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Abstract

An assessment of the sources of growth in agent- and general equilibrium-based models is presented, along a discussion of the strengths and weaknesses of existing approaches to growth modelling. The empirical and theoretical pitfalls of assuming wage-led growth or relying on meta-time market clearing assumptions are underlined. To address these issues, a mental-accounting consumer demand framework is developed, and a method of evaluating macroeconomic structural consistency of agent-based models is devised. It is claimed that structurally consistent agent-based models are as close counterparts of dynamic stochastic general equilibrium models as possible without compromising the assumption of no wage-led growth and while rejecting the meta-time simplification. Using three sectoral agent-based models, it was demonstrated that the variability of spending rates and including two final good sectors guarantee sustainability of growth, albeit at very weak rates due to structural consistency. Furthermore, it was found that including at least two final goods sectors is necessary for preventing collapse and ensuring realistic growth rates in agent-based models in which wage-led growth is forbidden. The main contribution of this paper is identifying the space for demand expansion and the structural inconsistency between demand, incomes, production, and firms' internal-division-of-funds structures, as the major sources of economic growth.

JEL codes: E71, O41, C63, E21, E22
Keywords: Agent-based macroeconomics, Structural consistency, Economic growth sources, Mental accounting

1. Introduction

In this paper, five issues are addressed. First, structural consistency (in the sense to be defined) of agent-based models (ABM) is discussed, and a way of evaluating dynamic stochastic general equilibrium (DSGE) and ABM approaches to growth modelling is presented. While the role of stock-flow consistency of ABM has been underlined and discussed in numerous studies (see, e.g., (Caiani et al. 2016)), the role of mutual consistency of the demand, production, and incomes structures has not been analysed. Furthermore, it is asked how is growth modelling possible if one rejects the predominant timing assumption in economic models, both ABM (see, for example, (Caiani et al. 2016; Dosi et al. 2010; Dosi et al. 2015; Dawid et al. 2019; Assenza et al. 2015)) and DSGE, that wages and incomes are spent on production, and the revenue generated in this process is the source of that demand. The analysis performed here can be treated as confronting the productivity-led general-equilibrium-like approach to growth modelling with variable-demand agent-based one (following Caballero's call to confront different modelling approaches, (Caballero 2010)). The comparison is performed under the condition that incomes paid at the end of a period cannot be spent for contemporary consumption or investment. In reference to this problem, the issue of what is the source of economic growth is addressed. Next, it is concluded that many ABM suffer from spurious real recessions and stagnations, and this calls for more elaborate production, sales and inflation modelling in the future. Finally, the issue of consumption microfoundations in DSGE and ABM that are contradictory with empirical studies, and (a form of) Lucas' critique are discussed. Basing on the findings of microeconometric studies, as well as cognitive psychology, behavioural economics, and consumer research, a mental-accounting-based framework is proposed for ABM. Moreover, the used modelling devices can be perceived as an application of contract and behavioural theories of the firm.

1.1. Structural consistency of ABM and comparing the AB and DSGE approaches to growth modelling

The proposed structural consistency of an ABM evaluation method is based on finding appropriate firms' internal-division-of-funds and debt-payments-burden parameters as well as relative size of production sectors that will clear the economy in its first period, given the assumed initial values. These include structures of demand, labour shares, firms' owners' profits, retained earnings, past and present credit and debt payments, and bank sector's balance sheet as well as cash flow structure. It is argued that this procedure is the closest one can get to a general equilibrium (GE) framework while using a stock-flow consistent, agent-based setting without compromising the assumptions of timing, i.e., new wages and incomes are paid at the end of a period, so they cannot be used to buy current output.

In this paper, basing on what ABM research and the performed analysis suggest (Dosi et al. 2010; Caiani et al. 2019a), a hypothesis is formed that (quick, or at rates observed empirically) economic growth is possible because the economies in question are structurally unbalanced. Another likely source of output increases is the space for demand expansions. These conclusions are based on the analysis of three models, each of which is constructed in the structurally consistent way mentioned above. The consistency does not only imply a great extent of (initial) coordination between final-goods sectors, the demand, income and firms' internal division of funds structures, but also leaves little space for demand expansion. The former point is made especially clear by expressing all variables in the initial period as functions of the two (or one) nominal productions, which yields a system of equations with no free terms, implying that the economy is described by a single equation. The method of pinning down a particular set of production and firms' parameters' values is given in section 3.

In such a framework, there is no wage-led growth, and wages are not paid ex nihilo, a modelling device used in many ABM and always present in DSGE. Moreover, the increases of total factor productivity do not automatically cause a rise in incomes, as current wages are set in the previous period. Additionally, they, as well as owners' incomes, are paid after sales take place. If these assumptions are treated as reflecting the real-world process, then given that new products must be paid for with money from the 'previous period', a natural question arises: how is growth possible? Even if it were due to wage-led expansion, new money for labour remuneration should come from somewhere. At least that is a conclusion if one considers timing to be an important component of the analysis and does not believe that wages are updated in continuous time. New consumer or corporate credit might seem to be the answer, nevertheless, a simple thought exercise demonstrates the possible weakness of such a hypothesis.

Consider the following system, with one final-good sector (with sales-production $F_t^{c,N}$) and m intermediate-goods sectors ($F_t^{n_j,N}, j \in \{1, ..., m\}$):

$$\begin{pmatrix} F_t^{c,N} \\ F_t^{n_1,N} \\ \vdots \\ F_t^{n_m,N} \end{pmatrix} = \begin{pmatrix} d_{t-1}^{CA,H} - dps_t^H + b_t^H + \varphi^{c,N} \cdot (d_{t-1}^{CA,f_c} - dps_t^{f_c}) \\ 0 \\ \vdots \\ 0 \end{pmatrix} +$$

$$+A \otimes \begin{pmatrix} (1-\varphi^{c,N}) \cdot (d_{t-1}^{CA,f_c} - dps_t^{f_c}) + b_t^{f_c} \\ d_{t-1}^{CA,f_{n_1}} - dps_t^{f_{n_1}} + b_t^{f_{n_1}} \\ \vdots \\ d_{t-1}^{CA,f_{n_m}} - dps_t^{f_{n_m}} + b_t^{f_{n_m}} \end{pmatrix} + B$$

where $d_{t-1}^{CA,i}$ is the beginning-of-period-t current account of sector i (where the subscript indicates that they were formed at the end of t-1), where H denotes the households - consumers - sector, dps_t^i denotes its (past) debt payments while b_t^i its new debt, and $\varphi^{c,N}$ allows for the possibility that some of the final-goods sector's funds are spent on the final good. A is a matrix of firms' internal-division-of-funds and sectoral flows coefficients, while B is the input of the banking sector (expenditures made from past bankers' wages and banks' direct or indirect investment in the real economy). These equations imply that, for every sector and the whole economy to grow, the sum of new debts and B must be greater than the sum of current debt payments. But B cannot be larger than these payments - and one has to keep in mind that some parts of the banks' cash flow will have to cover interest on deposits, wages, increase reserves, etc. Thus, this suggests that the rate of growth of consumer and corporate debt would have to be very high to constitute the growth engine. At the same time, it is at least strange, or unsettling, to suggest that real-world economies basically act as Ponzi schemes, especially taking into account the speed of their growth. Another concern is whether such a mechanism would be sustainable enough to uphold the rates of growth observed in reality, rather than collapsing. Moreover, for the real product to grow, the growth of nominal consumer and corporate debt would have to surpass not only the growth of debt payments, but also inflation.

In this paper, it is argued that the reason for growth rates reaching the levels observed empirically is either a structural imbalance of a considered agent-based economy, or large space for demand expansion. It is important to underline here, that in this work, the goal is the demonstration of possible deficiencies of the prevailing approaches to explaining economic growth, not to propose 'the' framework for such an analysis. In turn, the presented structural consistency evaluation method is a proposed benchmark against which future agent-based models can be compared. Furthermore, it can be applied to assess the type of structural inconsistency of such a model.

1.2. Spurious real recessions and stagnations in agent-based models

It is argued that many ABM suffer from spurious real recessions and stagnations, i.e. situations where nominal output (or sales) grows, but the real one undergoes a recession, or is flat (by 'spurious' it is meant that stagflations do not appear so often in real-world economies). In this work, it is demonstrated that the reason may lie in an inadequate modelling of inflation, production, and sales. However, another problem emerges: to prevent (or make rare) real decreases of output, nominal aggregate demand would have to grow as fast as productivity and inflation combined. Additionally, something that is already recognised in the ABM community is shown, namely the weaknesses (or even inadequateness) of traditional Cobb-Douglas production function (the dissatisfaction with this modelling device is shown by the widespread adoption of single-factor or Leontief functions in the agent-based literature, (Caiani et al. 2016; Dosi et al. 2010; Dawid et al. 2019)). Thus, the paper is concluded with a call for more elaborate production, sales, and inflation modelling.

1.3. Consumption microfoundations

There is a persisting inconsistency in the main, general-equilibrium-based approach to macroeconomic theory. The role of appropriate microfoundations is underlined, backed by various forms of Lucas' critique, generally agreeing on the claim that wrong assumptions about agents' behaviour not only can, but will lead to wrong conclusions (even if only qualitative) concerning the aggregate dynamics of real-world economies. Paradoxically, when critics of the models used in economic theory voiced their concerns whether these actually represent real-world behaviour, economists have often repeated the old argument of Milton Friedman, that only predictions and general intuition provided by a model matter (Friedman 1953). The 'as if' approach of applying intertemporal optimisation, loosely based on choice theory, to represent household and firm behaviour is the standard one. But, these two arguments cannot be valid at the same time, and the general appreciation of the role of microfoundations of macroeconomics among economists seems to tilt the balance toward the first position. However, there is mounting empirical evidence against the intertemporal optimisation model of consumption in the canonical form that is associated with the permanent income hypothesis/life-cycle model (PIH/LCM henceforth). Even its variation, the buffer-stock model, after finally being put to empirical verification, does not seem to be in accordance with the data.

Applying a 'Lucas' critique' would mean the rejection of these frameworks or a search for their further refinements. But, as noted by Deaton (1992), all of the approaches based on intertemporal framework share certain features, such as the dependence of the consumption Euler equation on the interest rate, or the resulting smoothness of consumer expenses. These characteristics are questionable in light of microeconomic studies of consumption and cognitive psychology research. An early contribution to this debate was provided by Flavin (1981), who rejected the rational expectations-permanent income hypothesis with an econometric model using aggregate data on the United States' economy. Further evidence against the PIH was provided by Campbell and Deaton (1989), who not only demonstrated that (aggregate) consumption is less smooth then predicted by permanent income hypothesis, but also claimed that this is due to the fact that it responds with a lag to changes in income. Earlier, Mankiw (1985) suggested that spending on consumer durables is much more sensitive to changes in the interest rate than is expenditure on nondurables and services. This could point to at least the need for two distinct Euler consumption equations. However, given the nature of consumer's intertemporal optimisation (as it is stated in standard macroeconomic literature), the interest rate will have a large impact on both goods even under separable preferences, because of changes in the budget constraint induced by adjustment of interest-rate-sensitive commodity. It may also indicate that for understanding and representing consumption dynamics, another explanation is needed. Jappelli and Pistaferri (2010) surveyed micro- and macroeconometric literature, and came to the conclusion that consumption behaviour consistent with permanent income hypothesis is contradictory to the empirical evidence, while Parker (2017) discovered that the pattern of spending of households is highly predictable by past income, years before the predictable lump-sum payment whose effects he investigated. Deaton (1991) discussed that precautionary saving and liquidity constraints could both be important parts of the solution of the consumption excess sensitivity (relative to the one resulting from PIH framework) puzzle. Carroll (1992) argued that unemployment expectations are crucial for buffer-stock behaviour, and, unlike Deaton, included unemployment in his model. He became the main proponent of the buffer-stock theory of consumption, arguing that it can explain several empirical puzzles (Carroll 1997). Carroll and Kimball argued that the consumption function (consumption rule) is concave, a property which is vital for understanding the emergence of buffer-stock behaviour (Carroll and Kimball 1996). Finally, Carroll showed that precautionary saving and liquidity constraints are interconnected (Carroll

2001).

Despite these promising theoretical results, the few empirical tests of the buffer-stock model were negative. Ludvigson and Michaelides (2001) showed that the standard buffer-stock model does not generate consumption growth and robust excess sensitivity that would be smoother than aggregate income growth. They proposed a buffer-stock model with incomplete information, but received a negative result, i.e. even this version of the buffer-stock framework failed to match the data. They concluded that an important implication of their model's results is that inferences about aggregate buffer-stock consumption cannot be made by analysing household-level, representative agent consumption functions. Jappelli et al. (2008) tested the buffer-stock theory on a panel data set of Italian households, with negative results.

One of the alternatives to intertemporal optimisation framework is mental accounting, introduced by Thaler (Thaler 1980; Thaler 1985; Thaler 1990; Thaler 1994; Thaler 1999), Kahneman and Tversky (Tversky and Kahneman 1981). Building on cognitive psychology, Thaler proposed foundations for a new approach of consumer behaviour with two crucial characteristics. First, current income flow influences expenditure more than the present value of lifetime wealth. Second, consumer spending tends to be grouped into categories, and subsequently potential expenditures are considered within their category. Tversky and Kahneman (1981) suggested a S-shaped utility function for gains and losses, but their approach applies solely to lotteries (or situations perceived as such), not to everyday decisions on how the available income of a consumer ought to be divided between categories of goods and saving. While Shefrin and Thaler (1988) proposed the behavioural lifecycle hypothesis to replace the PIH/LCM, what they did not demonstrate is how to apply the conditions they have enumerated in a macroeconomic model featuring both consumers and firms. Moreover, they did not show how their framework could accommodate different categories of goods, since they only considered current income, asset balance and future income. Heath and Soll (1996) introduced two interesting assumptions to mental accounting theory, namely that consumers set their category-related budgets in advance of consumption and that each of them is unlikely to allocate the exactly right amount of money (to ensure maximal satisfaction or to use arising opportunities). Similarly, Henderson and Peterson (1992), C. Y. Zhang and Sussman (2018a), and C. Y. Zhang and Sussman (2018b) underlined that consumers and investors often categorise their expenses and use separate budgets for each category. Antonides et al. (2011) provided strong empirical evidence for mental accounting consumer behaviour in the Dutch population. Nonetheless, all these works belong to the consumer research and psychology fields, and thus no general macroeconomic framework was proposed. To the author's knowledge, the only fully formalised mental accounting approach is the model of Montgomery et al. (2019). Since it is based on intertemporal optimisation, the changes of expenditures on each of the categories of goods from period to period are inevitably related to the interest rate. This fundamental assumption, however, is questioned by numerous microeconometric studies; after controlling for income in regression analysis, consumption was, in fact, found to be little sensitive to changes in the interest rate (Campbell and Mankiw 1989; Yogo 2004; Canzoneri et al. 2007). The latter conclusion is devastating also for the standard intertemporal-optimisation-based macroeconomic models. The new class of Heterogeneous Agents New Keynesian ones attempts to accommodate these facts by introducing random labour supply shocks (see, for instance, (Kaplan and Violante 2018)). Nevertheless, since the basic approach to modelling consumers' problems remains the same, the resultant Euler equation imposes a relationship between the interest rate and consumption. Indeed, it may be impossible to credibly introduce mental accounting using an intertemporal optimisation framework, as all first-order conditions of the household would be interrelated by the budget constraint, and thus by the interest rate (or any other device used to relate current to future variables). An easy solution may be at hand: agent-based models allow for analysing much broader range of behaviour rules. While it is not clear how to apply mental accounting theory on its own, a related concept - categorisation theories - may be invoked to create a new framework.

