affecting in turn aggregate credit supply and, through this channel, the real sectors of our simulated economy. Simulation results suggest that, when a mark-to-market accounting system is adopted, the growth rates of GDP and consumption are significantly smaller (by about 4.5 percentage points) with respect to the historical accounting standard scenario. This, in turn, also generates a significantly higher unemployment rate. Average investment growth is instead statistically indistinguishable across the two scenarios (see Table 2, section *MtM vs. Base*). But the negative effects of MtM do not only affect the first moment of the distribution of the main macro variables. As a matter of fact, we also find that for all the variables taken into account, the MtM scenario generates more volatility, as measured by the average of the standard deviation computed in each batch run for all variables (cf. Table 3). In this respect, our results reject the existence of a trade-off between the two accounting policies, with the historical accounting performing absolutely better than a MtM framework in all dimensions.

The second pairwise comparison between standalone policies aims at the evaluation of the effect of a particular form of unconventional monetary policy tool as carried out by the FED in the first years of the great financial crisis of 2008. In particular, we assume that this policy is permanent in our simulated economy. This argument is also in line with the work of Quint and Rabanal (2017), which discusses the role of UMP as a new tool that is likely to become employed also in more tranquil periods. The outcomes of our simulation exercises (see Table 2, section *UMP vs. Base*) suggest that the adoption of an unconventional monetary policy induces some improvement vis-à-vis the baseline scenario when assuming that historical accounting standards are in place. In particular, the average growth rates of GDP, consumption, and investment are larger when UMP is in place. This is due to the fact that, in our model, the unconventional monetary policy allows the banks to keep lower levels of the bad-debt-to-equity ratios, sustaining therefore their role as creators of funds, via their credit activities. All in all, this fuels growth in the real side of the economic system. The cost of such a policy is a higher inflation rate, which is 10%

Table 3 Comparison of different policies

Variable	GDP	Consumption	Investment	Unemployment	Inflation
MtM vs. Base					
ratio	1.057	1.103	1.016	2.328	1.054
p-value	0.018	0.080	0.653	0.008	0.072
UMP vs. Base					
ratio	0.999	0.977	0.981	1.007	0.976
p-value	0.998	0.496	0.482	0.927	0.336
MtM + UMP vs. Base					
ratio	1.0206	1.004	1.005	1.061	1.008
p-value	0.276	0.905	0.864	0.490	0.732
MtM + UMP vs. MtM					
ratio	0.977	0.964	1.007	0.941	0.975
p-value	0.166	0.234	0.730	0.400	0.255
MtM + UMP vs. UMP					
ratio	1.028	1.043	1.033	1.093	1.044
p-value	0.109	0.083	0.108	0.147	0.036
DM + MtM vs. DM					
ratio	0.973	0.988	0.995	1.265	0.982
p-value	0.062	0.637	0.824	0.299	0.346
DM + UMP vs. DM					
ratio	0.969	0.992	1.007	0.959	0.999
p-value	0.054	0.7545	0.797	0.423	0.959
DM + MtM + UMP vs. DM					
ratio	0.988	1.011	1.026	0.983	1.017
p-value	0.398	0.673	0.326	0.736	0.464
DM + MtM + UMP vs. DM + MtM					
ratio	1.022	1.033	1.026	1.033	1.046
p-value	0.192	0.137	0.276	0.390	0.065
DM + MtM + UMP vs. DM + UMP					
ratio	1.022	1.028	1.022	1.036	1.031
p-value	0.049	0.153	0.270	0.157	0.164
DM vs. Base					
ratio	0.983	1.040	0.938	1.610	0.965
p-value	0.394	0.264	0.037	0.084	0.179
DM + MtM vs. MtM					
ratio	0.907	0.973	0.920	1.261	0.904
p-value	0.000	0.413	0.000	0.360	0.000
DM + UMP vs. UMP					
ratio	0.951	1.051	0.956	1.0117	0.983
p-value	0.002	0.048	0.037	0.775	0.433

Table 3 (continued)

Variable	GDP	Consumption	Investment	Unemployment	Inflation
DM + MtM + UMP vs. MtM + UMP					
ratio	0.953	1.042	0.947	1.007	0.970
p-value	0.027	0.102	0.018	0.858	0.180

Volatility ratios across scenarios. *Base*, baseline with single mandate monetary policy. *MtM*, mark-to-market accounting policy. *UMP*, unconventional monetary policy. *DM*, dual mandate monetary policy

larger than in the baseline scenario while the unemployment rate is unchanged. Furthermore, the UMP policy does not seem to have any significant effect on the second moment of any of the macro variables under investigation (see Table 3). This absence of statistical difference, at least in terms of volatility, might be due to the fact that in the baseline scenario the economy does not experience prolonged and severe crises. As a consequence, the amount of bad debt acquired by the central banks through the UMP operations is relatively small.

Finally, the standalone application of both policies does not have significant impact on the first two moments when the dual mandate (DM) Taylor rule is applied by the central bank. Indeed, only a small positive impact on investment is achieved thanks to the UMP (see sections *DM + MtM vs. DM* and *DM + UMP vs. DM* of the two tables). This is coherent with the empirical literature according to which in the USA, where a dual mandate rule is actually implemented by the Federal Reserve, the effects of different UMPs have been small or negligible. Moreover, the DM Taylor rule appears to be able to dampen the negative impact of mark-to-market accounting.

4.2 Joint policy exercises

The second block of simulation scenarios focuses on policy combinations. In particular, we aim at evaluating the performances of a scenario wherein both the UMP and the MtM accounting standard are jointly in place.

When we compare such a scenario with the baseline (see Table 2, section *MtM + UMP vs. Base*), we find that the effects are broadly positive. In particular, we observe that the GDP, consumption, and investment growth rates are larger than in the baseline scenario (by factors almost equivalent to the ones found when only UMP is in place). This implies that the UMP can offset almost all the negative results brought about by the mark-to-market accounting standard.

The foregoing positive effect of the UMP can also be observed when we compare this joint policy scenario, with the one where only MtM is active (section *MtM + UMP vs. MtM*): GDP and consumption growth ratios are larger than 1 and they are slightly significant (with test size equal to 6%). A non-significant difference is instead observable when the policy mix is compared to the scenario in which only UMP is envisaged. The reason behind this outcome can be better grasped by means of a simple numerical example and recalling that the UMP de facto reduces the amount of bad loans. Imagine, for example, that at time t all conditions are exactly equivalent between the *Base* and the *MtM* scenarios, except for the amount of bad loans which are respectively equal to 50 and 80. In the second scenario, banks in $t+1$ will be willing to lend a lower amount of credit (cf. Eq. 6) limiting investment and GDP growth. However, if UMP is activated in the second scenario (*MtM* + *UMP* with $\alpha_{UMP} = 0.5$), the amount of bad debt in t after the central bank intervention will only be equal to 40. This amount is lower with respect to the *Base* scenario and, as a consequence, credit, investment, and growth will be higher in $t+1$ under this setup. More in general, ceteris paribus and for a given gap between the bad debts in the *Base* and the *MtM* scenarios, a value of α_{UMP} might exist such that the introduction of UMP offsets the negative effects on economic activity brought about by fair value accounting standard. With respect to the second moment instead, it seems that the policy mix does not have significant impacts on the macroeconomic variables here considered (see the second block of results in Table 3).