As Henderson and Peterson (1992) underlined in their review and synthesis of the literature, categorisation theories address the processing and grouping of information (treated very broadly), whereas mental accounting focuses on the outcomes of this actions. They described how people organise and process new information. While there are a few various categorisation theories, Henderson and Peterson argued that all of them can be described by a few shared principles. First, information about elements is organised into groups; they underline that mental accounting is a special case in that it evaluates information of an event positively or negatively. Second, grouping of elements is spontaneous and results from prior learning or many past choices, and may occur with minimal though and effort. It increases cognitive efficiency. Next, elements in a category are context-dependent, which is in line with mental accounting (Kahneman and Tversky 1984). However, most categorisation theories allow elements to belong to more than one category, while mental accounting does not (Shefrin and Thaler 1988). At the same time, categorisation allows to tackle problems associated with mental accounting. Firstly, the latter is unable to account for individual differences, while the former proposes that people differ with respect to a category or in the associations with it. Secondly, it can be argued that mental accounting theory concludes that people behave suboptimally, but categorisation theories, conversely, claim that grouping of information provides easier access to additional one and facilitate making a decision.

The empirical inadequateness of intertemporal-optimisation consumption framework is not the only problem that macroeconomics is faced with. There has been a growing awareness among economists that the standard models - DSGE with representative agents - are unsatisfactory research tools. Kirman (1992) claimed that a framework using agents that are utility maximisers is inappropriate for studying macroeconomic questions. He underlined the problems with making conclusions about the world using models that feature no trade and are effectively static within each period of the analysis. According to Kirman, there is no plausible formal justification for assuming that the collection of many (or a continuum of) individuals, acts in a manner representable by an individual maximizer. Furthermore, the responses of such a construct to some changes in parameters or structural shocks may not be the same as the aggregate reaction of the represented agents. His next argument has a computational economics flavour: any attempt to explain the behaviour of a group by the means of a representative individual is constraining. The sum of the behaviour of many agents may generate complicated dynamics. Finally, Kirman suggested that the way to develop appropriate microfoundations for macroeconomics should not start from the study of individuals in isolation, but ought to be based on studying the aggregate activity resulting from the direct interaction between different individuals.

Casting doubt on the supposed microfoundedness of DSGE models, Chari et al. (2009) questioned the entire logic of the contemporary mainsteam approach to macroeconomics. They argued that the shocks in New Keynesian models - as opposed to disturbances present in the neoclassical ones - are dubiously structural and that the new features, i.e. the forms of nominal rigidities, are inconsistent with microeconomic evidence. This is because researchers attempt to fit macroeconomic models to data, and if a fit is poor, then economists add various shocks and other features to their models. Then, economists use the same old aggregate data to estimate the associated new parameters. This tradition does not conform to microeconomic evidence, and therefore, as Chari et al. argued, New Keynesian models are plagued by free parameters. Thus, they claimed, New Keynesian DSGE are not useful for policy analysis, foremostly because these models rely on dubiously structural shocks. Furthermore, Chari et al. criticised backward indexation of prices and the Taylor rule as the common representation of the central bank's policy on the basis that both are inconsistent with the data (Chari et al. 2009).

Raising a partly similar critique, but from a keynesian, not neoclassical perspective, Stiglitz (2011) enumerated the shortcomings of a traditional

DSGE approach. He indicated the lack of complexities, inadequate modelling of risk, and little focus on distributional issues. Moreover, Stiglitz argued that it is hard to reconcile overall corporate financial policy with any model of rationality. In this he echoed the old - but unresolved - concerns of Simon, who for years had promoted the notion of bounded rationality (Simon 1955; Simon 1957; Simon 1978).

The community of macroeconomists has acknowledged some of these remarks. However, the response has not been much different than the prevailing practice of introducing small changes to the basic version of the model. The new class of models, named Heterogeneous Agent New Keynesian, while introducing distributional considerations, has retained many of the questioned characteristics of its representative-agent predecessors. Intertemporal optimisation approach to representing consumer behaviour yields the Euler equation; heterogeneity is achieved by the introduction of random labour supply shocks, lacking empirical justification (other than matching the income distribution data); corporate finance is not perceived as important for the macroeconomy, and it is still considered that working capital rented by households to firms is a good approximation of firms' internal funds division, organisation, and debt burden (Kaplan and Violante 2018).

Computational and behavioural economists have long criticised various features of the models of general equilibrium and dynamic stochastic general equilibrium (DSGE) families (Fagiolo and Roventini 2012; Caiani et al. 2016; Fagiolo and Roventini 2017; Landini et al. 2020). The most of the critical remarks concerned the (lack of) realism of these models' assumptions. Although representing consumption choices by intertemporal optimisation is widely criticised by researchers using agent-based models, all of the agent-based frameworks that have been presented to date have featured its counterparts. While no optimisation problems were introduced in any agent-based approach, most models rely on assuming buffer-stock or permanent-income-like behaviour of consumers, in the most extreme cases making agents spend all of the received income. Thus, it can be argued that the agent-based literature has not gone much further than the standard framework in representing consumer spending according to empirical evidence. The approach proposed by Salle et al. (2013) and Salle (2015) is an interesting example, since it can be perceived as a mix of PIH and mental accounting frameworks. In these models, consumption of a household is determined by a parameter that varies within specified bounds, according to changes of the gap between the real interest rate it expects and the current natural level. This value is then multiplied by the permanent income of a given consumer, determining the demand. Nevertheless, the main component of this approach is still the permanent income, and the consumption rate depends on the real interest rate.

1.4. Other problems with agent-based models

Although many computational economists have criticised the general equilibrium approach to macroeconomic modelling - the immediate adjustment (occurring in meta-time) of prices guaranteeing market clearing or the aggregate resource constraint - the agent-based approach does not have a unified measure of model consistency. On the contrary, the majority of published research papers had neither a definition nor any measure of it. According to Caiani et al. (2016), most agent-based models are not even stock-flow consistent (SFC). What is even more striking, there are very few agent-based models without the burn-in period of increased volatility and abrupt growth (or fall) of output (Caiani et al. 2016). Even the model of Caiani et al., despite the procedure of ensuring stock-flow consistency, suffers from this drawback. The presence of burn-in periods prevalent among agent-based models suggests that their structures - or at least the initial values of variables - are inconsistent to a degree that is not justifiable when comparing the volatility with the real-world data. This raises the question of whether agent-based models can be called realistic if they display dynamics not observed empirically and feature consumption rules that are at odds with empirical evidence. Another problem concerning the issue of structural consistency of an ABM is its definition. Is including a Leontief-like, or macro-accounting, sectoral flows matrix enough and is it feasible in this framework? The work of Zhong and He (2022) shows the difficulty that lies in using such an approach. It is probably impossible to apply it and maintain any kind of heterogeneity of consumers (or their independence: in (Zhong and He 2022) there are no other agents than firms).

Not only consumption is represented in economic models contrary to empirical evidence. While those presented in Dosi et al. (2010), Dosi et al. (2013), Dosi et al. (2015), Seppecher and Salle (2015), Seppecher et al. (2018), and Seppecher et al. (2019) do not exhibit volatile dynamics during burn-in (initial) periods and have remarkable insight on coordination between many interacting agents, growth in all of them relies on the wage-setting mechanism. It either prescribes all firms but the one which pays the highest wages, to increase their offer and attract new workers, or imposes that wages automatically increase, following productivity growth. In the first case, the firm with the highest offer changes its wage according to labour market tightness. Thus, these models belong to the wage-led growth category, but this notion has little empirical support (Skott 2017). Additionally, Seppecher et al. (2018), who analysed two intermediate and one final-good sector, did not present any measure of initial structural consistency of the model, apart from stock-flow consistency. The latter, however, as can be seen in the work of Caiani et al. (2016), is not sufficient to ensure that 'spurious' growth does not emerge in the model's output.

The banking sector, if it is present at all, is unrealistically represented both in agent-based and DSGE models. Most ABM that focus on the analysis of this sector restrict attention to the interbank network, bankruptcy avalanches, and stability of the system; important results in that strand of research include, among else, (Delli Gatti et al. 2010) and (Gurgone et al. 2018). However, in virtually all ABM that include a banking sector it is assumed either that all debt is taken out by firms and other banks or that households hold only consumer loans. Nonetheless, in reality the majority of banks' assets is constituted by multiperiod housing and consumption loans, and government (as well as the central bank) securities play an important role. Most models, conversely, either assume that all debt is incurred by firms or that all loans are one-period debts taken out for consumption purposes. The second approach may be dubious, since in reality housing loans are multiperiod and concern goods that differ tremendously from vast majority of consumer or even durable goods. Moreover, they concern a different market, which may be supplied by firms that differ in important ways from those operating in other sectors. What is more, houses, flats, mortgages and housing loans are hardly interchangeable with production capital of firms. To the author's knowledge it has not been proven or demonstrated empirically that their aggregate value is causally related to the latter. Additionally, management research clearly indicates that firms do not rent capital, and resort to credit only if their retained earnings are not sufficient to cover expenses (see, for example, (O'Brien 2003)). Even if a housing (or a durable) good is introduced in a DSGE framework, then it is interrelated with firms' production capital through the optimality conditions of the household. This displays another discrepancy between DSGE world and reality - there is not a single demonstration in the literature that the value of production capital of firms equals the value of savings of households. What the balance sheets of banking sectors demonstrate is even more devastating: the value of all loans and credit is less than the value of all deposits. While some GE-based macroeconomic models feature fiat money in addition to the saving good (capital), what is ignored is the major role of housing loans, reserves, government and central bank securities for the solvency of the banking sector, as well as the importance of such a large amount of new debt continually entering the economy.

The issue of the inconsistency suggested by burn-in periods in agent-based models raises a question of whether economic growth displayed by some of the models from this framework is not a result of only a mismatch between the structures of demand, supply and income assumed by the modeller. The major issue is how is growth possible in agent-based models and why it arises; such an analysis is likely to increase the understanding of economic growth sources in the real world. The DSGE framework ignores the timing of events during a given period, as well as assumes that wage-setting and rent from capital occur in meta-time, so that demand always equals supply. If growth is studied, the analysis focuses on balanced growth scenarios, with linear growth rate that can be easily removed or the distribution of shocks to the growth rate known to the agents (and thus enabling the modelling of their behaviour as Markov decision problems), so that the properties of the steady state of the system can be investigated. This, of course, is the effect of the adopted modelling approach, using dynamic system of difference or differential equations. However, it separates the analysis of economic growth from analysing economic fluctuations, and neglects entirely the interactions between demand and supply. The latter is the result of imposed aggregate resource constraint, which serves as one of the measures of internal consistency of an analysed system. Nevertheless, it precludes by assumption the possibility of a mismatch between supply and demand, and effectively pushes the volatility associated in reality with demand into the volatility of the remainder of the production function (i.e. the total factor productivity).

Research using agent-based models has proven to be very promising in numerous areas of economic inquiry. The mechanics of a Schumpeterian engine of growth were introduced and studied (Dosi et al. 2019; Dosi et al. 2018; Dosi et al. 2017; Dosi et al. 2015; Dosi et al. 2013; Dosi et al. 2010; Dosi et al. 2008), the role of stock-flow consistency was underlined (Caiani et al. 2016), firms' expectations and evolution of market strategies investigated (Salle et al. 2019; Seppecher et al. 2019; Seppecher et al. 2018; Salle and Seppecher 2018; Salle 2015; Salle et al. 2013). While agent-based models necessitate rigour in terms of stocks and flows of variables as well as timing of events, especially when wages and other types of income are determined and paid, all existing approaches face problems when studying economic growth. In all agent-based frameworks, it is a result of at least one of the following three factors. The first one is the mismatch between the structures of demand, supply and income, which is the cause for burn-in periods, but may also be one of the causes of growth. The second are imposed reservation wage shocks, which act also as demand shocks, thereby causing wage-led growth (Caiani et al. 2016; Caiani et al. 2019b; Caiani et al. 2019a). The third factor consists of imposed productivity shocks combined with endogenous investment in R&D leading to increased investment (or only one of these features), thereby raising output and wages, and so future demand as well. Moreover, frameworks characterised by such an approach feature also the previous, wage-led engine, (Caiani et al. 2018; Dosi et al. 2019; Dosi et al. 2018; Dosi et al. 2017; Dosi et al. 2015; Dosi et al. 2013; Dosi et al. 2010; Dosi et al. 2008; Dosi et al. 2006). However, how can wage or income growth precede the aggregate gains obtained due to an innovation? In reality consumers do not receive their income in continuous time, so what is the reason for the increase in demand necessary for the growth of output? If the answer were that new investment is the cause for the increase of wages, then another question arises: why would firms invest if they did not expect an increase in demand?

This is the fundamental problem underlying the ways that investment and transactions, timing of wage-setting, structures of incomes, production and foremostly demand are modelled. It is worth noting that although the activity of marketing is nothing else than new demand generation (or enhancing the existing one), there is scarcely any formal model proposing to include this economic channel in a theoretical framework. In this paper, a method of representing this impact as a part of an agent-based mental accounting framework is proposed. Additionally, a method of establishing and assessing initial structural consistency of agent-based models and its initial values is presented, along with the features that are necessary for this procedure. The mental accounting framework with variable rates of consumption from accounts is compared with a 'static' mental accounting model (with the aforementioned rates held constant) and with a quasi-buffer-stock model comprising only one, consumption good, sector. The comparison of the first two shows that new demand creation and consumer expenditure fluctuations are vital components for understanding economic growth, but also suggests that the assumed initial consistency of the economy is an unwanted feature, hindering growth by imposing structural constraints on its pace. The results of the third model indicate that introducing a second final (in this case, housing/durable) good sector to the model has a stabilising effect on its output, showing the way for building more realistic agent-based models.

2. The model

2.1. Mental accounting framework

There seems to be a general consensus among economists that marginal propensities to consume are variable. This assumption is reflected in how DSGE models are constructed, and was fully introduced in several agent-based models (Salle et al. 2013; Seppecher and Salle 2015), or included only partially, using a switching rule representing the buffer-stock behaviour (Salle and Seppecher 2018; Seppecher et al. 2018; Seppecher et al. 2019). The problem underlying any attempt at constructing a mental accounting framework using an agent-based models is characterising what triggers a change in the marginal or total propensity to consume out of an account (a category devoted for a certain type of goods). As noted above, microeconometric studies have often rejected the proposition that interest rates have major impact on individual consumption. Changes in disposable income, marketing, and inflation, on the other hand, seem good candidates for variables affecting the changes of propensities to consume.

The model features eight types of sectoral agents: h_1 - households (workers) of type 1, h_2 - households (workers) of type 2 , own_1 - owners of firms producing the consumption good (f_1), own_2 - owners of firms producing the durable/housing good (f_2), b - workers of the banking sector (B). From now on, for convenience and interpretation reasons, each sector will be addressed using plural forms (the sector of consumption good firms; durable good firms, etc.) or as an aggregate firm. While heterogeneity and plurality of agents are much stressed in agent-based literature, the approach adopted here is to focus ideas and display the role of sectoral balance in the initial consistency procedure and macroeconomic evolution of an economy more clearly. Also, it is widely accepted in the agent-based stream of economic research that interactions of many entities yield emergent properties; the goal here is to study only those that occur at sectoral levels.

All consumers (agents excluding firms and the banking sector) are assumed to divide their disposable incomes into three accounts: one per each good category, a minimum saving rate. Additionally, if an agent is a loan-taker, then a fourth budget is present, relating to the disposable income as well. Within each of the two consumption budgets, expenditure rates vary according to behavioural rules - one for the growth and one for the fall of perceived income. This echoes the preference reversal theory (Kahneman and Tversky 1984). Moreover, all consumers that have saving accounts, $d_t^{SA,i}$ (in addition to current accounts, $d_t^{CA,i}$), spend a fraction of it in each period, according to a rate shifting between two values, depending on whether the perceived income change is positive or negative. The expenditure rates corresponding to no change in the perceived income are denoted by $\bar{\beta}^{c,i}$ and $\bar{\beta}^{hs,i}$; for h_1, own_1, own_2, b. Households type 2 are assumed to be hand-to-mouth, as this type of consumers is believed to constitute a non-negligible fraction of population in modern developed economies (Kaplan and Violante 2018; Kaplan et al. 2014; Kaplan and Violante 2014). Time periods in the model are interpreted as quarters.

Average (i.e. given no change in perceived incomes) and minimum saving rates are denoted by $\bar{\sigma}^i_{sr}$, $\sigma^i_{sr,min}$. The shares of budgets for each of the goods are defined as:

$$\eta^i_c = \bar{\beta}^{c,i} + \bar{\sigma}^{c,i}_{sr}$$
$$\eta^i_{hs} = \bar{\beta}^{hs,i} + \bar{\sigma}^{hs,i}_{sr}$$

where $\bar{\sigma}^i_{sr} = \bar{\sigma}^{c,i}_{sr} + \bar{\sigma}^{hs,i}_{sr}$.

Additionally, for $i \in \{h_1, h_2, own_1\}$ we have η_h, which determines the size of the 'budget' for new debt and $\sigma^{h,i}$ - the degree of volatility of the behavioural decision variable $\beta^{\bar{h},i}_t$. It can be perceived as self-constraints that agents adopt in order not to borrow too much, or as a reduced-form representation for credit constraints. Disposable incomes of different types of agents equal end-of-period $(t-1)$ (at the same time, beginning-of-period t) current accounts (minus debt payments, if any). For $i \in \{h_1, h_2, own_1\}$, we have:

$$\tilde{\Omega}^i_t = d^{CA,i}_{t-1} - dps^i_t$$

Owners of the firms type 2 and bankers (own_2, b) are assumed not to take out debt. This is because the model is sectoral, and debt-taking behaviour of own_2, b sectors would effectively mean that they partly pay themselves their incomes with new debt. To avoid such Ponzi-like mechanisms, the assumption is that as sectors, own_2, b do not hold debt. Thus, for $i \in \{own_2, b\}$ we have:

$$\tilde{\Omega}^i_t = d^{CA,i}_{t-1},$$

For h_2, given the assumption of no savings, a simpler mechanism is adopted: they divide disposable income, $d^{CA,h_2}_t - dps^{h_2}_t$, according to a constant parameter β^{ch,h_2}, where d^{CA,h_2}_t denotes the current account of h_2.

The effect of marketing on consumers' preferences is represented through the variable $\rho^A_{pref,t}$:

$$\begin{cases} \rho^A_{pref,t} = \rho_M^{\rho^{dA}_{pref}}, & \text{if } \rho^A_t > 1 \\ \rho^A_{pref,t} = 1, & \text{if } \rho^A_t \leq 1 \end{cases}$$

however, since the growth of TFP is assumed to be constant, and there are no random shocks to the supply side or to the marketing process, the value of $\rho^A_{pref,t}$ will be constant as well (and above 1).

Expenditure variables of $i = h_1, own_1, own_2, b$ are functions of perceived income changes, which in turn are functions of disposable income one-period (gross) growth rates, inflation for the price of a good (Π^c_t or Π^h_t), and the effect of marketing efforts of firms.

$$\hat{\Omega}_t^{c,i} = \frac{\tilde{\Omega}_t^i}{\tilde{\Omega}_{t-1}^i} \cdot (\Pi_t^c)^{-\rho_\Pi^c} \cdot (\rho_{pref,t}^A)^{\rho_{pref}^{dA}}$$

$$\hat{\Omega}_t^{h,i} = \frac{\tilde{\Omega}_t^i}{\tilde{\Omega}_{t-1}^i} \cdot (\Pi_t^h)^{-\rho_\Pi^h} \cdot (\rho_{pref,t}^A)^{\rho_{pref}^{dA}}$$

The levels of $\bar{\beta}^{c,i}$ and $\bar{\beta}^{hs,i}$ are related with each other and the average saving rate:

$$\bar{\beta}^{hs,i} = 1 - \bar{\beta}^{c,i} - \bar{\sigma}_{sr}^i$$

All consumers apart from h_2 are assumed to display 'consumption habits' behaviour, i.e. when confronted with a perceived income increase, the expenditures grow less than proportionally. Similarly, given a perceived income fall, the nominal demand fall is smaller. For the first case, we have:

$$\beta_t^{c,i} = \beta_{c1}^i + \beta_{c5}^i \cdot \exp(\beta_{c3}^i \cdot (\tilde{\Omega}_t^{c,i} - 1))$$

and for the second:

$$\beta_t^{c,i} = \beta_{c2}^i + \beta_{c6}^i \cdot \exp(\beta_{c4}^i \cdot (\tilde{\Omega}_t^{c,i} - 1))$$

Similarly for the η_{hs} account:

$$\beta_t^{hs,i} = \beta_{hs1}^i + \beta_{hs5}^i \cdot \exp(\beta_{hs3}^i \cdot (\tilde{\Omega}_t^{h,i} - 1))$$

and

$$\beta_t^{hs,i} = \beta_{hs2}^i + \beta_{hs6}^i \cdot \exp(\beta_{hs4}^i \cdot (\tilde{\Omega}_t^{h,i} - 1))$$

Any attempt to reproduce at least qualitative features of reality using a highly aggregative model, such as this one, is challenging. One of the biggest obstacles is representing credit, which in the case of agent-based models is vital, as stock-flow consistency and positive net worth as well as net cash flow of the banking sector must be ensured. It is also clear that any solution not including explicitly the demographic structure and income distribution mimicking the real counterparts will be only an approximation, since in reality many housing loans are taken out by young workers. In this model, as for the demand for the housing good in excess of the available funds (i.e. the sums of the c, hs budgets and the savings budget comprised of the resultant saving rates from the former categories in addition to the minimum one), for $i \in \{h_1, h_2, own_1\}$ the average spending rate is $\bar{\beta}^{h,i}$. It also plays an important role in the establishing the internal consistency of the model procedure. Similarly to the other accounts, for the η_h account, given an increase of perceived income, we have:

$$\beta_t^{h,i} = \beta_{h1}^i + \beta_{h5}^i \cdot \exp(\beta_{h3}^i \cdot (\hat{\Omega}_t^{h,i} - 1))$$

and for a decrease:

$$\beta_t^{h,i} = \beta_{h2}^i + \beta_{h6}^i \cdot \exp(\beta_{h4}^i \cdot (\hat{\Omega}_t^{h,i} - 1))$$

As for the spending using saving accounts, it is assumed to follow a simple switching rule, governed by

$$\begin{cases} \bar{\beta}_{IN}^{SA,i}, & \text{if } \hat{\Omega}_t^i \geq 1 \\ \bar{\beta}_{DCR}^{SA,i}, & \text{if } \hat{\Omega}_t^i < 1 \end{cases}$$

Various saving rates play an important role for the identification of mental accounting parameters. Saving rates within each budget in the mental accounting system of an agent that are associated with constant perceived income change are determined as:

$$\bar{\sigma}_{sr}^{c,i} = \frac{\bar{\beta}^{c,i}}{\bar{\beta}^{c,i} + \bar{\beta}^{hs,i}} \cdot (\bar{\sigma}_{sr}^i - \sigma_{sr,min}^i)$$

$$\bar{\sigma}_{sr}^{hs,i} = \frac{\bar{\beta}^{hs,i}}{\bar{\beta}^{c,i} + \bar{\beta}^{hs,i}} \cdot (\bar{\sigma}_{sr}^i - \sigma_{sr,min}^i)$$

These saving rates - average in the sense of corresponding to constant perceived disposable income - are at the same maximal. This is due to the assumed 'consumption habits' behaviour - both the reduction and increase of consumption due to a decrease or growth of perceived income are smaller in magnitude than these changes. Additionally, we have the degree of variability of the new debt account (of course, it cannot be interpreted as a saving rate):

$$\bar{\sigma}_{sr}^{h,i} = \frac{\bar{\beta}^{h,i}}{\bar{\beta}^{hs,i}} \cdot \bar{\sigma}_{sr}^{hs,i}$$

Given the assumption on consumption-habits behaviour of consumers when faced with an perceived income decline, and expansionary demand given its increase (although of very small magnitude), $\bar{\beta}$ are the lowest values β can take within an account. This is because a fall in perceived income leads to a smaller percentage decrease in expenditures, while income growth implies a larger increase in the expenditures. The upper values of the accounts, $\eta_c, \eta_{hs}, \eta_h$, are the limits of possible growth of the respective behavioural parameter.

2.2. Consumers

2.2.1. Wages and profits

The revenue of consumption-good and durable/housing-good firms in period $t-1$ is denoted by $\Pi_{t-1}^{f_1}$, $\Pi_{t-1}^{f_2}$ respectively. Next period wages are assumed to be set in the process of bargaining between firms and workers. As a result of these negotiations, we have

$$\Omega_t^c = \varphi_{f_1}^{LS,w} \cdot \frac{\Pi_{t-1}^{f_1}}{L_{t-1}^c}$$

$$\Omega_t^{ch} = \varphi_{f_2}^{LS,w} \cdot \frac{\Pi_{t-1}^{f_2}}{L_{t-1}^h}$$

Owners of the firms are assumed to obtain a fixed share of revenues. These shares are specified by the firms' internal contract. For each $j \in \{1, 2\}$, we have

$$\Pi_{t-1}^{own_j} = \varphi_{f_j}^{own_j} \cdot \Pi_{t-1}^{f_j}$$

where $\Pi_{t-1}^{f_j}$ denotes revenues of type j firms, $j \in \{1, 2\}$ (see subsections 2.4 and 2.5).

For $i \in \{h_1, h_2, own_1\}$, the available incomes in period t are the differences between beginning-of-period current accounts and debt payments:

$$\tilde{\Omega}_t^i = dep_{t-1}^{CA,i} - dps_t^i$$

while for own_2 we have:

$$\tilde{\Omega}_t^{own_2} = \Pi_{t-1}^{own_2},$$

and for b:

$$\tilde{\Omega}_t^b = \Omega_t^b$$

All wages and profits are paid at the end of a given period and deposited into current accounts. These funds cannot be used for purchases until the next period.

2.2.2. Consumer behaviour

Desired consumption expenditures from accounts into which the agent's current account net of debt payments and saving account are divided, devoted to consumption and durable goods, are determined as follows.

For $i \in \{h_1, own_1\}$, the demand for the consumption good in constituted by parts related to current account (or current available funds) and saving accounts, while the demand for the durable/housing good consists of available funds and debt elements:

$$dem_t^{c,i} = \beta_t^{c,i} \cdot \tilde{\Omega}_t^i + \beta_t^{SA,i} \cdot dep_{t-1}^{SA,i} \cdot (1 + r_{t-1}^{cr})$$

$$dem_t^{e,i} = \beta_t^{SA,i} \cdot dep_{t-1}^{SA,i} \cdot (1 + r_{t-1}^{cr})$$

$$dem_t^{hs,i} = \beta_t^{hs,i} \cdot \tilde{\Omega}_t^i$$

$$dem_t^{h,i} = \beta_t^{h,i} \cdot \tilde{\Omega}_t^i + dem_t^{hs,i}$$

As for h_2, not holding any saving deposits:

$$dem_t^{c,h2} = \beta_{ch}^{h_2} \cdot \tilde{\Omega}_t^{h_2}$$

$$dem_t^{hs,h2} = (1 - \beta_{ch}^{h_2}) \cdot \tilde{\Omega}_t^{h2}$$

$$dem_t^{h,h2} = \beta_t^{h,h2} \cdot \tilde{\Omega}_t^{h2} + dem_t^{hs,h2}$$

As explained above, own_2, b do not hold debt. Thus, for $i \in \{own_2, b\}$

$$dem_t^{c,i} = \beta_t^{c,i} \cdot d_t^{CA,i} + \beta_t^{SA,i} \cdot dep_{t-1}^{SA,i} \cdot (1 + r_{t-1}^{cr})$$

$$dem_t^{e,i} = \beta_t^{SA,i} \cdot dep_{t-1}^{SA,i} \cdot (1 + r_{t-1}^{cr})$$

$$dem_t^{hs,i} = \beta_t^{hs,i} \cdot \tilde{\Omega}_t^i$$

Debt of $i \in \{h_1, h_2, own_1\}$ for the housing/durable good is set as:

$$b_t^i = \beta_t^{h,h2} \cdot \tilde{\Omega}_t^{h2} = dem_t^{h,i} - dem_t^{hs,i}$$

All these individual consumer demands are summed, and form aggregate consumer demands, $DEM_t^{c,cons}, DEM_t^{h,cons}$.

2.2.3. Deposits

The end-of-period current accounts, used in the next period as (parts of) available income, are, respectively for $i \in \{h_1, own_1, own_2, b\}$,

$$dep_t^{CA,h_1} = \Omega_t^c \cdot {L_t}^c \cdot LS^{c,h_1} + \Omega_t^h \cdot {L_t}^h \cdot LS^{h,h_1}$$

$$dep_t^{CA,own_1} = \Pi_t^{f_1,own_1}$$

$$dep_t^{CA,own_2} = \Pi_t^{f_2,own_2}$$

$$dep_t^{CA,b} = \Omega_t^b$$

The end-of-period current accounts of firms ($j \in \{1, 2\}$), on the other hand, are equal to the sum of the remaining own funds (after paying debts, investing and making intra-sectoral payments) and returns net of labour remuneration (in sectors $s \in \{c, h\}$, respectively) and owners' profits:

$$dep_t^{CA,f_j} = OF_t^{mid,f_j} + \Pi_t^{f_j} - \Pi_t^{own_j} - \Omega_t^s \cdot L_t^s$$

The values of saving accounts of h_1 and own_1 at the end of a period are equal to the value from the previous one plus interest and what remains on the beginning-of-the-period current account after debt payments and spending.

$$dep_t^{SA,h_1} = dep_{t-1}^{SA,h_1} \cdot (1 + r_{t-1}^d) - P_t^c \cdot e_t^{h_1} + (d_{t-1}^{CA,h_1} - dps_t^{h_1} - P_t^c \cdot c_t^{h_1} - P_t^h \cdot hs_t^{h_1})$$

$$dep_t^{SA,own_1} = dep_{t-1}^{SA,own_1} \cdot (1 + r_{t-1}^d) - P_t^c \cdot e_t^{own_1} + (d_{t-1}^{CA,own_1} - dps_t^{own_1} - P_t^c \cdot c_t^{own_1} - P_t^h \cdot hs_t^{own_1})$$

For owners of firms of type 2 and bankers, we have

$$dep_t^{SA,own_2} = dep_{t-1}^{SA,own_2} \cdot (1 + r_{t-1}^d) - P_t^c \cdot e_t^{own_2} + (d_{t-1}^{CA,own_2} - P_t^c \cdot c_t^{own_2} - P_t^h \cdot hs_t^{own_2})$$

$$dep_t^{SA,b} = dep_{t-1}^{SA,b} \cdot (1 + r_{t-1}^d) - P_t^c \cdot e_t^b + (d_{t-1}^{CA,b} - P_t^c \cdot c_t^b - P_t^h \cdot hs_t^b)$$

Since it is assumed that households of the second type spend all of their available resources (unless the aggregate demand is in excess of the aggregate supply), they do not have a savings account, but if demand is rationed, then the remainder of households type 2 demand is retained in the current account.

$$dep_t^{CA,h_2} = \Omega_t^c \cdot {L_t}^c \cdot LS^{c,h_2} + \Omega_t^h \cdot {L_t}^h \cdot LS^{h,h_2} + (d_{t-1}^{CA,h_2} - dps_t^{h_2} - P_t^c \cdot c_t^{h_2} - P_t^h \cdot hs_t^{h_2})$$

The beginning-of-next-period current accounts are equal to dep_t^{CA}, while the funds kept in the saving accounts are increased by the interest rate r_t^{SA}. As mentioned before, consumption expenditures are made using accounts that were formed in the preceding period.