All these results concerning the joint policy exercises are valid even when the dual mandate Taylor rule is applied (see the fourth block of both result tables). This, however, shall not lead to the conclusion that dual and single mandate monetary policies are equivalent. As a matter of fact, by focusing on the last block of results in Table 2, one can observe that a dual mandate Taylor rule significantly outperforms the single mandate monetary policy when the mark-to-market accounting is in place (section *DM* + *MtM vs. MtM*).

The key to understand and interpret the transmission mechanisms underlying this set of results is the existence of a positive feedback between GDP, private credit, and bad debt which are positively correlated. Furthermore, this positive correlation is also dynamic and persists at several lags, as also reported in Figs. 4 and 5 of Appendix 3. In particular, the fair value accounting policy amplifies such a positive feedback. In periods of economic expansion, with faster GDP growth, the riskiness of government bonds is reduced, and the value of the bonds held as assets in the banks' balance sheets is increased. Such a positive feedback greases the wheels of the money creation process, as more credit flows to the real sector. But a large availability of credit might also be pernicious, and might lead to a larger fraction of non-performing loans due to the bankruptcies of a number of consumption-good firms, unable to keep up with the competitive pressures. Absent any form of unconventional monetary policy, an accumulation of bad debt leads to a fall in the credit supply and endogenously generates recessions. The UMP, instead, puts a halt to such a positive feedback mechanism of the credit cycle. By cleaning up banks' balance sheet and taking out a fraction of the bad debt burden, the UMP prevents large falls in the credit supply, supporting the investment activity of firms in the real sector.

5 Conclusions

Accounting policies have received little attention in the macroeconomic literature during the past decades, notwithstanding their potential macro-financial implications. The importance of such policies has been reconsidered in the aftermath of the financial crises of 2008. Our paper contributes to the debate on the macroeconomic effects of accounting practices by comparing the effects of mark-to-market standard (i.e., fair value) and historical accounting principle. To perform this task, we have employed a modified version of the K+S agent-based model (building on Dosi et al. 2010; Dosi et al. 2013; Dosi et al. 2015) and we have considered accounting standards as a slow-moving policy variable. In addition, we have studied the interaction of accounting standards with unconventional monetary policy practices which have been introduced by central banks after the 2008 financial crisis and that are still in place (? [, see, as an example,)]arslan2020central.

More precisely, in our model, the fair value accounting is introduced by means of a periodic revision in the evaluation of the assets held by the banking industry. In particular, the solvency and the liquidity risk of the public sector lead to such revaluations. We do so by introducing a negative correlation between government risk (solvency or/and liquidity) and bonds value. The unconventional monetary policy instruments are proxied by a program in which the central bank buys banks' non-performing loans (i.e., toxic assets), cleaning up their balance sheets. In doing so, it supports both the liquidity and the solvency of the banking industry, as well as their credit activity, in through this channel, investment in the real sector.

Simulation results show that mark-to-market accounting standard amplifies financial instability and worsens macroeconomic dynamics. This stems from the higher pro-cyclicality of bank credit and the increasing number of non-performing loans, in tune with the intuitions by Bignon et al. (2009) and Heaton et al. (2010). On the contrary, unconventional monetary policies improve the macroeconomic performance. Finally, when both policies are in place, we find that unconventional monetary practices dominate the negative impact of the application of the fair value. This implies that unconventional monetary policy instruments could become a permanent option in the toolbox of central banks.

The next step in our future research is the introduction of a secondary market for sovereign bonds. This would allow us to both study additional details of unconventional balance sheet interventions by central banks and increase the degree of realism in the analysis of quantitative easing policies. Moreover, we would like to extend our analysis to study the impact of accounting standards and new types of unconventional policies on the green transition building upon (Lamperti et al. 2021). Finally, we would like to model the interbank market to account for another potential source of financial instability (see, e.g., Popoyan et al. 2020).

Appendix 1. Full model description

Here we present the full structure of the K+S/DSK model with heterogeneous banks and an energy sector (Dosi et al. 2015; Lamperti et al. 2019).[14] The economy comprises a capital-good, a consumption-good, and a banking sector. In addition, an energy system provides electricity to firms; as electricity is produced on demand, the energy sector does not affect the dynamics of the model while bringing the

[14]This section heavily draws on the original papers.

opportunity to study green monetary policies in future research. The consumption and capital good are vertically integrated while the baking sector provides credit to consumption-good firms only.

1.1 The capital-good sector

Firms in the capital-good industry produce machine tools using only labor and energy. They innovate and imitate in order to increase labor productivity and energy efficiency of the machines they produce, as well as to reduce their own production costs. Innovation and imitation are costly and the capital-good firms need to invest a fraction of their past sales in R&D to carry out these two processes.

The technology embedded in a specific vintage τ is characterized by the level of *labor productivity* and *energy efficiency*. It can be fully represented by four coefficients $(A^k_{i,\tau}, B^k_{i,\tau})$, with $k \in \{L, EE\}$. Let us start with labor productivity, LP. In this case, $A^{LP}_{i,\tau}$ stands for the productivity of machine i in the production of the final good, while $B^{LP}_{i,\tau}$ is the productivity of the production technique needed by the capital-good firm to manufacture the machine itself. The apex EE, instead, refers to energy efficiency: $A^{EE}_{i,\tau}$ represents the output per energy unit obtained by using the machine tool manufactured by firm i, and $B^{EE}_{i,\tau}$ represents the output per energy unit during the production phase of firm i. Given the monetary wage, $w(t)$, and the cost of energy, $c^{en}(t)$, the unitary cost of production for capital-good firm i is given by:

$$c^{cap}_i(t) = \frac{w(t)}{B^{LP}_{i,\tau}} + \frac{c^{en}(t)}{B^{EE}_{i,\tau}}. \tag{9}$$

Similarly, the unitary production cost of a consumption-good firm j is:

$$c^{con}_j(t) = \frac{w(t)}{A^{LP}_{i,\tau}} + \frac{c^{en}(t)}{A^{EE}_{i,\tau}}. \tag{10}$$

Firms in the capital-good industry adaptively attempt to increase market shares and profits. They try to improve their technology by means of innovation and imitation, which are costly processes. In particular, firms invest a fraction of their past sales in R&D, in the attempt to discover a new technology or to imitate their more advanced competitors. As explained in Dosi et al. (2010), both innovation and imitation are modeled as two-step processes. The first step captures the stochastic nature of technical change and determines whether a firm successfully innovates or imitates. This is formalized in the model through a draw from a Bernoulli distribution, where the (real) amount invested in R&D, that is, ultimately, number of people devoted to search, affects the likelihood of success. The second step determines the size of the technological advance:

$$A^k_{i,\tau+1} = A^k_{i,\tau}(1 + \chi^k_{A,i}) \quad \text{for } k = LP, EE \tag{11}$$

$$B^k_{i,\tau+1} = B^k_{i,\tau}(1 + \chi^k_{B,i}) \quad \text{for } k = LP, EE, \tag{12}$$

where $\chi^k_{A,i}$ and $\chi^k_{B,i}$ are independent draws from $Beta(\alpha^k, \beta^k)$ distributions over the supports $[\underline{x}^k, \overline{x}^k]$, respectively, for $k \in \{LP, EE\}$. The support of each distribution defines the potential size of the technological opportunity (see Dosi 1988) along the corresponding dimension. Specifically, in case of successful innovation, the new vintage of capital goods will be characterized by a novel combination of labor productivity and energy efficiency. Finally, successful imitators have the opportunity to copy the technology of the closest competitors in the technological space.[15]

1.2 The consumption-good sector

Firms in the consumption-good industry produce a homogeneous good using their stock of machines, energy, and labor under constant returns to scale. Their demand comes from the consumption expenditures of workers. The desired level of production Q^d_j depends upon adaptive expectations $D^e_j = f[D_j(t-1), D_j(t-2), ..., D_j(t-h)]$, desired inventories ($N^d_j$), and the actual stock of inventories (N_j):

$$Q_j(t)^d = D^e_j(t) + N^d_j(t) - N_j(t), \tag{13}$$

where $N_j(t) = \iota D^e_j(t), \;\; \iota \in [0, 1]$.