2.3. Firms

Computational economists have always underlined the importance of increasing the realism of economic models (Tesfatsion 2006), and yet very rarely any attempt was made to ensure that the share of investment in final output, produced by the model, was in some - if only qualitative - bounds encompassing real-world values. The usual approach is to derive the value of investment on the basis of a production function used by a researcher. This, however, may pose problems, related to the concept of production function. On the empirical side, many researchers considered only demand for individual firms' products, thus treating it solely as a function of price and shocks (Ackerberg et al. 2015; Pozzi and Schivardi 2016; Kumar and H. Zhang 2019) . Furthermore, most recent estimation techniques entirely ignore demand for final goods by implicitly adopting the general-equilibrium assumption of market clearing and production being equal to consumers' income. As for structural estimation, usually DSGE models are fitted to data (Carlsson et al. 2021). Demand disaggregated on industry levels remains largely not studied. The prevailing theoretical macroeconomic framework ignores this issue by assuming Dixit-Stiglitz aggregator function for intermediate goods or for preferences. But demand - understood as the amount of expenditures per each good type - as a function of consumers' incomes has not been considered as a theoretical category other than the simplification of the general equilibrium setting. In the latter, firstly, there exists a commodity that is at the same time a factor of production and the means of saving. Secondly, it is assumed that all resources are spent by consumers. Thirdly, all transactions occur in meta-time, so markets can clear (and always do). In a dynamic and intertemporal optimisation setting, this leads to the problems outlined above, indicated by empirical research. Moreover, if demand in reality is independent from production in the sense that no aggregate resource constraint is imposed, current income is not used for current consumption and Euler equations do not hold, and if production is not of a fairly simple technological-view of the firm form (in a GE setting, one might add), any estimation of production functions conforming with this is very likely to yield biased estimates.

2.3.1. Labour force, demand expectations and production

The modelling of production functions in a non-GE setting is problematic, which is partly reflected by the fact of how popular the Leontief production function is among researchers using agent-based models. The latter representation, however, often leads to conclusion that investment is equal to capital replacement and increments, thus yielding the size of investment relative to output too small in comparison to what can be seen in the data. Official statistics usually reveal that in most countries investment comprises 5-20 percent of gross domestic product.

The generalised framework for the analysis of (or using) production is the translog production function, which is only a second-degree Taylor expansion using assumed inputs. While it often proves to fit the data well, can we be sure that it represents the actual production process? It is worth noting that both in a GE setting (which almost exclusively uses a standard Cobb-Douglas form) and in the prevailing econometric approach, demand is assumed to always equal production, and so any demand fluctuations (except for the time-preference shocks in DSGE), if they are present, are in fact a part of the production function residual - interpreted as total factor productivity. Thus, supply-side and demand-side fluctuations are entangled in such a representation.

Moreover, the relation between the total factor productivity and the capital input is ambiguous: should they be separable or not? If the answer were yes, then it would imply that all machines and technical devices are costlessly replaceable for new ones. But this is not true; computers do not upgrade by default. If, conversely, they were not separable, then similar problems are present: how does the old undepreciated stock gain new or better functionality? On the other hand, inseparability of total factor productivity and the labour input leads to the conclusion that no matter what the level of technology is, capital always increases production in the same fashion, i.e. it depends only on the value/number of machines or firms' stock of funds. There are further unanswered questions. If variable capacity utilisation and stocks of (unsold) output are present in a model, what their relation to capital/machines should be? Why would firms invest rather than increase capital intensity (i.e. are the costs of increasing it so high)?

In this paper, the focus is on the demand, firms' internal funds, and sectoral stability, therefore a reduced-form approach to production modelling is adopted. A multiplicative function is assumed. Total factor productivity A_t (treated jointly with marketing efforts) is assumed to grow at a constant (gross) rate ρ_A and to be the same for both sectors. Production capital (machines, buildings, etc.) stocks, Z_t^c, Z_t^h , are held constant - firstly, because it is unclear what the relation between them and A_t should be, secondly, because such supply-side variations might be a force changing the model's dynamics. Thirdly, the goal is to focus on the impact of mental-accounting demand with variable spending rates on the dynamics and output's fluctuations relative to the version of the mental-accounting model with constant rates and a quasi-buffer-stock-model (see section 4).

Labour market and wage frictions (in the sense of a mismatch between aggregate supply and demand for this resource) are a common feature in some of the state-of-the-art agent-based models (Dosi et al. 2017; Dosi et al. 2018; Caiani et al. 2019a; Caiani et al. 2019b). However, all of the existing studies either assume that capacity utilisation is not a feature of an adopted production function, or impose a constant capital-labour or production-labour ratio. Without these assumptions, with predetermined wage, it is not clear why firms would hire new workers (unless demand spiked dramatically) or not reduce the labour force to the minimum corresponding to the maximum capacity. The arguments of an increased depreciation rate of capital are hardly convincing, given how much of the contemporary economies is constituted by services. Moreover, matching the real-world investment shares in GDP would require enormous depreciation rates. Most importantly, assuming both that the labour demand of firms is a linear function of capital or output and that the labour supply is finite, then if a model does not feature labour market frictions (also understood as a reservation wages pressure), but features growth, the effect will be that after some number of periods the amount of labour employed will remain fixed at the maximum level. This paper aims at focusing solely on mental accounting consumption framework and demand fluctuations at the sectoral level. It is unclear how an aggregate labour market frictions framework should be applied in an ABM. In this paper, the labour force is taken to evolve according to production-side factors rather than demand-matching ones, i.e. labour demand in sector $s \in \{c, h\}$ is

$$L_t^{s,dem} = L_{t-1}^s \cdot (\rho_t^A)^{\rho_{dA}}$$

where ρ_t^A is the gross change rate of A_t. We can interpret this equation as a condition that the demand for labour is generated by the financial and production conditions within a firm and its development prospects. Of course, the model presented here is sectoral, and since the simplifying assumption that A_t grows at a constant rate ρ_A is adopted, labour force will increase for a few periods in the simulations, before achieving its upper bound.

Firms in both sectors form their expectations of the aggregate sectoral demand knowing the amount of investment and sectoral flows beforehand (we can think about it as of contracted transactions of known size). Thus, they only need to forecast the consumer demand. Very little agent-based research has been concerned with firms' demand expectations. In fact, in the most of the literature, firms do not have any. At the same time, in the most prominent strand of research that incorporates this feature, the forecasts are strictly heuristic (i.e. no learning process is assumed, and the functional form may not be the profit-maximising one) and backward-looking, myopic (equal to the demand from the previous period), or equal to a weighted average of past demands (Dosi et al. 2010; Dosi et al. 2013; Dosi et al. 2015; Dosi et al. 2017; Dosi et al. 2018; Dosi et al. 2019). But various forecasting rules may have different effects on the dynamics, and since the goal is to study the effects of variable demand in a structurally consistent framework, a simplifying assumption is adopted that firms can forecast consumer, investment and sectoral demand perfectly.

$$\mathbb{E}_t^{f_1}(DEM_t^{c,cons}) = DEM_t^{h,cons}$$

$$\mathbb{E}_t^{f_2}(DEM_t^{h,cons}) = DEM_t^{c,cons}$$

Given these, both sectors form (perfect) expectations about the aggregate demands for each good:

$$\mathbb{E}_t^{f_1}(DEM_t^{C}) = \mathbb{E}_t^{f_1}(DEM_t^{c,cons}) + I_t^c \cdot P_t^c + SF_t^c$$

$$\mathbb{E}_t^{f_2}(DEM_t^{H}) = \mathbb{E}_t^{f_2}(DEM_t^{h,cons}) + I_t^h \cdot P_t^h + SF_t^h$$

where SF_t^c, SF_t^h are intra-sectoral flows and I_t^c, I_t^h are real investments.

Production takes place before interactions with consumers on the market. Capacity utilisations are chosen to match the expected aggregate demands unless they would be in excess of 1, taking into account stocks of unsold goods. In such a case, they are fixed at that level.

$$\vartheta_t^c = \frac{(\mathbb{E}_t^{f_1}(DEM_t^{C}) - y_t^{c,stock} \cdot P_t^c)}{(A_t \cdot \bar{Z}^c \cdot (L_t^c)^{1-\alpha_c} \cdot P_t^c)}$$

$$\vartheta_t^h = \frac{(\mathbb{E}_t^{f_2}(DEM_t^{H}) - y_t^{h,stock} \cdot P_t^h)}{(A_t \cdot \bar{Z}^h \cdot (L_t^h)^{1-\alpha_h} \cdot P_t^h)}$$

Then, new production in each of the sectors $s \in \{c, h\}$ is

$$F_t^s = A_t \cdot \bar{Z}^s \cdot (L_t^s)^{1-\alpha_s} \cdot \vartheta_t^s$$

2.3.2. Investment, intra-sectoral transactions, and debt payments

To simplify the analysis and in order to rule out fluctuations that have their origin in the supply chain, it is assumed that each sector represents both final-good firms and their suppliers. Thus, final goods can be bought for investment purposes. Since marketing efforts and all expenditures on machines and materials are treated collectively as I_t^c or I_t^h, intuitively it is helpful to think of the final goods as comprising both consumer-bought goods and business-to-business services as well as supply chains.

$$I_t^{c,opt} = \frac{\Phi_c^{f_1} \cdot dep_{t-1}^{CA,f_1}}{P_t^c}$$

$$I_t^{h,opt} = \frac{\Phi_h^{f_1} \cdot dep_{t-1}^{CA,f_2}}{P_t^h}$$

and the corresponding optimal levels of debt are

$$b_t^{f_1,opt} = I_t^{c,opt} \cdot P_t^c - \varphi_{f_1}^{OF} \cdot (dep_{t-1}^{CA,f_1} - dps_t^{f_1})$$

$$b_t^{f_2,opt} = I_t^{h,opt} \cdot P_t^h - \varphi_{f_2}^{OF} \cdot (dep_{t-1}^{CA,f_2} - dps_t^{f_2})$$

where $\varphi_{f_j}^{OF}$ are internal-division-of-funds parameters, with $\varphi_{f_j}^{OF} + \varphi_{f_j}^{rest} = 1$, $j \in \{1, 2\}$.

For each sector $s \in \{c, h\}$, denote by SF_t^{sts} the period-t intrasectoral flow of funds, and for each respective sector of firms $j \in \{1, 2\}$, B_t^{loss,f_j} is the loss suffered by the banking sector if a given aggregate firm fails to pay some or all of its debt payments. OF_t^{mid,f_j} = denotes the amount left on the current account of a firm after all the expenditures are done. The investment and division-of-funds rule $j \in \{1, 2\}$ is as follows:

if $(I_t^{s,opt} \cdot P_t^s \geq \varphi_{f_j}^{OF} \cdot (dep_{t-1}^{CA,fj} - dps_t^{fj})) \wedge ((dep_{t-1}^{CA,fj} - dps_t^{fj}) \geq 0)$:
  if $d_t^{CA,fj} \cdot \eta_{fj} \leq dps_t^{rem,f_j}$:
    $b_t^{f_1} = 0$
  else if $(d_t^{CA,fj} \cdot \eta_{fj} > dps_t^{rem,f_j}) \wedge (d_t^{CA,fj} \cdot \eta_{fj} < dps_t^{rem,f_j} + b_t^{f_j,opt} \cdot (r_t^{cr} + \frac{1}{CD}))$:
    $b_t^{f_j} = (r_t^{cr} + \frac{1}{CD})^{-1} \cdot (d_t^{CA,fj} \cdot \eta_{fj} - dps_t^{rem,f_j})$
  else

$b_t^{f_j} = b_t^{f_j,opt}$
$I_t^s = \varphi_{f_j}^{OF} \cdot (dep_{t-1}^{CA,fj} - dps_t^{fj}) + \frac{b_t^{f_j}}{P_t^s}$
$B_t^{loss,f_j} = 0$
$OF_t^{mid,f_j} = 0$
$SF_t^{sts} = \varphi_{f_j}^{rest} \cdot (dep_{t-1}^{CA,fj} - dps_t^{f_j})$
else if $I_t^{s,opt} \cdot P_t^s < \varphi_{f_j}^{OF} \cdot (dep_{t-1}^{CA,f_j} - dps_t^{f_j}) \wedge (dep_{t-1}^{CA,f_j} - dps_t^{f_j}) \geq 0:$
$b_t^{f_j} = 0$
$I_t^s = I_t^{s,opt}$
$B_t^{loss,f_j} = 0$
$OF_t^{mid,f_j} = \varphi_{f_j}^{OF} \cdot (dep_{t-1}^{CA,fj} - dps_t^{fj}) - I_t^{s,opt} \cdot P_t^s$
$SF_t^{sts} = \varphi_{f_j}^{rest} \cdot (dep_{t-1}^{CA,fj} - dps_t^{f_j})$
else
$b_t^{f_j} = 0$
$I_t^s = 0$
$B_t^{loss,f_j} = dps_t^{f_j} - dep_{t-1}^{CA,f_j}$
$OF_t^{mid,f_j} = 0$
$SF_t^{sts} = 0$

Thus, the sizes of investment, sectoral flows and debt are determined by the size of available funds after debt payments and by the maximum debt-payments-ratio rule.

2.4. Consumption good market clearing

Denoting the aggregate demand, the consumer demand, and the excess demand for good c by $DEM_t^C, DEM_t^{c,cons}, ExcDEM_t^C$ respectively, the market for this product operates in the following way:

if $F_t^c \cdot P_t^c + y_t^{c,stock} \cdot P_t^c < DEM_t^C:$
$ExcDEM_t^C = DEM_t^C - F_t^c \cdot P_t^c - y_t^{c,stock} \cdot P_t^c$
$y_{t+1}^{c,stock} = 0$
$\Pi_t^{f_1} = F_t^c \cdot P_t^c + y_t^{c,stock} \cdot P_t^c$
$FG_t^c = \Pi_t^{f_1} - (I_t^c \cdot P_t^c + SF_t^c)$
else
$ExcDEM_t^C = 0$
$y_{t+1}^{c,stock} = F_t^c \cdot P_t^c + y_t^{c,stock} \cdot P_t^c - DEM_t^C$
$\Pi_t^{f_1} = DEM_t^C$
$FG_t^c = DEM_t^{c,cons}$

where $y_t^{c,stock}$ is the stock of unsold goods from the previous period (of course, given the simplification of perfect demand forecasts and the dynamics restricted by structural consistency, $y_t^{c,stock}$ will always be 0; see section 5), while FG_t^c is a measure of final good output, i.e. the value of final c-goods sold bought by consumers. Another considered version of output (or domestic product) is $FGI_t^c = FG_t^c + I_t^c \cdot P_t^c$.

2.5. Housing/durable good market clearing

Adopting analogical definitions for the good h market, we have

if $F_t^h \cdot P_t^h + y_t^{h,stock} \cdot P_t^h < DEM_t^H$:

$$ExcDEM_t^H = DEM_t^H - F_t^h \cdot P_t^h - y_t^{h,stock} \cdot P_t^h$$
$$y_{t+1}^{h,stock} = 0$$
$$\Pi_t^{f_1} = F_t^c \cdot P_t^h + y_t^{h,stock} \cdot P_t^h$$
$$FG_t^h = \Pi_t^{f_1} - (I_t^h \cdot P_t^h + SF_t^h)$$

else

$$ExcDEM_t^H = 0$$
$$y_{t+1}^{h,stock} = F_t^c \cdot P_t^h + y_t^{h,stock} \cdot P_t^h - DEM_t^H$$
$$\Pi_t^{f_1} = DEM_t^H$$
$$FG_t^h = DEM_t^{h,cons}$$

2.6. The banking sector

Assets of the banking sector consist of the value of past and new loans, old and new reserves, and securities. $SCRT^{B,c}$ and $SCRT^{B,h}$ denote the constant quantities of central-bank issued bonds, paying the interest equal to $r_t^{CB,sc}$ (while the interest on reserves held in the central bank are $r_t^{CB,d}$). Firstly, they represent the non-negligible part of real-world banking sector's assets, which is constituted by government and central bank's bonds and securities. A simplifying assumption is that these quantities remain constant throughout the simulation, and their values change according to the prices of the two goods, P_t^c, P_t^h. Their initial stocks are set relative to the two nominal sectoral productions, using parameters $\omega_{sc,c}^B, \omega_{sc,h}^B$.

The net cash flow of the banking sector is the difference between the sum of interest from all past credit that has not been paid off, interest on the central bank's securities, described above, and the sum of interest on (precious period's) savings deposits and bankers' wages.

$$NCF_t^B = \sum_{i_{deb}}(dps_t^i) + SCRT_t^{B,c} \cdot P_t^c \cdot r_t^{CB,sc} + SCRT_t^{B,h} \cdot P_t^h \cdot r_t^{CB,sc}$$
$$- \sum_{i_{sav}}(d_{t-1}^{SA,i} \cdot r_{t-1}) - \Omega_t^b - \sum_{i_{deb}}(B_t^{loss,i})$$

Denoting by Dep_t^{SA}, Dep_t^{CA} the aggregate value of savings and current accounts, liabilities of banks (net of wages, as they are included in the net cash flow, which will enter the sector's assets in the form of new reserves) are defined as $Liab_t^B = Dep_t^{SA} + Dep_t^{CA}$. The sector needs to meet the minimum reserves criterion; if it fails to do so, then the central bank costlessly provides the missing amount (OMO^1). This is because there is effectively only one commercial bank and a form of credit constraints are already included in the decision rules of debt-taking agents, i.e. they are prudent and either try to stick to their maximum debt-payments-to-current-account ratios (in the case of f_1, f_2) or use self-regulating rules (as in the case of consumer loans). The banking sector follows the following rule when they add new reserves (or cover a negative net cash flow using old ones) and set wages for the next period:

if $RESV_{t-1} + NCF_t^B < \omega_{RESV}^B \cdot Liab_t^B$
  $OMO_t^1 = \omega_{RESV}^B \cdot Liab_t^B - (RESV_{t-1} + NCF_t^B)$
  $RESV_t = RESV_{t-1} + NCF_t^B + OMO_t^1$
  if $NCF_t^B > 0 \wedge NCF_{t-1}^B > 0$
    $\Omega_{t+1}^b = \Omega_t^b \cdot \frac{NCF_t^B}{NCF_{t-1}^B}^{\rho_{LB_1}}$
  else
    $\Omega_{t+1}^b = \Omega_t^b \cdot \rho_{LB_2}$
else
  $OMO_t^1 = 0$
  $RESV_t = RESV_{t-1} + NCF_t^B$
  if $NCF_t^B > 0 \wedge NCF_{t-1}^B > 0$
    $\Omega_{t+1}^b = \Omega_t^b \cdot (\frac{NCF_t^B}{NCF_{t-1}^B})^{\rho_{LB_1}}$
  else
    $\Omega_{t+1}^b = \Omega_t^b \cdot \rho_{LB_2}$

The value to the banking sector of each credit given to agent $i \in \{h_1, h_2, own_1, f_1, f_2\}$ in the period $t-\tau$ is the sum of all remaining payments (to be made in the future) from past and new debts.

$$Cr_t^{t-\tau,i} = (\frac{(CD-\tau+1)\cdot(CD-\tau)}{2\cdot CD} \cdot r_{t-\tau}^{cr} + \frac{CD-\tau}{CD}) \cdot b_{t-\tau}^i$$

$$AllCr_t^i = \sum_{\tau=0}^{\tau=CD-1} Cr_t^{t-\tau,i}$$

$$AllCr_t = \sum_i All_{Cr,t}^i$$

Thus, the new value of the assets of the sector is

$$Assets_t^B = AllCr_t + SCRT^{B,c} \cdot P_t^c + SCRT^{B,h} \cdot P_t^h + RESV_t^B$$

If net worth, $NW_t^B = Assets_t^B - Liab_t^B$, is negative, the central bank issues the missing amount and passes it (again, costlessly) to the sector, as OMO_t^2. Current reserves are then revised as $RESV_t = RESV_t + OMO_t^2$.

2.7. Inflation and central bank's interest rate policy

It is assumed that there are no markup shocks or any other supply-side disturbances, i.e. inflation is purely demand-driven, with the parameters $\sigma_{\Pi_c}, \sigma_{\Pi_h}$ interpreted as firm sectors exhibiting some monopolistic strength. For $s \in \{c, h\}$ (and the corresponding $j \in \{1, 2\}$):

$$\Pi_t^s = 1 + (\Pi_{t-1}^{f_j} / \Pi_{t-2}^{f_j})^{\sigma_{\Pi_s}}$$

Composite inflation is calculated as a weighted average of the two inflations, with the weights being equal to (previous period's) shares of each of the sectors' revenues in total revenues.

$$\Pi_t^{comp} = \Pi_t^c \cdot \frac{\Pi_{t-1}^{f_1}}{\Pi_{t-1}^{TOT}} + \Pi_t^h \cdot \frac{\Pi_{t-1}^{f_2}}{\Pi_{t-1}^{TOT}}$$

The central bank is assumed to follow a very simple inflation targeting rule. The interest rates are set at the beginning of a period.

if $\Pi_t^{comp} \geq \Pi_{tolmax}^{comp}$
$r_t^{CB,sc} = r_{t-1}^{CB,sc} + 0.0025$
$r_t^{CB,d} = r_{t-1}^{CB,d} + 0.0025$
else
$r_t^{CB,sc} = r_{t-1}^{CB,sc} - 0.0025$
$r_t^{CB,d} = r_{t-1}^{CB,d} - 0.0025$

3. Structural consistency of the modelled economy

The procedure for matching the initial structures of incomes, demand, production, debt, investment and sectoral flows is as follows:

1) Set the labour share and internal-division-of-funds parameters in both firm sectors and in the banking sector.

Step 2) is necessary due to the multiperiodicity of credit - when the model is started, all debt-taking agents ought to already have debts according to the specified behaviour rules. At the same time, some way of reducing arbitrariness of these loans' values should be devised.

2) Express the outputs of both production sectors, all the incomes (except for the banking sectors' workers' wages), current and saving accounts of the dummy past CD periods (where CD is the duration of all consumers' and firms' loans) as fractions of the time-0 nominal productions of both sectors, using the values set in 1). Additionally, debts are set according to the behavioural rules, described in section 2.1, applied to the past incomes.

3) Set the partial wages (corresponding to inflows from each of the production/labour sectors) in the banking sector (see below for discussion of setting this value).

4) Construct variables that are sums of individual demands for a given type of good, having source in one of the sectors.

5) Obtain the ratio between the two nominal outputs. Next, calculate the fractions of firms' current accounts that are spent on debt payments. If either of them is larger than 1 or negative, return to 1) and change the internal-division-of-funds parameters or consumers' average consumption rates.

6) If the debt payments ratios satisfy the condition, use them to calculate relative debts of firms (in the sense of point 1)).

7) Set a value for nominal production of the consumption good, $F_0^{c,N}$, normalise the price to 1, P_0^c. From 5) obtain $F_0^{h,N}$ and set P_0^h.

8)The remaining initial values of the model can be obtained in a straightforward way either by multiplying the relative expressions from the previous points by $F_0^{c,N}$ and $F_0^{h,N}$ or by deriving other ones from the latter.

Past periods are labelled as p_n for $n \in 0, ..., CD-1$, where p_0 is the last past period before $t = 0$.

3.1. Past productions, wages and owners' profits

Define the relative nominal productions in the past periods as

$$rF^{cN}_{p_n} = (\rho_A)^{-(n+1)}$$

$$rF^{hN}_{p_n} = (\rho_A)^{-(n+1)}$$

A word of caution concerning the notation is needed: here, time subscripts of past wages denote the period when it was set by a contract (contrary to the notation from the model runs, where the subscript denotes the period at the end of which the wage is paid) - so $r\Omega^c_{p_0}$ is paid in $t = 0$, $r\Omega^c_{p_1}$ was paid in $t = p_0$, $r\Omega^c_{p_2}$ was paid in $t = p1$, etc.

$$r\Omega^c_{p_n} = \varphi^{LS,w}_{f_1} \cdot \frac{rF^{cN}_{p_n}}{L^c_0}$$

$$r\Omega^h_{p_n} = \varphi^{LS,w}_{f_2} \cdot \frac{rF^{hN}_{p_n}}{L^h_0}$$

$$r\Pi^{own_1}_{p_n} = \varphi^{own_1}_{f_1} \cdot rF^{cN}_{p_n}$$

$$r\Pi^{own_2}_{p_n} = \varphi^{own_2}_{f_2} \cdot rF^{hN}_{p_n}$$

Because any agent-based system is dynamic by nature, deriving the bankers' wage from an equilibrium state is impossible. Calculating it on the basis of a past net cash flow of banks is not feasible either, as its past value affects the latter. Therefore, the relative wages of bankers paid at the end of $t = p_0$ and used in $t = 0$ are simply assumed to be equal to arbitrary fractions of nominal productions,

$$\Omega^b_{p_0} = \omega_w \cdot {A_0}^{-1}$$

Note that many such constants will (together with other, appropriately set, parameters - see below) yield a solution satisfying the required constraints on the division of internal funds of firms, positive net cash flow and net worth of the banking sector, and on the relative sizes of nominal productions. At the same time, given the rule according to which bankers' wages change, the exact value of the above constant does not to be particularly relevant, since given the small value of the initial net worth of banks it cannot differ substantially from ω_w.

3.2. Past debts

Define auxiliary variables (ρ_A is the assumed constant growth rate of productivity/technology factor A_t):

$$rdps_p^{fj,dummy} = \sum_{n=0}^{CD-1} (\frac{CD-n}{CD} \cdot r_{p_n}^{cr} + \frac{1}{CD}) \cdot {\rho_A}^{-(n+1)}$$

and, for consumers,

$$rdps_p^{ag} = \sum_{n=1}^{CD} (\frac{CD-n+1}{CD} \cdot r_{p_{(CD-n)}} + \frac{1}{CD}) \cdot (\rho_A)^{-(n+2)}$$

Note that we could define a separate variable $rdps_p^{ag}$ for own_1, since the wage contract is set basing on the production from the previous period, but as the assumed past periods are not simulated, any approximation of the agents' past behaviour will be inexact. Thus, for simplicity, the dummy variable is the same for $i \in \{h_1, h_2, own_1\}$, and the past debts, originating from incomes from sector $s \in \{c, h\}$ (numbered from p_0 as the most recent to p_{CD-1}) for $i \in \{h_1, h_2\}$ and own_1 are:

$$rb_{p_n}^{s,i} = (1 + \bar{\beta}^{h,i} \cdot rdps_p^{ag})^{-1} \cdot \bar{\beta}^{h,i} \cdot (r\Omega_{p_n}^s \cdot L_0^s)$$

$$rb_{p_n}^{c,own_1} = (1 + \bar{\beta}^{h,own_1} \cdot rdps_p^{ag})^{-1} \cdot \bar{\beta}^{h,own_1} \cdot (r\Pi_{p_n}^{own_1})$$

And the past debt payments are

$$rdps_0^{c,i} = \sum_{n=1}^{CD} (\frac{n}{CD} \cdot r_{p_{(CD-n)}}^{cr} + \frac{1}{CD}) \cdot rb_{p_{(CD-n)}}^{c,i}$$

$$rdps_0^{h,i} = \sum_{n=1}^{CD} (\frac{n}{CD} \cdot r_{p_{(CD-n)}}^{cr} + \frac{1}{CD}) \cdot rb_{p_{(CD-n)}}^{h,i}$$

Past debts are used to calculate the value of all credit, while debt payments enter the net cash flow of the banking sector in period 0. The non-negativity of its net worth and its net cash flow serves as another measure of the model's stock-flow consistency (a qualitative one, as the actual SFC is achieved by accounting for all transactions and changing the agents' deposits accordingly).

3.3. Past profits of owners of firms, current and saving accounts

Let $\varphi_{f_j}^{LS,h_n}$ denote labour shares of the households (workers) of type n in firm j and $\varphi_{f_j}^{LS,w}$ is the hired labour share. As for profits of owners and wages of workers and deposits of all consumers in $t = 0$, we have

$$rd_{p_0}^{CA,c,h_1} = r\Omega_{p_1}^{c} \cdot L_0^c \cdot \varphi_{f_1}^{LS,h_1}$$

$$rd_{p_0}^{CA,h,h_1} = r\Omega_{p_1}^{h} \cdot L_0^h \cdot \varphi_{f_2}^{LS,h_1}$$

$$rd_{p_0}^{CA,c,h_2} = r\Omega_{p_1}^{c} \cdot L_0^c \cdot \varphi_{f_1}^{LS,h_2}$$

$$rd_{p_0}^{CA,h,h_2} = r\Omega_{p_1}^{h} \cdot L_0^h \cdot \varphi_{f_2}^{LS,h_2}$$

$$rd_{p_0}^{CA,c,own_1} = r\Pi_{p_0}^{own_1}$$

$$rd_{p_0}^{CA,c,own_2} = r\Pi_{p_0}^{own_2}$$

Past saving accounts for $i \in \{h_1, own_1, own_2, b\}$:

$$rd_{p_0}^{SA,c,i} = \Theta^i \cdot rd_{p_0}^{CA,c,i}$$

where Θ^i is the assumed size of the stock of savings of agent i relative to the size of the current account.

3.4. Demand expressions

The considered system is basically a two dimensional one, with two unknowns, F^{cN}, F^{hN}, but no free terms. Thus, in order of solutions satisfying the conditions specified outside of the system (the requirements that $F^{cN}, F^{hN} > 0$ and that the ratios of firms' debt payments to current accounts are positive but smaller than one, $0 < \eta_{f_1}, \eta_{f_2} < 1$) to exist, one must choose the values of firms' internal funds division parameters and the value of the ratio $\frac{F^{hN}}{F^{cN}}$.