Given the desired level of production, firms evaluate their desired capital stock (K^d). If the actual capital stock is not sufficient to produce the desired amount, firms invest in order to expand their production capacity (expansionary investment EI):

$$EI^d_j(t) = K^d_j(t) - K_j(t). \tag{14}$$

Firms also invest to replace current machines with more technologically advanced ones. In particular, given $\Xi_i(t)$, the set of all vintages of machines owned by firm j at time t, the machine of vintage τ is replaced with a new one if:

$$\frac{p^{new}}{c^{con}_j(t) - c^{new}} = \frac{p^{new}}{\left[\frac{w(t)}{A^{LP}_{i,\tau}} + \frac{c^{en}(t)}{A^{EE}_{i,\tau}}\right] - c^{new}_j} \leq b \tag{15}$$

where p^{new} and c^{new} are the price and unitary cost of production associated to the new machine and b is a pay-back parameter determining firms' "patience" in obtaining net returns on their investments.[16] Gross investment of each firm is the sum of expansion and replacement investments. Aggregate investment just sums over the investments of all consumption-good firms.

Consumption-good firms choose their capital-good supplier comparing price, productivity, and energy efficiency of the currently manufactured machine tools they are aware of. Indeed , as the capital-good market is characterized by imperfect information wherein consumption-good firms buy from a subset of machine-tool producers, machine production is a time-consuming process: consumption-good firms receive

[15]The technological space is modeled as a Euclidean space where ℓ^2 is chosen as the metric determining distance between couples of points. Each point represents a technology.

[16]This is in line with a large body of empirical analyses showing that replacement investment is typically not proportional to the capital stock (e.g., Feldstein and Foot 1971; Eisner 1972; Goolsbee 1998).

the ordered machines at the end of the period. Pricing follows a variable mark-up rule.[17]

Consumption-good firms must finance their investments as well as their production. In line with a large body of literature (Stiglitz and Weiss 1981; Greenwald and Stiglitz 1993), we assume imperfect credit markets. Firms first employ their stock of liquid resources, and if the latter does not fully cover total production and investment costs, they borrow external funds from a bank. More precisely, we assume that each firm deposits its net cash flows at the bank and, if it falls short of that, it can get access to an overdraft credit line. The bank sets the maximum amount of credit as a multiple of firms' deposits and it allocates them to borrowers on a pecking-order basis according to the ratio between net worth and sales (see Dosi et al. 2013).[18] Total credit demand by firms can be higher than the maximum supply of credit, in which case credit rationing arises.[19]

Firms sets the price of their final good applying a variable mark-up (μ_j) on their unit cost of production:

$$p_j^{con}(t) = c_j^{con}(t)[1 + \mu_j(t)]. \tag{16}$$

The mark-up change over time according to the evolution of firm's market share, f_j (? [, in line with a lot of evolutionary literature and also with "customer market" models originally described by)]PnW70:

$$\mu_j(t) = \mu_j(t-1)\left[1 + \upsilon \frac{f_j(t-1) - f_j(t-2)}{f_j(t-2)}\right] \tag{17}$$

with $0 \leq \upsilon \leq 1$.

The consumption-good market is characterized by imperfect information (see Rotemberg 2008, for a survey on consumers' imperfect price knowledge). As a consequence, consumers cannot instantaneously switch to the most competitive producer even if the good is homogeneous. In turn, market shares evolve according to a "quasi replicator" dynamics: more competitive firms expand while firms with a relatively lower competitiveness level shrink. The competitiveness of firms depends on price as well as on unfilled demand.

At the end of every period, capital- and consumption-good firms compute their profits, pay taxes, and update their stock of liquid assets. A firm exits the market if its stock of liquid assets is negative or if its market share approaches zero. As the number of firms is fixed over time, each bankrupt firm is replaced by a new entrant.[20]

[17]These assumptions find all in line with large bodies of literature; see, e.g.,Rotemberg (2008) for details on pricing, imperfect information, and behavioral attitudes of consumers and Boca et al. (2008) for presence of gestation lag effects in firms' investments.

[18]Notice that firms' deposits constitute the only "debt" of the bank in the model. Accordingly, the rule for the determination of maximum credit is equivalent to one where the bank sets credit supply in order not to violate a target on the debt-to-asset ratio. See Dosi et al. (2013) and Dosi et al. (2015) for further details.

[19]Finally, also the firms that are not credit rationed face limits in the utilization of their overdraft credit. The ratio between a firm's debt and its sales cannot exceed a maximum threshold that depends on the firm's past sales. In general, we refer the interested reader to Dosi et al. (2013) for additional information on the role of the banking sector and credit supply in influencing model's dynamics.

[20]Furthermore, in line with the empirical literature on firm entry (Caves 1998), we assume that entrants on average have smaller capital and stock of liquid assets than the incumbents.

1.3 The banking sector

In our model, money supply depends on the lending activity of banks. Since we have assumed that firms in the capital-good sector are paid before starting the production of machines, credit is provided only to consumption-good firms. In particular, we model commercial banks that gather deposits and provide credit to firms. The number of banks is fixed and is related to the number of firms in the consumption-good sector: $B = F_2/a$ where the positive integer a can be taken as a proxy for the level of competition in the banking market and it is set according to the empirical literature on topologies of credit markets. Bank-firm couples are drawn initially and maintained fixed over time (the relationship holds true for both deposits and credit); hence, we assume that the firm-bank network is fixed over time.

Banks are heterogeneous in a number of respects. Following the empirical evidence on the skewness of the bank size distribution, the banks' number of clients is determined by a random draw NL_k from a Pareto distribution defined by the shape parameter $pareto_a$. Therefore, each bank k has a portfolio of clients Cl_k with clients listed as $cl = 1, \ldots, Clk$. In what follows, we first present how total available credit is determined by each bank, and how credit is allocated to each firm. Next, we move to describe the organization of the credit flow in the economy and the liquidity account of the banks. Finally, we report the management of banking failures.

Banks are heterogeneous in terms of their fundamentals and their client portfolio, as well as their supply of credit, which is a function of their equity ($NW^b_{k,t}$). On the one hand, capital adequacy requirements inspired by Basel-framework rules (see, e.g., Delli Gatti et al. 2010; Cincotti et al. 2010; Ashraf et al. 2016) constrain banks' credit supply. On the other hand, in line with the empirical evidence, banks maintain a buffer over the mandatory level of capital, whose magnitude is strategically altered over the business cycle according to their financial fragility (see Eq. 6). Following Adrian and Shin (2010), we proxy banks' fragility by the variable $Bda_{k,t}$, defined as the ratio between accumulated bad debt (i.e., loans in default) and bank assets (i.e., sum of the stocks of loans, sovereign bonds, and reserves held by the bank). Therefore, given the parameter $\tau \in [0, 1]$ (fixed by the regulatory authority), the higher the bad-debt-to-asset ratio, the lower the credit the bank provides to its clients, as explained in Section 3. Credit supply is thus impacted by changes in the banks' balance sheet, which itself is affected by bank profits net of loan losses. This creates a negative feedback loop from loan losses to changes in banks' equity with a reduction in the amount of credit supplied by the lender in the next period.