First, consumer demands must be formulated as expressions of behavioural parameters and incomes in the form of parts of nominal outputs. We obtain four demand expressions; the lower index shows which good is demanded while the upper one - the sector that is the source of the demand, and therefore also by which nominal production the original values are divided:

$$DEM_c^{F^c,noI} = \bar{\beta}^{c,h_1} \cdot (rd_{p_0}^{CA,c,h_1} - rdps_c^{h_1}) + \bar{\beta}_{IN}^{SA,h_1} \cdot rd_{p_0}^{SA,c,h_1} \cdot (1 + r_{p_0}^d) + \beta^{ch,h_2} \cdot (rd_{p_0}^{CA,c,h_2} - rdps_c^{h_2}) + \bar{\beta}^{c,own_1} \cdot (rd_{p_0}^{CA,own_1} - rdps_c^{own_1}) + \bar{\beta}_{IN}^{SA,own_1} \cdot rd_{p_0}^{SA,own_1} \cdot (1 + r_{p_0}^d) + \bar{\beta}^{c,b} \cdot rd_{p_0}^{CA,c,b} + \bar{\beta}_{IN}^{SA,b} \cdot rd_{p_0}^{SA,c,b} \cdot (1 + r_{p_0}^d)$$

$$DEM_c^{F^h} = \bar{\beta}^{c,h_1} \cdot (rd_{p_0}^{CA,h,h_1} - rdps_h^{h_1}) + \bar{\beta}_{IN}^{SA,h_1} \cdot rd_{p_0}^{SA,h,h_1} \cdot (1 + r_{p_0}^d) + \beta^{ch,h_2} \cdot (rd_{p_0}^{CA,h,h_2} - rdps_h^{h_2}) + \bar{\beta}^{c,own_1} \cdot rd_{p_0}^{CA,own_2} + \bar{\beta}_{IN}^{SA,own_2} \cdot rd_{p_0}^{SA,own_2} \cdot (1 + r_{p_0}^d) + \bar{\beta}^{c,b} \cdot rd_{p_0}^{CA,h,b} + \bar{\beta}_{IN}^{SA,b} \cdot rd_{p_0}^{SA,h,b} \cdot (1 + r_{p_0}^d)$$

$$DEM_h^{F^c,noI} = \bar{\beta}^{hs,h_1} \cdot (rd_{p_0}^{CA,c,h_1} - rdps_c^{h_1}) + \bar{\beta}^{h,h_1} \cdot (rd_{p_0}^{CA,c,h_1} - rdps_c^{h_1}) + (1 - \beta^{ch,h_2}) \cdot (rd_{p_0}^{CA,,h_2} - rdps_c^{h_2}) + \bar{\beta}^{h,h_2} \cdot (rd_{p_0}^{CA,c,h_2} - rdps_c^{h_2}) + \bar{\beta}^{hs,own_1} \cdot (rd_{p_0}^{CA,own_1} - rdps_c^{own_1}) + \bar{\beta}^{h,own_1} \cdot (rd_{p_0}^{CA,own_1} - rdps_c^{own_1}) + \bar{\beta}^{hs,b} \cdot rd_{p_0}^{CA,c,b}$$

$$DEM_h^{F^h,noI} = \bar{\beta}^{hs,h_1} \cdot (rd_{p_0}^{CA,h,h_1} - rdps_h^{h_1}) + \bar{\beta}^{h,h_1} \cdot (rd_{p_0}^{CA,h,h_1} - rdps_h^{h_1}) + (1 - \beta^{ch,h_2}) \cdot (rd_{p_0}^{CA,,h_2} - rdps_h^{h_2}) + \bar{\beta}^{h,h_2} \cdot (rd_{p_0}^{CA,h,h_2} - rdps_h^{h_2}) + \bar{\beta}^{hs,own_2} \cdot d_{p_0}^{CA,own_2} + \bar{\beta}^{hs,b} \cdot rd_{p_0}^{CA,h,b}$$

These expressions will be used to construct a system of equations that describes the economy in the initial period.

3.5. The initial system, determination of firms' debt-payments-to-current-accounts ratios and the size of both sectors

Defining $\varphi_{f_j}^{LS} = \varphi_{f_j}^{LS,w} + \varphi_{f_j}^{own_j}$, $j \in \{1, 2\}$, assuming as above that the past growth rate of production is equal to ρ_A, we have

$$rd_{p_0}^{CA,f_j} = (1 - \varphi_{f_j}^{LS} \cdot {\rho_A}^{-1}) \cdot {\rho_A}^{-1}$$

technically, we might also consider using $\varphi_{f_j}^{LS,w} \cdot {\rho_A}^{-1} + \varphi_{f_j}^{own_j}$ (as the owners' profits are calculated using current revenues of firms), but the difference is very small.

Similarly to the procedure in the later periods of the model's simulations, current accounts of firms net of debt payments are divided into two parts, according to $\varphi_{f_j}^{OF}$ and $\varphi_{f_j}^{rest} = 1 - \varphi_{f_j}^{OF}$. Moreover, the time-0 debts of firms are assumed to have evolved similarly to past debts, i.e. with a growth rate of ρ_A. Thus, defining debt payments $(rdps_0^{f_1}, rdps_0^{f_2})$ as fractions of current accounts, $\eta_{f_1} \cdot rd_{p_0}^{CA,f_1}, \eta_{f_2} \cdot rd_{p_0}^{CA,f_2}$, we have that aggregate expenditures of each sector of firms are equal to $(1-\eta_{f_j}) \cdot rd_{p_0}^{CA,f_j} + \eta_{f_j} \cdot rdps_p^{fj,dummy-1} \cdot \rho_A \cdot rd_{p_0}^{CA,f_j}$. It is also assumed that debt in period $t = 0$ grows at the same (gross) rate as in the past, i.e. it is ρ_A times larger than the one taken out in $t = p_0$ Therefore, the two equations describing the balance between aggregate demand and supply in the initial period are

$$F^{cN} = DEM_c^{F^c,noI} \cdot F^{cN} + \eta_{f_1} \cdot rdps_p^{f_1,dummy-1} \cdot \rho_A \cdot rd_{p_0}^{CA,f_1} \cdot F^{cN} + (1 - \eta_{f_1}) \cdot rd_{p_0}^{CA,f_1} \cdot F^{cN} + DEM_c^{F^h} \cdot F^{hN}$$

$$F^{hN} = DEM_h^{F^h,noI} \cdot F^{hN} + \eta_{f_2} \cdot rdps_p^{f_2,dummy-1} \cdot \rho_A \cdot rd_{p_0}^{CA,f_2} \cdot F^{hN} + (1 - \eta_{f_2}) \cdot rd_{p_0}^{CA,f_2} \cdot F^{hN} + DEM_h^{F^c} \cdot F^{cN}$$

or

$$1 = DEM_c^{F^c,noI} \cdot + \eta_{f_1} \cdot rdps_p^{f_1,dummy-1} \cdot \rho_A \cdot rd_{p_0}^{CA,f_1} + (1 - \eta_{f_1}) \cdot rd_{p_0}^{CA,f_1} + DEM_c^{F^h} \cdot \frac{F^{hN}}{F^{cN}}$$

$$\frac{F^{hN}}{F^{cN}} = DEM_h^{F^h,noI} \cdot \frac{F^{hN}}{F^{cN}} + \eta_{f_2} \cdot rdps_p^{f_2,dummy-1} \cdot \rho_A \cdot rd_{p_0}^{CA,f_2} \cdot \frac{F^{hN}}{F^{cN}} + (1 - \eta_{f_2}) \cdot rd_{p_0}^{CA,f_2} \cdot \frac{F^{hN}}{F^{cN}} + DEM_h^{F^c}$$

and so we can obtain the expression for the debt-payments-to-current-account ratios of the two firms

$$-(1-DEM_c^{F^c,noI}-DEM_c^{F^h}\cdot\frac{F^{hN}}{F^{cN}}-rd_{p0}^{CA,f_1})\cdot(1-rdps_p^{f_1,dummy^{-1}}\cdot\rho_A\cdot rd_{p0}^{CA,f_1})^{-1}=\eta_{f_1}$$

$$-(\frac{F^{hN}}{F^{cN}}-DEM_h^{F^h,noI}\cdot\frac{F^{hN}}{F^{cN}}-DEM_h^{F^c}-rd_{p0}^{CA,f_2}\cdot\frac{F^{hN}}{F^{cN}})\cdot$$
$$\cdot(1-rdps_p^{f_2,dummy^{-1}}\cdot\rho_A\cdot rd_{p0}^{CA,f_2}\cdot\frac{F^{hN}}{F^{cN}})^{-1}=\eta_{f_2}$$

Therefore, $\frac{F^{hN}}{F^{cN}}$ needs to be chosen so that the following four conditions are satisfied

$$\begin{cases}(1-DEM_c^{F^c,noI}-DEM_c^{F^h}\cdot\frac{F^{hN}}{F^{cN}}-rd_{p0}^{CA,f_1})<0\\ -(\frac{F^{hN}}{F^{cN}}-DEM_h^{F^h,noI}\cdot\frac{F^{hN}}{F^{cN}}-DEM_h^{F^c}-rd_{p0}^{CA,f_2}\cdot\frac{F^{hN}}{F^{cN}})<0\end{cases}$$

and

$$\begin{cases}\eta_{f_1}<1\\ \eta_{f_2}<1\end{cases}$$

These conditions yield the interval which must contain $\frac{F^{hN}}{F^{cN}}$ (described by the last equation in this section). The particular chosen values for the analysed mental-accounting models (see section 4) were taken to be the middles of the respective intervals. Note that in the one-sector model it suffices to ensure that $\eta_{f_1}\in[0,1]$, and the size of F^{cN} can be arbitrary.

$$(1-DEM_c^{F^c,noI}-rd_{p0}^{CA,f_1})\cdot DEM_c^{F^h\,-1}<\frac{F^{hN}}{F^{cN}}<(1-DEM_h^{F^h,noI}-rd_{p0}^{CA,f_2})^{-1}\cdot DEM_h^{F^c}$$

Once $\frac{F^{hN}}{F^{cN}}$ and $F^{cN},P_0^c,P_0^h,Z^c,Z^h$ are set, it is possible to derive all other variables from $t=0$ using their relative (i.e. divided by the appropriate nominal production) counterparts.

4. Alternative consumption representations

The main version of the framework will be called mental-accounting with variable rates model, abbreviated as MA-VR. The other two will be abbreviated as MA-CR (mental-accounting with constant rates) and qBSM (for quasi-buffer-stock model), respectively.

4.1. Constant mental accounting buffer stock model

This model is the same as the variable-spending-rates one presented above, with the exception that consumption rules are static, i.e. agents always consume fixed shares $\bar{\beta}^c$, $\bar{\beta}^{hs}$, $\bar{\beta}^h$, except for the rule for spending using savings account, which is the same. The MA-CR is treated as an equivalent of a GE-based model, excluding the assumptions of wages paid ex nihilo, capital being rented - not owned - by firms (and firms not having own funds) and the meta-time Walrasian auctioneer price-setting.

4.2. One good quasi-buffer-stock model

This version is constructed analogically to the previous two, but there is only one sector, c. The difference is that consumer debts are spent on consumption good, which is the only one in the economy. The values of $\bar{\beta}^c$ are equal to $1 - \bar{\sigma}_{sr}$. The rule for spending using savings account is the same as in the other two versions. This model is used to show the benefits of including two sectors and using the variable-rates mental accounting framework.

5. Performance comparison

Contrarily to the majority of ABM (and all of the DSGE) literature the three analysed models do not feature any external shocks. All dynamics are the result of endogenous interactions within each model. As can be seen from all figures, the MA-CR model without the demand-generation engine and variable spending rates is unable to recover from the fall of the growth rate in the second half of the simulation, and the economy continues to decrease. Note also that this happens despite labour demand growth in the first periods of the simulation - recall that demand for labour was assumed to depend only on the rate of total factor productivity (TFP) growth, and this was assumed to be constant and positive (of course, after some time the demand is unsatisfied because of rigid supply). Wages, however, depend on sales in the previous periods, so labour remuneration cannot grow faster - and so wage-led growth is ruled out. On the other side of the spectrum, the qBSM version features an extremely volatile business cycle, with growth rates outside of the set of values observed in real-world economies, and implying the collapse of the model. Comparing the evolution of the levels of real productions, Fig.1, show that variable expenditure rates and including at least two sectors are crucial features for modelling economic growth. Again, the readers are reminded that in the presented models there are no reservation wage shocks and wages are set in a backward-looking way, independently of new productivity growth.

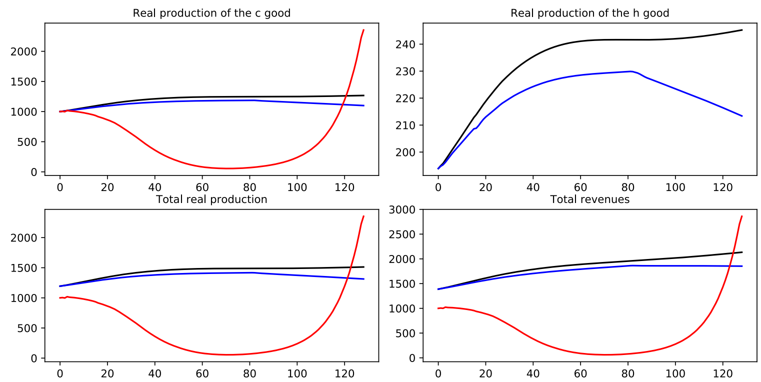

Fig.1. Black, blue and red lines denote MA-VR, MA-CR, qBSM values, respectively.

That including two sectors is likely to ensure stability (or less volatile growth) is indicated by the comparison of the qBSM and MA-CR models (red line and blue line). Interestingly, while the consistency-of-intial-conditions procedure clearly worked for MA-VR and initially also for MA-CR versions, the qBSM is still very sensitive to debt payments growth, and resulted in extremely volatile business cycle, displaying values which clearly indicate its inadequateness. On the other hand, the MA-CR displays stability, but the real production begins to fall since the 74th period, and would eventually collapse if the simulation were to go on, as there are no new-demand creating elements included in that model. Conversely, in the MA-VR, although slowly, the growth rate of real production increases after the slowdown.

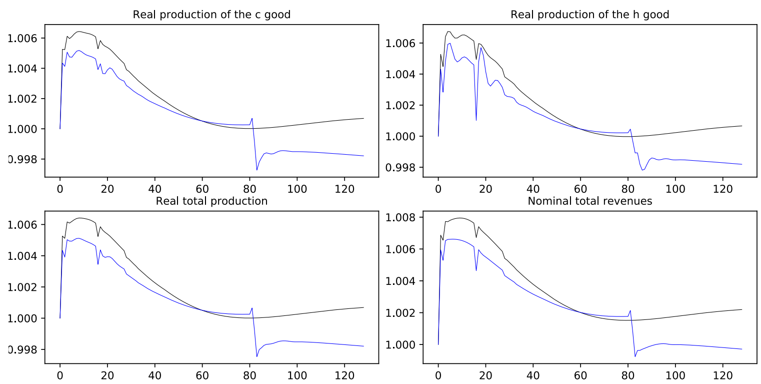

Fig.2. Black, blue and red lines denote MA-VR, MA-CR, qBSM values, respectively.

Figure 2 shows the growth rates of real productions and nominal total revenues for both MA versions of the model. The first thing that may seem striking and characterises almost all of the presented variables' dynamics is the fact that they look (qualitatively) so similar to the familiar impulse response functions from DSGE models. This is a demonstration of the claim that the presented models are agent-based counterparts of a balanced, dynamic-systems-based framework. The dynamics displayed here results from the fact that the model is dynamic by construction - even in the structural-consistency procedure past growth was assumed; moreover, the growth does not fade in the MA-VR version, but continues with a (very slow) tendency to rebuild. Of course, as suggested in the introduction, this is taken as evidence that the sources of robust growth (with realistic rates) must lie in the structural inconsistency exhibiting demand-drivenness of an economy, or more space for demand increase in the mental-accounting decision rule. The latter, however, would imply much higher saving rates for consumers - and this does not suit some quickly growing economies in which such parameters are reported to be small, for instance the United States of America.

At the beginning of the simulation, production of the durable/housing good exhibits slightly faster growth than the one of the consumption good sector. However, it quickly becomes slower, and stays so throughout the sample. It should be noted that these differences are of very small magnitude. An important point is that productions in this model are different objects than in a GE-based model, and that 'aggregate output' or 'gross domestic product' may be defined in several ways, e.g. as revenues of firms $\Pi_t^{f_1}, \Pi_t^{f_2}$, or as the value of 'final consumer goods' and investment (FGI), or only as the value of 'final consumer goods' (FG), i.e the overall expenditures made

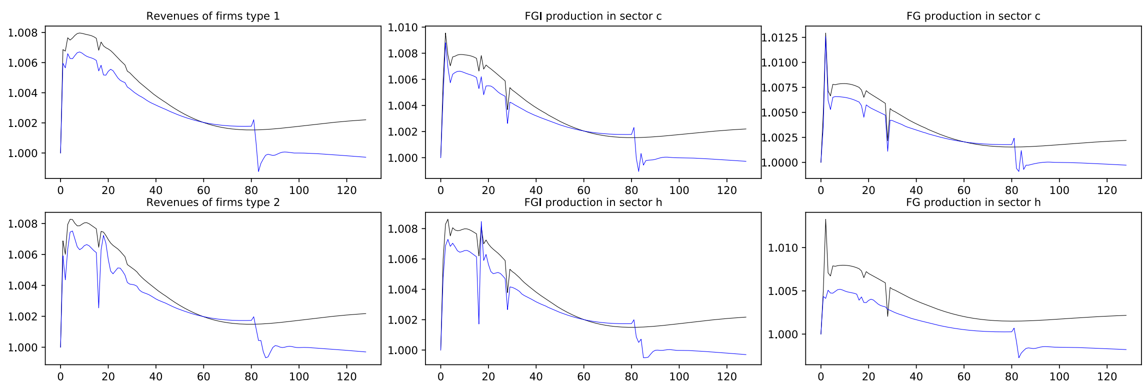

Fig.3. Black, blue and red lines denote MA-VR, MA-CR, qBSM values, respectively.

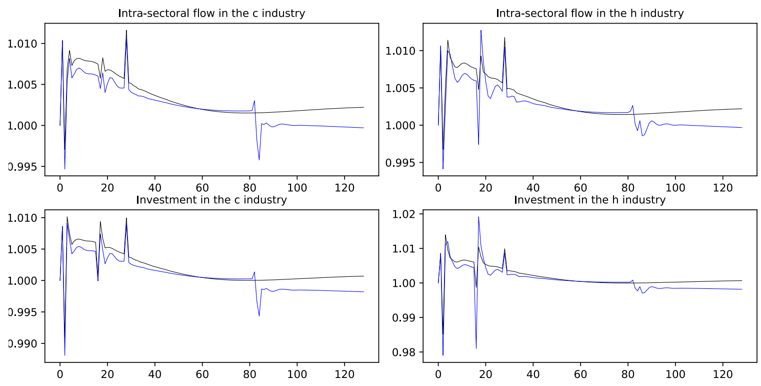

Fig.4. Black, blue and red lines denote MA-VR, MA-CR, qBSM values, respectively.

by consumers. These various measures of nominal and real output display different dynamics. What figure 4 and 5 show is that while the growth of MA-CR becomes quicker than that of MC-VR somewhere between periods 50 and 60, it leads to a very small leap followed by much larger drop. Since the decision rules for firms are identical in both models, it suggests that firms in MA-CR increased the amount of new debt, but this growth of investment and sectoral flows was not compensated by a sufficient growth of demand in subsequent periods, and resulted in a fall of the growth rate level. What figure 7 shows is that consumer debt in MA-CR increased even more, but without the positive feedback between firms' revenues, agents' incomes and consumer spending rules, it leads only to a debt overhang and the drop in output. This shows why variable-spending-rate demand is a needed modelling device if one refutes the assumptions of wage growth preceding output growth and automatic equality between incomes and nominal production. Figure 5 also provides the demonstration that the initial consistency procedure generates a balanced-growth-like behaviour.

It is worth underlining once again that the inflation considered in this study is purely demand-driven, dependent on the previous period growth of revenues of firms multiplied by a parameter. This, combined with the absence of random shocks from the model and the small rate of growth, is the cause for the smoothness of the three kinds of (gross) inflation and for the values of inflations close to one (Fig.6). Figure 6 not only indirectly shows that demand expansion fuelled by debt is unable to create fast growth and medium levels of inflation in a structurally-consistent framework, but also demonstrates the problem already discussed, namely the difficulty of inflation and production modelling in agent-based models. While other values of σ_{Π_c} and σ_{Π_h} could have been chosen, those that differ only slightly (see Fig.10) from the baseline cause spurious real recessions (i.e. caused solely by the fact

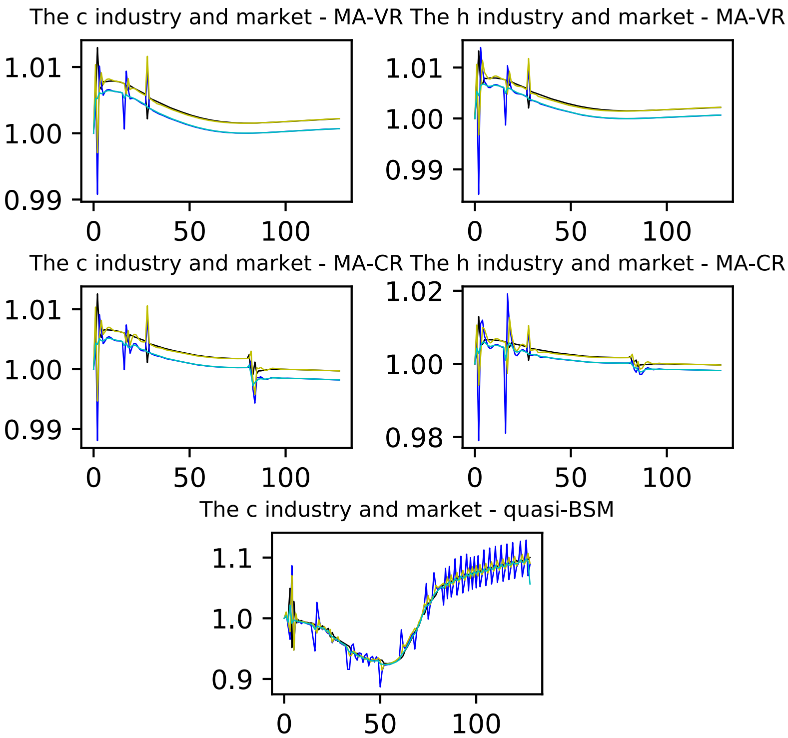

Fig.5. Black, blue, yellow and cyan lines denote consumer demand, investment, sectoral flows, and real production, respectively.

that the growth of nominal prices outpaces the growth of nominal demand). This is yet another indication that the structurally-consistent approach to agent-based modelling (and potentially, more generally, to growth modelling) is inadequate and does not capture the relevant real-world features.

Figures 7 and 8 can serve as another argument against the debt-fuelled growth hypothesis - when agents are self-regulating (or if we treat this modelling device as a reduced form for credit constraints), debt cannot play the role of a major or long-term growth engine. Figure 8 shows that with self-regulating (or: prudent; we can also interpret their behaviour as a reduced form for credit constraints) agents and the lack of the structural growth engine the economy cannot sustain such high a rate of inflow of new money as initially. Note, however, that the gross growth rate of new debt does not fall to 1 in both versions of mental-accounting models, but in the case of MA-CR this strengthens the slow decrease of the economy at the end of the simulation, i.e. it has converse effects than in MA-VR version (in this context, the reader is encouraged to look at, e.g., Fig.2.).

Figure 9 shows that more robust long-term growth is possible when

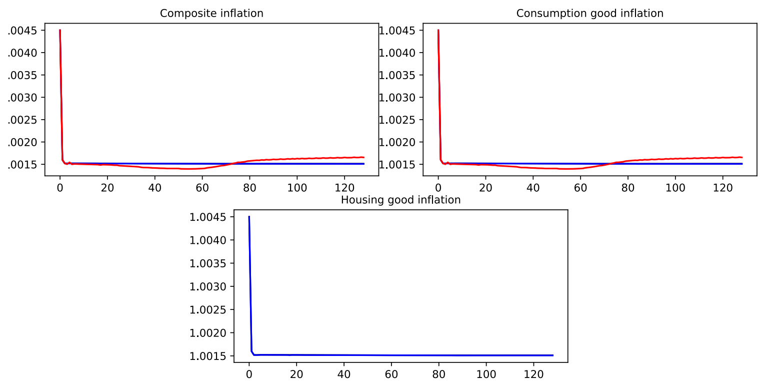

Fig.6. Black, blue and red lines denote MA-VR, MA-CR, qBSM versions; values from the first and the are too similar to be discerned.

variable demand is introduced, along with the demand-creating marketing mechanism, to the model. It holds even if the overall variability within the division-of-funds mental accounting variables are allowed to change only in a very small interval.

5.1. Spurious real recessions in agent-based models

Figure 10 illustrates the issue of spurious real recessions in ABM, discussed in the introduction. In another version of MA-VR model, differing only in the size of $\sigma_{c,1}, \sigma_{c,2}$ coefficients in the inflation equations, spurious stagflations appear. The mechanism of this phenomenon is trivial, namely, demand growth is slower than that of inflation, causing the fall of production.

6. The methodology of agent-based models and economic theory

The DSGE framework has been extensively criticised from various angles - from the assumed microfoundations to the serious problems with their estimation (for an overview of these issues, see, e.g., (Dosi and Roventini 2019), (Howitt 2012), (Caballero 2010), (Chari et al. 2009), (Ackerman 2002)). Paraphrasing Einstein (1936), when the very foundations of macroeconomics have become problematic - as many computational economists have claimed for some time - and when experience forces us to seek a newer and more solid foundation, the economist cannot surrender the critical contemplation of the theoretical foundations. It is probably uncontroversial to repeat after Einstein that the goal of theoretical work is to produce order among observed

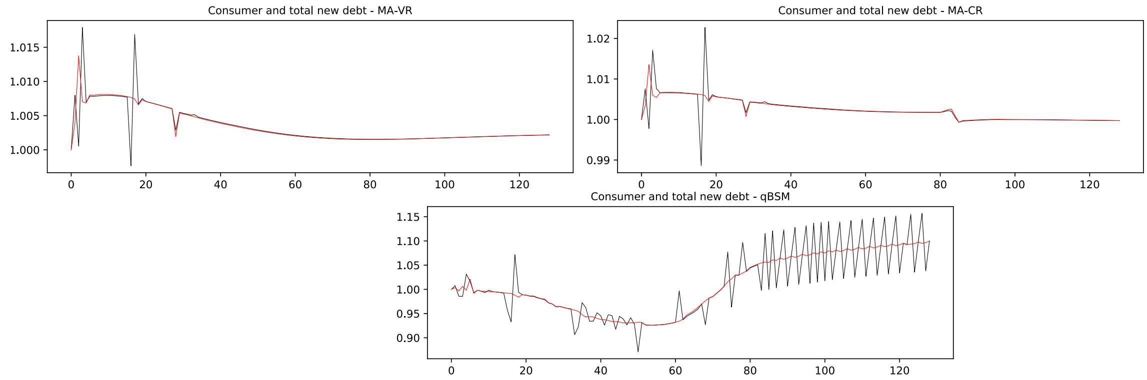

Fig.7. Black line denotes total new debt, while the red one shows the changes of new consumer debt.

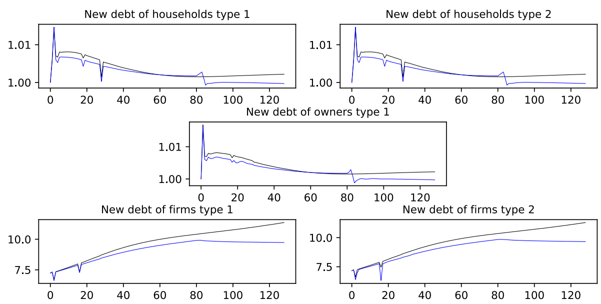

Fig.8. Black and blue lines denote variables from the MA-VR and MA-CR models. Note that the reported values of firms' debts are in absolute terms

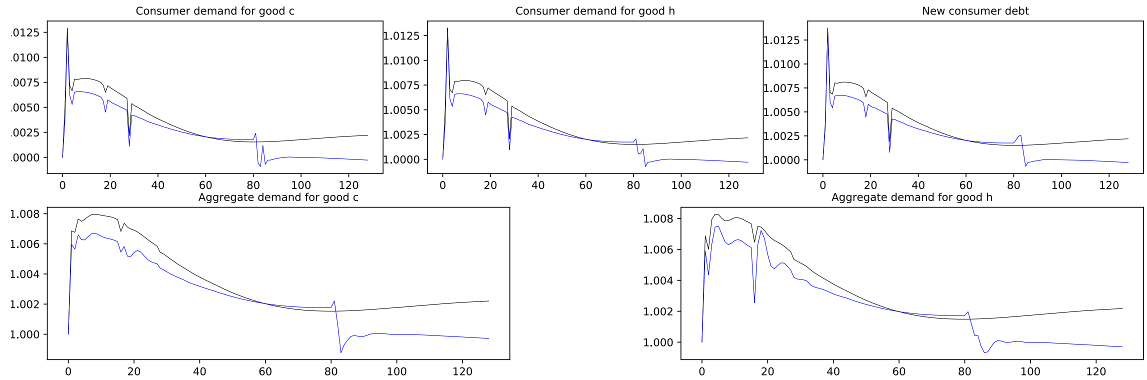

Fig.9. Black and blue lines denote variables from the MA-VR and MA-CR models, respectfully.

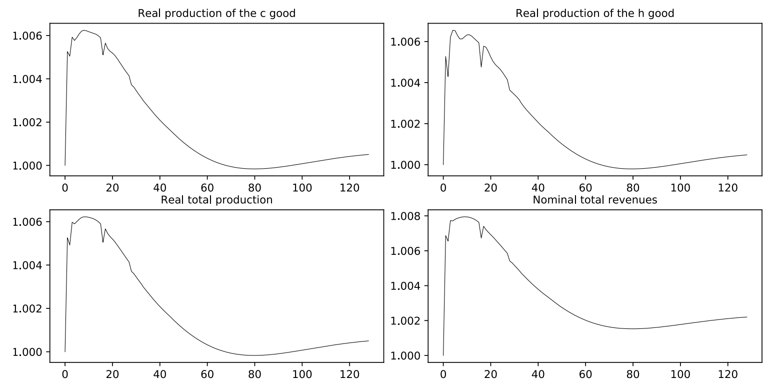

Fig.10. All variables are from a MA-VR model with higher $\sigma_{c,1}, \sigma_{c,2}$ coefficients, i.e. with inflation more responsive to the signal given by the gross change in nominal revenues.

data with the means of general concepts, dependencies between them, and relations between concepts and sense experience. This is due to the fact that data on its own (or 'primary concepts', i.e. those that are directly connected with experiences) is lacking in logical unity (Einstein 1936). Thus, the need for a theoretical system arises. Although there are many examples of agent-based models, there is hardly any widely accepted theory, or a unified theoretical approach in agent-based macroeconomics.