Consumption-good firms needing credit apply to banks for a loan. Banks take their allocation decisions by ranking the applicants in terms of their creditworthiness, defined by the ratio between past net worth ($NW_{j,t-1}$) and past sales ($S_{j,t-1}$). Banks provide credit as long as their supply of loans ($TC_{k,t}$) is fully distributed. Hence, a firm's ability to obtain credit depends on its financial status which determines its ranking, but also on the financial fragility of its bank. It follows that in any period the stock of loans of the bank satisfies the following constraint: $\sum_{cl=1}^{Cl_k} Deb_{cl,k,t} = Loan_{k,t} \leq TC_{k,t}$.

The banks earn profits out of the loans they allocate as well as the sovereign bonds they own. As the firm-bank links are fixed, the interest rates on loans are not used by banks to compete between themselves, but rather to mirror the riskiness of their clients. The interest rate on loans (r_t^{deb}) is computed with a mark-up on the central bank interest rate (r_t^{cb}), where the latter is fixed by the central bank according to the Taylor rule described in Section 3.

Banks fix the risk premium paid by their clients depending on their position in the credit ranking. In every period, four credit classes are created by the banks, corresponding to the quartiles in their ranking of clients. Given the base loan rate $r_t^{deb} = (1 + \mu^{deb})r_t$, firm j in credit class $q = 1, 2, 3, 4$ pays the interest rate: $r_{j,t}^{deb} = r_t^{deb}(1 + (q - 1)k_{const})$ where μ^{deb}, k_{const} are scaling parameters. Firms' deposits are rewarded at the rate r_t^D, banks' reserves at the rate $r^r es_t$, and sovereign bonds pay an interest amounting to $r^b onds_t = (1+\mu^{bonds})r_t$, with $\mu^{bonds} \in [-1, 0]$. The different interest rates are set so that $r_t^D \leq r^r es_t \leq r^b onds_t \leq r \leq r^d eb_t$.

At the end of each period, the profits of the banks are computed as:

$$\Pi_{k,t}^b = \sum_{cl=1}^{Cl_k} r_t^{deb} + r_t^{res} Res_{k,t} + r_t^{bonds} Bonds_{k,t} - r^D Depo_{k,t} - BadDebet_{k,t}.$$

Banks experience a loan loss whenever one of their clients exits the market with a positive debt. Banks' profits net of taxes ($Net\Pi_{k,t}^b = (1 - tr)\Pi_{k,t}^b$) are then added to their net worth ($NW_{k,t}^b$), which is equal to the difference between assets and liabilities. Banks' assets are composed of their reserves at the central bank ($Res_{k,t}$), their stock of sovereign bonds ($Bonds_{k,t}$), and their stock of loans ($Loans_{k,t}$), while firms' deposits ($Depo_{k,t}$) are the only liabilities. Accordingly, the net worth of the bank reads $NW_{k,t}^b = Loans_{k,t} + Res_{k,t} + Bonds_{k,t} - Depo_{k,t} + Net\Pi_{k,t}^b$. Loan losses represent a negative shock to bank profits, which may well become negative. If the net worth of the bank is not sufficient to cover such losses, the bank goes bankrupt. Whenever a bank fails ($NW_{k,t}^b < 0$), the Government steps in and bails it out providing fresh capital. The cost of the public bail out ($G_{t,k}^{bailout}$) is the difference between the failed bank's equity before and after the public intervention. We assume that the bank's equity after the bailout is a fraction of the smallest incumbent equity, provided it respects the capital adequacy ratio.

1.4 The energy sector

The energy sector is akin to Lamperti et al. (2018, 2019, 2020, 2021). Energy production is performed by a profit-seeking, vertically integrated monopolist employing power plants embodying *green* and *dirty* technologies. The energy monopolist produces on-demand electricity for firms in the capital-good and consumption-good industries and we exclude the possibility of energy shortages. In addition, we assume that energy costs are comparatively small with respect to labor costs, so that firms' production and investment decisions are driven by the relative labor productivity of different machines, with a residual role of energy efficiency. Under this setup, the model's dynamics are not sensitive to the competition between *green* and *dirty* technologies. We will exploit this feature in future research to study green fiscal and monetary policies.

Indeed, the energy-producing firm needs to replace obsolete plants, as well as to perform expansion investments whenever the current capacity is insufficient to cover demand. New plants are built in house, but the costs of building new green and dirty plants differ. More specifically, we normalize to zero the costs of building new dirty plants, whereas a cost of must be sustained in order to install a new green plant. Conversely, variable production costs are assumed to be negligible for green plants while positive for dirty ones (as we include the price of fossil fuel inputs, which is kept constant in the current setup).

The energy producer also tries to innovate in order to discover new technologies (which can be either green or dirty). Successful innovation in the green technology reduces the fixed costs, thus encouraging the installment of green plants, while innovating in the dirty technology shrinks production costs, making fossil fuel plants more competitive.

Electricity production follows a merit-order rule: plants are ranked on the basis of their marginal cost and employed for power generation until energy demand is satisfied. Then, the cost of electricity ($c^{en}(t)$) is computed through an additive markup rule over the marginal generation cost of the last activated plant.

1.5 The public sector

The public sector levies taxes on profits and wages, and pays a subsidy to unemployed workers corresponding to a fraction of the current market wage. In the model, the wage rate is determined by both institutional and market factors. Wages are therefore indexed upon inflation gap, average productivity, and unemployment rate and write:

$$\frac{\Delta w_t}{w_{t-1}} = \pi^T + \psi_1(\pi_{t-1} - \pi^T) + \psi_2 \frac{\Delta \bar{AB}_t}{\bar{AB}_{t-1}} - \psi_3 \frac{\Delta U_t}{U_{t-1}}, \tag{18}$$

where $\bar{AB}$ indicates the average productivity in the economy and $\psi_1, \psi_2, \psi_3 > 0$. Unemployed workers receive a public subsidy (w_t^u) which is a fraction of the current wage — i.e., $w_t^u = \varphi w_t$, with $\varphi \in [0, 1]$. The total amount of unemployment subsidies to be paid by the Government is therefore $G_t = w_t^u(L^S - L_t^D)$. We also assume that workers fully consume their income and accordingly, aggregate consumption depends on the income of both employed and unemployed workers: $C_t = w_t L_t^D + G_t$.

Taxes are gathered by the government at the constant tax rate tr. Public expenditures are composed of the cost of the debt, the bank bailout cost, and unemployment subsidies. Public deficit is then equal to $Def_t = Debt_t^{cost} + G_t^{bailout} + G_t - Tax_t$. If $Def_t > 0$, the Government has to issue new bonds, which are bought by banks according to their share in the total supply of credit (see also Section 3). If the supply of government bonds is higher than what banks are able to buy, the central bank steps in and buys the remaining debt, behaving as a lender of last resort. If $Def_t < 0$, the Government uses the surplus to repay its debt. The debt-related expenditures at time t are therefore $Debt_t^{cost} = r^{bonds} Bonds_{t-1}^{stock}$ with r^{bonds} being constant over time.

In the benchmark scenario, the tax and unemployment subsidy rates are kept fixed throughout all the simulations. This implies that they act as automatic stabilizers and that the public deficit is free to fluctuate over time. It follows that the accounting rule $Debt_t = Debt_{t-1} + Def_t$ is satisfied.

The model satisfies the standard national account identities: the sum of value added of capital- and consumption-good firms equals their aggregate production (in our simplified economy, there are no intermediate goods). That in turn coincides with the sum of aggregate consumption, investment, and change in inventories (ΔN_t):

$$\sum_{i=1}^{F_1} Q_{i,t} + \sum_{j=1}^{F_2} Q_{j,t} = Y_t = C_t + I_t + \Delta N_t.$$

Appendix 2. Baseline parametrization

Table 4 Baseline parametrization, main parameters

Symbol	Description	Value
γ_π	Taylor rule sensitivity to inflation	1.10
γ_U	Taylor rule sensitivity to unemployment	1.10
r^{bonds}	Interest rate on government bonds	0.01
r^T	Interest rate target	0.025
ϖ_1	Mark-to-market sensitivity to solvency risk	0.20
ϖ_2	Mark-to-market sensitivity to liquidity risk	0.20
τ^B	Regulatory parameter	0.08
β	Credit sensitivity to financial fragility	1.00
α_{UMP}	Unconventional monetary policy aggressiveness	0.50

For all the other parameters' values, see Dosi et al. (2015)

Appendix 3. Replication of stylized facts

3.1 Macro stylized facts

Let us start by looking at how the model replicates the macro empirical regularities (much more details on these results in Dosi et al. (2010) and Dosi et al. (2013)). Also in this version, the model is able to generate endogenous self-sustained growth patterns characterized by the presence of persistent fluctuations (see Fig. 1) as well as fat-tailed growth rate distributions (see Figs. 2 and 3). Furthermore, the relative magnitudes of the volatilities of GDP, consumption, and investment are respected: in Table 1, we have instead report a list of important stylized facts that the model is able to reproduce.

We also observe in Fig. 4 that the dynamic auto- and cross-correlation of GDP with consumption and investment are respected: consumption in highly pro-cyclical

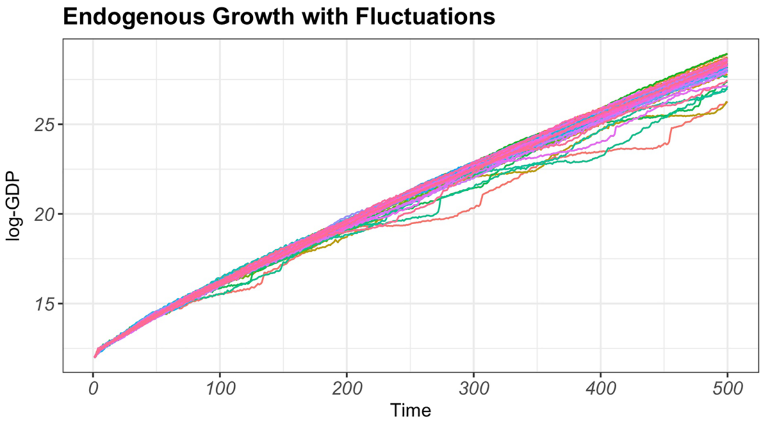

Fig. 1 Log-GDP time series for each Monte Carlo run displaying long-run trends with short-run business cycles

and synchronized with GDP (possibly reflecting a long-run cointegration relation) and investment is pro-cyclical and lagging.

Figure 5 presents instead the dynamic cross-correlations of GDP and private debt and of GDP and the amount of deposits: both are pro-cyclical and slightly leading.

Finally, we present some additional evidence on the dynamic auto- and cross-correlation between credit variables. In particular, Fig. 6 presents private debt and bad debt. These dynamic correlations are of particular importance for interpreting the results that we will present in the next section concerning the unconventional monetary policy and the mark-to-market accounting policy. Indeed, it is possible to see that private debt and bad debt are dynamically positively correlated; hence, they might possibly be a source of positive feedback mechanisms in the model aggregate dynamics.

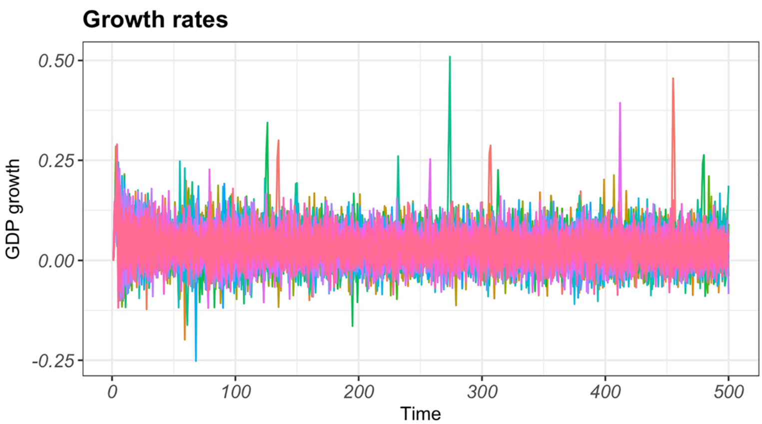

Fig. 2 GDP growth rate time series for each Monte Carlo run

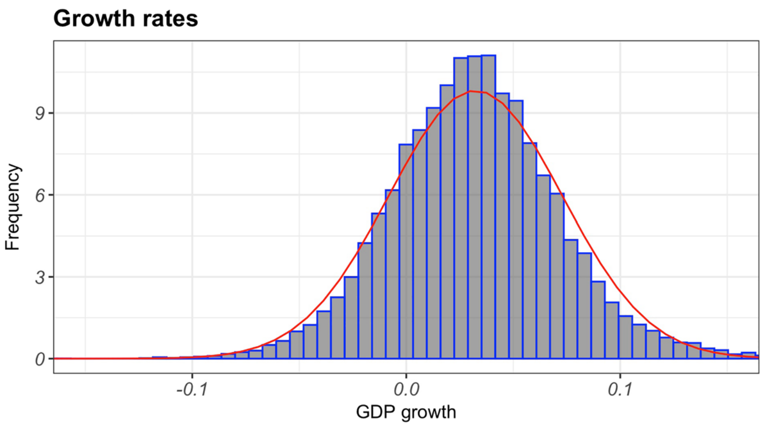

Fig. 3 Monte Carlo pooled growth rate distribution (histogram) versus a normal distribution with equivalent mean and standard deviation (red kernel density)

3.2 Micro stylized facts

Concerning the micro stylized facts, we here focus on the distributional properties of the firms. In particular, we investigate the size and the growth rate distributions (see respectively Figs. 7 and 8), the productivity growth distribution (see Fig. 9), and the persistence in productivity (see Fig. 10).