Due to the impossibility of proving theorems using mathematical analysis, one might ask whether any theory is possible in this framework. This depends on what definition is adopted. If we understand a theory as a system of well-substantiated explanations - laws, hypothesis, empirical research justifying some methodological solutions, and stylised facts, in other words, as an explanatory framework that facilitates understanding of a complex system, such as economies, then the agent-based approach constitutes a promising theory-building tool. It provides researchers with an opportunity for constructing a unified growth-business-cycle theory; it may be vital, as a crucial question remains unanswered. Is the separation of the real-world positive feedbacks (in terms of complex systems, a positive feedback is the one that drives change, while a negative one maintains stability in a system (Mitleton-Kelly 2008)) possible, justifying the study of a stationarised economy (as in exogenous and balanced endogenous growth DSGE models or ABMs after the burn-in periods)? In other words, is economic growth something that can be discarded from the analysis? How often are economies on balanced growth paths? Is there no need for off-the-equilibrium theories?

Agent-based research provided many examples of models but has rarely proposed any theories or called for building them. Many researchers confined their papers to show only what agent-based models are (potentially) capable of. While not defined explicitly as (collections of) theories, one may treat as such the frameworks of 'Keynes meeting Schumpeter' model and its predecessors (Dosi et al. 2010; Dosi et al. 2013; Dosi et al. 2015; Dosi et al. 2017; Dosi et al. 2018; Dosi et al. 2019), or the SFC-wage-led-growth one (Caiani et al. 2016; Caiani et al. 2018; Caiani et al. 2019b; Caiani et al. 2019a). However, as stated in the introduction, the sources of growth in both frameworks may be problematic, empirically (little evidence for wage-led growth) and methodologically (no measure for structural, not only stock-flow, consistency). In other branches of macroeconomics researchers also have focused on applying models to a particular problem, but the used ones vary greatly between each other, with various sets of frictions applied and different model structures adopted, as if each question concerned a different world. Despite the plethora of modelling devices, the default approach is still to initially apply 'the simplest model possible' and to introduce modifications only if it is unsatisfactory. What this practice actually shows is at least that there is almost no consensus at all among macroeconomists about how the economy works. At worst, it indicates that the 'epicycle critique' of Fagiolo and Roventini (2017) is justified. However, a similar approach - keeping an agent-based model as simple as possible to make causal relations from assumptions to outcomes clearer - has probably more than a few proponents among computational economists (Fagiolo and Roventini 2012). But since the real world is a complex system (which is a claim with which probably any computational economist will agree, given that systems of even relatively simple forms that do not ignorie the timing of events within a period and stock-flow consistency generate feedback loops, endogenous cycles, and many other phenomena), one may doubt whether there are any simple, univariate causal relations at all. After all, the essence of complex systems is that they are characterised by emergent phenomena - and while a researcher can justify the dynamics of a studied system by the interplay of some features of the model, the hope for a single-cause explanation should probably be abandoned. There is also a problem that has not been considered in agent-based literature. This approach has traditionally been presented as a bottom-up perspective; the self-organisation capabilities of markets were underlined. Nevertheless, this is very close to saying that an economy starting from an abstract, history-myopic and unbalanced situation can, after sufficiently long span of burn-in periods, reach a point past which all fluctuations are stationary. This is in conflict with the insistence on realism and poses questions raised before in the introduction.

Another mode of proceeding with theory-building utilising complex systems is at hand: starting the analysis of agent-based models from empirically grounded microfoundations and gradually expanding their scope to reveal what phenomena the new layers generate. The traditional approach of agent-based research is the bottom-up one, in which one starts with constructing many microeconomic agents, prescribes their decision rules, and then observes if a macroeconomic order emerges during simulations. However, this poses problems. People operate within certain institutional, legal and industrial organisation framework. Economies have their structures, but can we decisively claim that all of these result from current microeconomic interactions, rather than being partly inherited? In this paper, it is argued that careful construction of the macro-layer of the complex systems that agent-based models are, is necessary for credibly representing real-world economies. Of course, the framework presented here is too simplistic to fully serve this purpose, but it serves as a demonstration of several crucial features that agent-based models (especially those focused on economic growth) possibly should have, such as a housing/durable good sector and a procedure for establishing structural consistency, as well as assessing the degree and nature of a system's inconsistency. Moreover, it builds a mental-accounting consumer framework and shows that robustness of growth depends on whether demand is able to respond to signals such as perceived income increase, even in a structurally-consistent setting in which the maximal possible variability of consumer demand (measured with the sizes of average saving rates) is small.

7. Conclusions

In this paper, a mental accounting demand framework was introduced, which is advantageous for two reasons. First, this is a step towards improving microfoundations of consumption in agent-based models and connecting them with this theory, supported by psychological, cognitive and behavioural economics' studies. Additionally, it facilitates constructing agent-based models with more than one final-good sectors. The consequence of representing human agents' demand using this method is that it is time-variable, and allows for expansions of consumer spending.

A discussion of approaches to modelling economic growth was proposed. The sources of this phenomenon in general-equilibrium and agent-based approaches, along with the inability of the theory to explain its mechanism, and the lack of empirical evidence for some proposed solutions, were considered. The meta-timing assumption implicit in GE-based models and wage-led growth in ABM were pointed out as the main culprits, but insufficient discussion of the initial structure and values of ABM is another problematic issue. The question of whether the theoretical devices introduced in a model are responsible for growth, or is the structural imbalance (inconsistency) the cause (despite stock-flow consistency of a model), has not been asked or answered before.

A method of constructing a benchmark for assessing structural consistency or the kind and degree of structural imbalance (e.g. demand-drivenness) of a modelled economy was established. It also may be used as a form of comparison between GE-based dynamic models and ABM, and as a test of TFP-only-led growth. The results presented in this paper show a negative outcome of the latter: if incomes are lagged and they, along with other expenditure such as investment, do not adjust in a market-clearing way, then without a demand engine (i.e. demand variability and its creation by firms) long-term robust growth is not possible. Another inference that can be made basing on the analysis performed in this work is that the source of quick growth is likely to lie in the structural imbalances of an economy. It was demonstrated that, under assumptions about no wage-led growth, firms' division of own funds, and structural stability of the model, debt engine is not enough to ensure quick growth if mental saving accounting accounts are small, i.e. there is little space for demand expansion. Nevertheless, it is not granted that enlarging them would be enough for high sustained growth. It may be that demand-orientation (structural instability) of an economy is an essential condition for the emergence of output growth at medium or high rates. Finally, a possible problem of spurious real recessions, caused solely by inflation rate surpassing the growth rate, in agent-based models was pointed out. Its practical meaning is that, most likely, more elaborate inflation and production modelling is needed in such a framework, especially if enhancing models' realism is important for agent-based modellers' community.

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8. Appendix A

Behavioural decision rule variables' parameters are identified using the points of no change in the perceived income growth, $\tilde{\Omega}^{s,i}_{id} = 1$, for $s \in \{c, hs, h\}$ and small variations from it, $\tilde{\Omega}^{DCR,s,i}_{id} = 1+\delta_1$, $\tilde{\Omega}^{IN,s,i}_{id} = 1+\delta_3$, where $\delta_1 = -0.01$, $\delta_3 = 0.01$. The expenditure changes after the shifts in disposable income and the behavioural funds' division variable, y^s_{IN}, y^s_{DCR} are equal to:

$$y^s_{IN} = \beta^{IN,i} \cdot (1 + \delta_3) - \bar{\beta}^c = (\beta^{IN,i} \cdot \delta_3 + \Delta_{IN,s} \cdot (1 + \delta_3))$$

and

$$y^s_{DCR} = (\beta^{DCR,i} \cdot \delta_1 + \Delta_{DCR,s} \cdot (1 + \delta_1))$$

The above equations give us the correspondence between y^s_{IN}, y^s_{IN} and $\Delta_{IN,s}, \Delta_{DCR,s}$. Assuming $y_{IN,s} > 0$ and $y_{DCR,s} < 0$, the expressions providing bounds on the required changes in behavioural parameters and expenditure shifts are:

$$\Delta_{IN,s} < \eta_s - \bar{\beta}^s$$

$$\Delta_{DCR,s} < \eta_s - \bar{\beta}^s$$

or

$$y^s_{IN} < \bar{\beta}^s \cdot \delta_3 + (\eta_s - \bar{\beta}^s) \cdot (1 + \delta_3)$$

$$y^s_{DCR} < \bar{\beta}^s \cdot \delta_1 + (\eta_s - \bar{\beta}^s) \cdot (1 + \delta_1)$$

By choosing a point in the interval $(0, \bar{\beta}^s \cdot \delta_3 + (\eta_s - \bar{\beta}^s) \cdot (1 + \delta_3))$ we can determine the value of income change in response to δ_3. The lower bound on y^s_{DCR} is chosen such that its absolute value is smaller than the reaction to δ_3, so that the response to δ_1 is weaker as well. Note that the sizes of $\bar{\sigma}^i_{sr}$ limit the magnitudes of possible changes of the behavioural parameters. Moreover, the lower bounds on expenditure changes do not result from the reasoning given above, so they must be provided by the researcher. While in the absence of empirical or experimental studies the ones adopted in this study may appear arbitrary, they represent the underlying assumption that an (perceived) income change considered to be permanent causes temporary increase in expenditures of a magnitude larger than one, while a decrease results in changes that are smaller in absolute value. This has several justifications. First, given an economy that is structurally consistent in the sense defined in this paper, the hypothesis whether demand expansions are able to sustain fast long-run growth is tested. Second, it represents both consumption habits - for income falls - and consumption booms.

Identifying

$$\Delta_{IN,s} = (y^s_{IN} - \bar{\beta}^s \cdot \delta_3) * (1 + \delta_3)^{-1}$$

$$\Delta_{DCR,s} = (y^s_{DCR} - \bar{\beta}^s \cdot \delta_1) * (1 + \delta_1)^{-1}$$

Thus,

$$\beta^{IN,s} = \bar{\beta}^s + \Delta_{IN,s}$$

$$\beta^{DCR,s} = \bar{\beta}^s + \Delta_{DCR,s}$$

and

$$\beta_{s1} = \beta_{s2} = \eta_s$$

$$\beta_{s5} = \beta_{s6} = \bar{\beta}^s - \beta_{s1} < 0$$

$$\beta_{s3} = \log\left(\frac{\beta^{IN,s} - \beta_{s1}}{\beta_{s5}}\right) \cdot \frac{1}{\delta_3}$$

$$\beta_{s4} = \log\left(\frac{\beta^{DCR,s} - \beta_{s2}}{\beta_{s6}}\right) \cdot \frac{1}{\delta_3}$$

9. Appendix B

Table 1 presents the values assigned to various parameters of all of the three versions of the model; as for the second version of MA-VR, which serves as a demonstration of spurious real recession phenomenon, it differs from the original one only in the values of $\sigma_{\Pi_c}, \sigma_{\Pi_h}$, which are equal to 0.0017 in this version.

Table 1: Parameter values

Parameter symbol	Parameter value
$\bar{\sigma}^i_{sr}$	$1.02^{1/4} - 1$
$\bar{\sigma}^i_{sr,min}$	$1.004^{1/4} - 1$
$\bar{\beta}^{c,i}$	0.8
$\bar{\beta}^{hs,i}$	$1 - \bar{\beta}^{c,i} - \bar{\sigma}^i_{sr}$
$\bar{\beta}^{h,i}$	0.13
$\bar{\beta}^{SA,i}_{IN}$	$0.5 \cdot \bar{\sigma}^i_{sr}$
$\bar{\beta}^{SA,i}_{DCR}$	$1.1 \cdot \bar{\sigma}^i_{sr}$
η^i_c	$\bar{\beta}^{c,i} + \bar{\sigma}^{c,i}_{sr}$
η^i_{hs}	$\bar{\beta}^{hs,i} + \bar{\sigma}^{hs,i}_{sr}$
η^i_h	$\bar{\beta}^{h,i} + \bar{\sigma}^{h,i}_{sr}$
Θ^i	1
r^{cr}_0	0.04
r^d_0	0.01
r^{cr}_0	0.04
r^{cr}_0	0.04
$r^{CB,sc}_t$	0.03
$r^{CB,d}_t$	0.0025
ω^B_{RESV}	0.3
$\omega^B_{sc,c}$	0.33
$\omega^B_{sc,h}$	0.33
L^c_0	14.4
L^h_0	7.2
$L^{h_1}_0$	18.4
$L^{h_2}_0$	3.2
φ^{f_j,h_1}_{LS}	$\frac{18.4}{21.6}$
φ^{f_j,h_2}_{LS}	$\frac{3.2}{21.6}$
α^c	0.55
α^h	0.55

Table 1 – Parameter values

Parameter symbol	Parameter value
ϑ_t^c	0.8
ϑ_t^h	0.8
$\varphi_{f_j}^{LS}$	0.65
$\varphi_{f_j}^{LS,w}$	0.55
$\varphi_{f_1}^{own_1}$	0.1
$\varphi_{f_2}^{own_2}$	0.1
$\varphi_{f_1}^{OF}$	0.35
$\varphi_{f_2}^{OF}$	0.4
$\varphi_{f_1}^{rest}$	0.65
$\varphi_{f_2}^{rest}$	0.6
σ_{Π_c}	0.00151
σ_{Π_h}	0.00151
ρ_M	1.05
ρ_A	1.0045
$\rho_{pref}{}^{dA}$	0.9
ρ_{dA}	0.9
ρ_{LB_1}	0.4
ρ_{LB_2}	0.8
ω_w	0.03

The investment coefficients of firms are calculated in $t = 0$ as

$$\Phi_c^{f_1} = \varphi_{f_1}^{OF} \cdot (1 - \eta_{f_1}) * rd_{p0}^{CA,f_1} + \eta_{f_1} \cdot (rdps_p^{f_1,dummy})^{-1} \cdot \rho_A \cdot rd_{p0}^{CA,f_1}$$

$$\Phi_h^{f_2} = \varphi_{f_1}^{OF} \cdot (1 - \eta_{f_1}) * rd_{p0}^{CA,f_1} + \eta_{f_1} \cdot (rdps_p^{f_1,dummy})^{-1} \cdot \rho_A \cdot rd_{p0}^{CA,f_1}$$

10. Appendix C

Because the MA-VR and MA-CR models are not initialised in a stationary state and past growth was assumed, a few first periods are characterised by space for increasing debt and quite quick growth of demand. This is reflected in the fast increases of banks' net worth and cash flow (also caused by the fact that NW_0 and NCF_0 are small relative to the sizes of F^{cN}, F^{hN}) in the first twenty five periods. Note that even small variability of mental-accounting spending rates prevents such large drops in the net cash flow as can be observed for MA-CR. A similar drop is not manifested by the net worth because of the open market operations described in subsection 2.7.

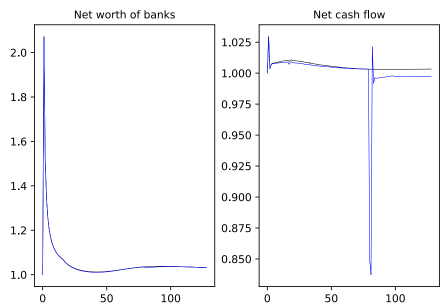

Fig.11. Black lines denote variables from the MA-VR model, while blue lines represent values from the MA-CR version.