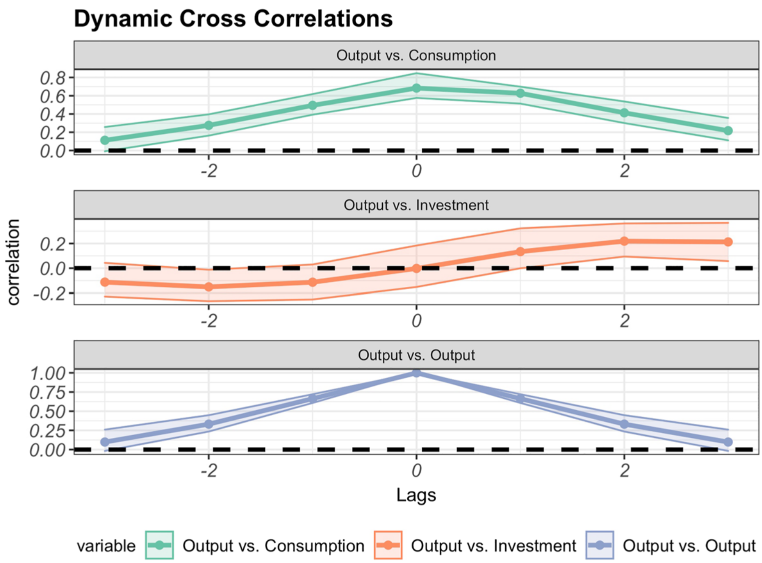

Fig. 4 Dynamic auto-correlation of GDP (green) and dynamic cross-correlations between BP filtered (6,32,12) GDP and consumption (red) and between GDP and investment (blue). Shaded area indicates the min-max range

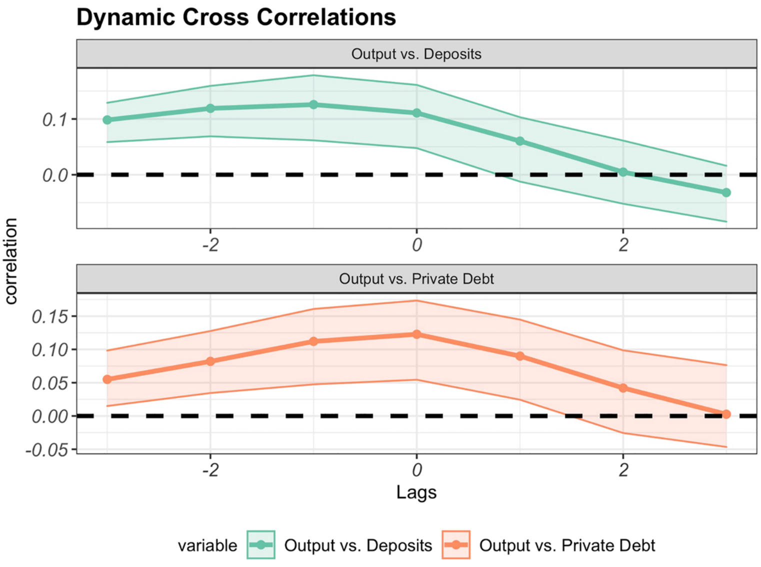

Fig. 5 Dynamic cross-correlation between BP filtered (6,32,12) GDP and outstanding private debt (green) and between GDP and deposits (red). Shaded area indicates the min-max range

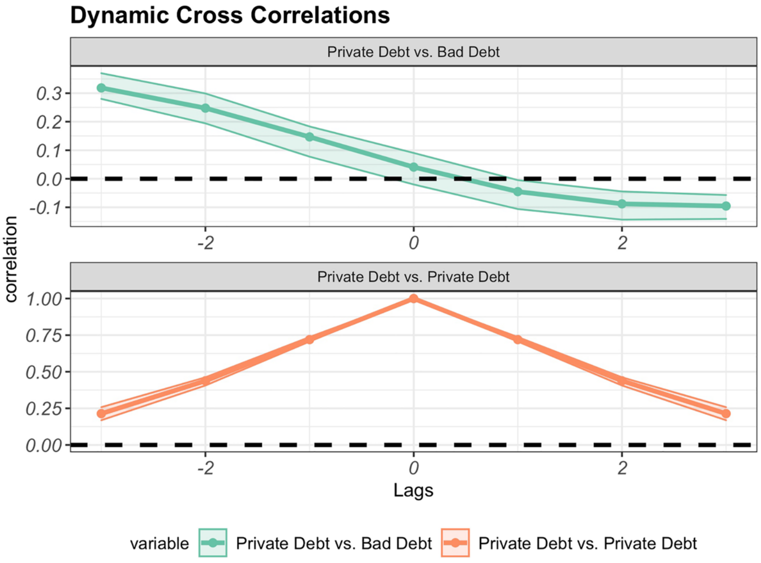

Fig. 6 Dynamic auto-correlation of BP filtered (6,32,12) total private debt outstanding and dynamic cross-correlation between private debt outstanding and the total amount of bad debt (red). Shaded area indicates the min-max range

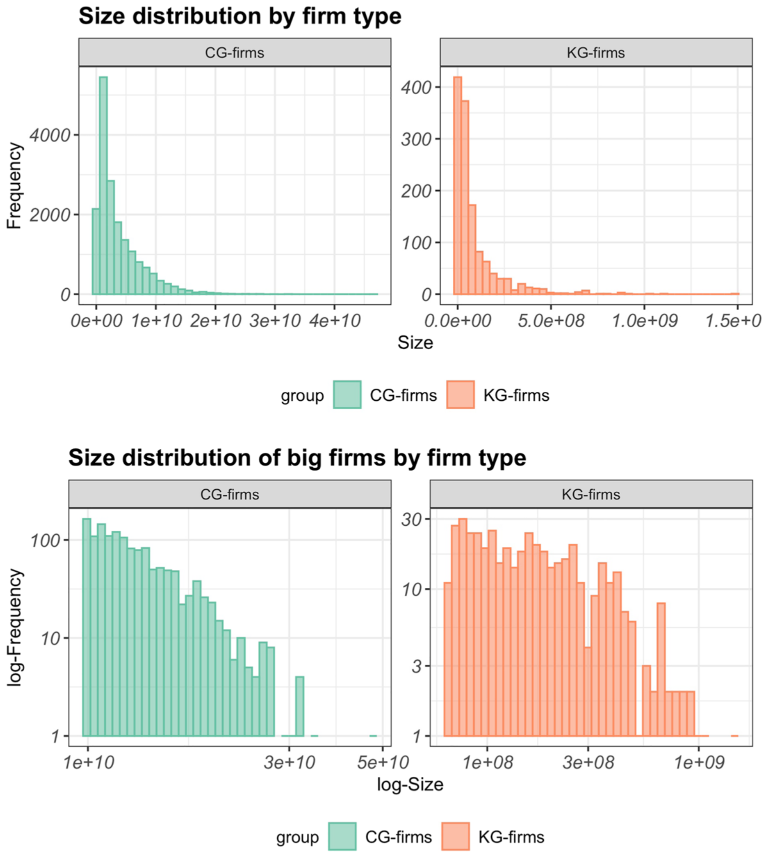

Fig. 7 Size distribution of all firms (upper panels) and size distribution of large firms in the log-log plane (lower panels). CG stands for consumption good, while KG for capital good

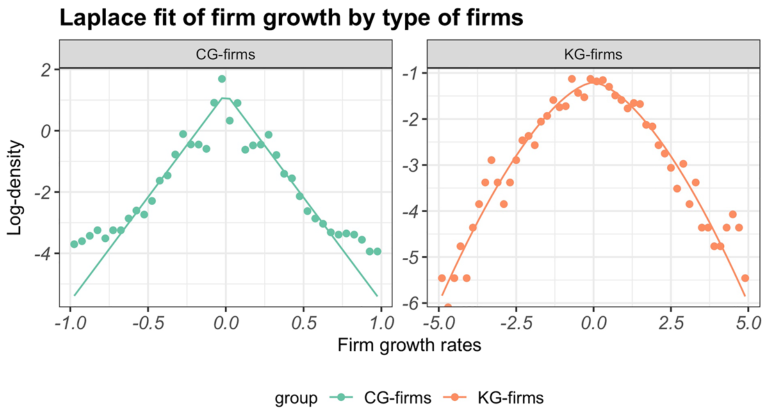

Fig. 8 Laplace fit (fitted lines) of the empirical (points) growth rate distributions of firms. CG stands for consumption good, while KG for capital good

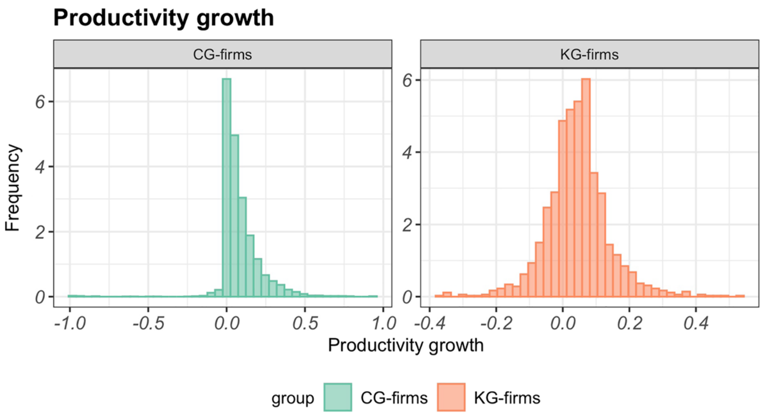

Fig. 9 Productivity growth distributions. CG stands for consumption good, while KG for capital good

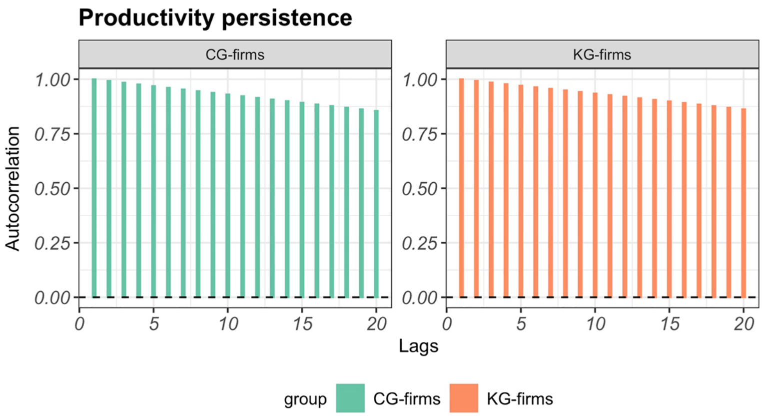

Fig. 10 Productivity persistence, as measured by the average auto-correlation function. CG stands for consumption good, while KG for capital good

References

Adrian T, Shin HS (2010) Liquidity and leverage. J Financ Intermed 19(3):418–437
Altavilla C, Giannone D (2017) The effectiveness of non-standard monetary policy measures: evidence from survey data. J Appl Econ 32(5):952–964
Arslan Y, Drehmann M, Hofmann B et al (2020) Central bank bond purchases in emerging market economies. BIS Bulletin 20, Bank for International Settlements
Ashraf Q, Gershman B, Howitt P (2016) How inflation affects macroeconomic performance: an agent-based computational investigation. Macroecon Dyn 20(2):558–581
Assenza T, Cardaci A, Delli Gatti D, Grazzini J (2017) Policy experiments in an agent-based model with credit networks. Economics - The Open-Access. Open-Assessment E-Journal, 66
Barth M (1994) Fair value accounting: evidence from investment securities and the market valuation of banks. Account Rev 69(1):1–25
Barth ME, Landsman WR, Wahlen JM (1995) Fair value accounting: effects on banks' earnings volatility, regulatory capital, and value of contractual cash flows. J Bank Financ 19(3-4):577–605

Baumeister C, Benati L (2013) Unconventional monetary policy and the great recession: estimating the macroeconomic effects of a spread compression at the zero lower bound. Int J Central Bank 9(2):165–212

Bernanke B, Gertler M, Gilchrist S (1994) The financial accelerator and the flight to quality. Working Paper 4789, National Bureau of Economic Research

Bhat G, Frankel R, Martin X (2011) Panacea, pandora's box, or placebo: feedback in bank mortgage-backed security holdings and fair value accounting. J Account Econ 52(2):153–173

Bhattarai S, Neely C (2016) A survey of the empirical literature on U.S. unconventional monetary policy. Working Papers 2016-21, Federal Reserve Bank of St. Louis

Bignon V, Biondi Y, Ragot X (2009) An economic analysis of fair value: accounting as a vector of crisis. Prisme 15, Cournot Centre for Economic Studies

Boca A, Galeotti M, Himmelberg CP, Rota P (2008) Investment and time to plan and build: a comparison of structures vs. equipment in a panel of Italian firms. J Eur Econ Assoc 6(4):864–889

Borio C, Zabai A (2016) Unconventional monetary policies: a re-appraisal. BIS Working Papers 570, Bank for International Settlements

Botzem S, Quack S (2009) (No) Limits to Anglo-American accounting? Reconstructing the history of the International Accounting Standards Committee: a review article. Acc Organ Soc 34(8):988–998

Boyer R (2007) Assessing the impact of fair value upon financial crises. Socio-Econ Rev 5(4):779–807

Caballero R, Farhi E (2018) The safety trap. Rev Econ Stud 85(1):223–274

Caballero R, Farhi E, Gourinchas P-O (2017) The safe assets shortage conundrum. J Econ Perspect 31(3):29–46

Caves RE (1998) Industrial organization and new findings on the turnover and mobility of firms. J Econ Liter 36(4):1947–1982

Chen H, Cúrdia V, Ferrero A (2012) The macroeconomic effects of large-scale asset purchase programmes. Econ J 122(564):F289–F315

Christensen J, Rudebusch G (2012) The response of interest rates to US and UK quantitative easing. Econ J 122(564):F385–F414

Chung H, Laforte J.-P., Reifschneider DL, Williams J (2011) Estimating the macroeconomic effects of the Fed's asset purchases. FRBSF Econ Lett 2011-03:1–5

Cincotti S, Raberto M, Teglio A (2010) Credit money and macroeconomic instability in the agent-based model and simulator Eurace. Economics - The Open-Access. Open-Assessment E-J 4:1–32

Colasse B (2010) Les fondements de la comptabilité. La Découverte

Dawid H, Delli Gatti D (2018) Agent-based macroeconomics. In: Hommes C, LeBaron B (eds) Handbook of computational economics, vol IV. Elsevier

De Santis RA, Zaghini A (2021) Unconventional monetary policy and corporate bond issuance. Eur Econ Rev 135:103727

Delli Gatti D, Gallegati M, Greenwald B, Russo A, Stiglitz JE (2010) The financial accelerator in an evolving credit network. J Econ Dyn Control 34(9):1627–1650

Demiralp S, Eisenschmidt J, Vlassopoulos T (2021) Negative interest rates, excess liquidity and retail deposits: banks' reaction to unconventional monetary policy in the euro area. Eur Econ Rev 136:103745

Dosi G (1988) Sources, procedures, and microeconomic effects of innovation. J Econ Lit 26(3):1120–1171

Dosi G, Fagiolo G, Napoletano M, Roventini A (2013) Income distribution, credit and fiscal policies in an agent-based Keynesian model. J Econ Dyn Control 37:1598–1625

Dosi G, Fagiolo G, Napoletano M, Roventini A, Treibich T (2015) Fiscal and monetary policies in complex evolving economies. J Econ Dyn Control 52:166–189

Dosi G, Fagiolo G, Roventini A (2010) Schumpeter meeting Keynes: a policy-friendly model of endogenous growth and business cycles. J Econ Dyn Control 34:1748–1767

Dosi G, Roventini A (2019) More is different... and complex! The case for agent-based macroeconomics. Journal of Evolutionary Economics. forthcoming

Duca J (2013) Did the commercial paper funding facility prevent a great depression style money market meltdown? J Financ Stab 9(4):747–758

Eisner R (1972) Components of capital expenditures: replacement and modernization versus expansion. Rev Econ Stat, 297–305

Engen EM, Laubach T, Reifschneider DL (2015) The macroeconomic effects of the Federal Reserve's unconventional monetary policies. Finance and Economics Discussion Series 2015-5, Board of Governors of the Federal Reserve System (U.S.)

Fagiolo G, Guerini M, Lamperti F, Moneta A, Roventini A (2019) Validation of agent-based models in economics and finance. In: Computer simulation validation. Springer, pp 763–787
Fagiolo G, Roventini A (2017) Macroeconomic policy in DSGE and Agent-Based Models redux: new developments and challenges ahead. J Artif Soc Soc Simul 20(1):1
Fama EF (1970) Efficient capital markets: a review of theory and empirical work. J Financ 25(2):383–417
Farmer R, Zabczyk P (2016) The theory of unconventional monetary policy. Discussion Paper 11196, CEPR
FASB (1991) Disclosures about fair value of financial instruments. Statement of Financial Accounting Standards No 107
Feldstein MS, Foot DK (1971) The other half of gross investment: replacement and modernization expenditures. The Review of Economics Statistic, 49–58
Gaffard J-L, Napoletano M (2012) Agent-based models and economic policy, vol 124. Revue de l'OFCE
Gagnon J, Raskin M, Remache J, Sack BP (2011) Large-scale asset purchases by the Federal Reserve: did they work? Economic Policy Review, 41–59
Gambacorta L, Hofmann B, Peersman G (2014) The effectiveness of unconventional monetary policy at the zero lower bound: a cross-country analysis. J Money Credit Bank 46(4):615–642
Goolsbee A (1998) The business cycle, financial performance, and the retirement of capital goods. Rev Econ Dyn 1(2):474–496
Gorodnichenko Y, Ray W (2017) The effects of quantitative easing: taking a cue from treasury auctions NBER Working Papers 24122. National Bureau of Economic Research, Inc
Greenwald BC, Stiglitz JE (1993) Financial market imperfections and business cycles. Quart J Econ 108(1):77–114
Guerini M, Lamperti F, Mazzocchetti A (2018) Unconventional monetary policy: between the past and future of monetary economics. Eur J Econ Econ Polic: Interv 15(2):122–131
Guerini M, Moneta A (2017) A method for agent-based models validation. J Econ Dyn Control 82(C):125–141
Heaton JC, Lucas D, McDonald RL (2010) Is mark-to-market accounting destabilizing? Analysis and implications for policy. J Monet Econ 57(1):64–75
Kapetanios G, Mumtaz H, Stevens I, Theodoridis K (2012) Assessing the economy-wide effects of quantitative easing. Econ J 122(564):F316–F347
Kolasinski AC (2011) Mark-to-market regulatory accounting when securities markets are stressed: lessons from the financial crisis of 2007–2009. J Account Econ 52(2):174–177
Krishnamurthy A, Vissing-Jorgensen A (2011) The effects of quantitative easing on interest rates: channels and implications for policy. Brookings Papers on Economic Activity 42(2 (Fall)):215–287
Kuttner KN (2018) Outside the box: unconventional monetary policy in the great recession and beyond. J Econ Perspect 32(4):121–46
La Porta R, Lopez-de-Silanes F, Shleifer A, Vishny R (1998) Law and finance. J Polit Econ 106(6):1113–1155
Lamperti F, Bosetti V, Roventini A, Tavoni M (2019) The public costs of climate-induced financial instability. Nat Clim Change 9(11):829–833
Lamperti F, Bosetti V, Roventini A, Tavoni M, Treibich T (2021) Three green financial policies to address climate risks. J Financ Stab 54:100875
Lamperti F, Dosi G, Napoletano M, Roventini A, Sapio A (2018) Faraway, so close: coupled climate and economic dynamics in an agent-based integrated assessment model. Ecol Econ 150:315–339
Lamperti F, Dosi G, Napoletano M, Roventini A, Sapio A (2020) Climate change and green transitions in an agent-based integrated assessment model. Technol Forecast Soc Chang 153:119806
Landsman W (2006) Fair value accounting for financial instruments: some implications for bank regulation. BIS Working Paper 209, Bank for International Settlements
Lester R, Kothari SP (2012) The role of accounting in the financial crisis. Account Horiz 26(2):335–351
Lo A (2004) The adaptive markets hypothesis: market efficiency from an evolutionary perspective. J Portfolio Manag 30(5):15–29
Lo AW (2017) Adaptive markets: financial evolution at the speed of thought. Princeton University Press
Martin C, Milas C (2012) Quantitative easing: a sceptical survey. Oxf Rev Econ Policy 28(4):750–764
Mazzocchetti A, Raberto M, Teglio A, Cincotti S (2018) Securitization and business cycle: an agent-based perspective. Ind Corp Chang 27(6):1091–1121
Peersman G (2011) Macroeconomic effects of unconventional monetary policy in the euro area. CESifo Working Paper Series 3589, CESifo Group Munich

Phelps ES, Winter SG (1970) Optimal price policy under atomistic competition. In: Microeconomic foundations of employment and inflation theory. WW Norton, New York, pp 309–337
Popoyan L, Napoletano M, Roventini A (2020) Winter is possibly not coming: mitigating financial instability in an agent-based model with interbank market. J Econ Dyn Control, 117
Quint D, Rabanal P (2017) Should unconventional monetary policies become conventional? Discussion Papers 28/2017, Deutsche Bundesbank
Rodnyansky A, Darmouni OM (2017) The effects of quantitative easing on bank lending behavior. Rev Financ Stud 30(11):3858–3887
Rogoff K (2017) Dealing with monetary paralysis at the zero bound. J Econ Perspect 31(3):47–66
Rossi B (2021) Identifying and estimating the effects of unconventional monetary policy: how to do it and what have we learned? Econ J 24(1):C1–C32
Rotemberg JJ (2008) Behavioral aspects of price setting, and their policy implications. NBER Working Paper 13754, National Bureau of Economic Research
Schasfoort J, Godin A, Bezemer D, Caiani A, Kinsella S (2017) Monetary policy transmission in a macroeconomic agent-based model. Adv Complex Syst 20(8):1850003
SEC (2008) Report and recommendations pursuant to section 133 of the emergency economic stabilization act of 2008 study on mark-to-market accounting. Technical report, United States Securities and Exchange Commission
Shiller RJ (2003) From efficient markets theory to behavioral finance. J Econ Perspect 17(1):83–104
Stiglitz JE, Weiss A (1981) Credit rationing in markets with imperfect information. Am Econ Rev 71(3):393–410
Swanson E (2017) Measuring the effects of Federal Reserve forward guidance and asset purchases on financial markets. NBER Working Paper 23311, National Bureau of Economic Research
Vandin A, Giachini D, Lamperti F, Chiaromonte F (2020) Automated and distributed statistical analysis of economic agent-based models. LEM Working Paper 2020/31, Sant'Anna School of Advanced Studies
Windrum P, Fagiolo G, Moneta A (2007) Empirical validation of agent-based models: alternatives and prospects. J Artif Soc Social Simul 10(2):8