Economic Forecasting with an Agent-based Model

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Abstract

We develop the first agent-based model (ABM) that can compete with and in the long run significantly outperform benchmark VAR and DSGE models in out-of-sample forecasting of macro variables. Our ABM for a small open economy uses micro and macro data from national sector accounts, input-output tables, government statistics, and census data. The model incorporates all economic activities as classified by the European System of Accounts as heterogeneous agents. The detailed structure of the ABM allows for a breakdown into sector level forecasts. In a recent application, we have used the detailed structure of the ABM to forecast the medium-run macroeconomic effects of lockdown measures taken in Austria to combat the COVID-19 crisis. Other potential applications of the model include stress-testing and predicting the effects of monetary or fiscal macroeconomic policies.

Keywords: agent-based models, behavioral macro, macroeconomic forecasting, micro data
JEL: E70, E32, E37

1. Introduction

This study presents a novel agent-based model (ABM) that derives macroeconomic aggregates of a national economy from the micro-founded behavior of heterogeneous agents, based on detailed macroeconomic (national accounting) and microeconomic datasets. To validate this ABM, we compare its forecast performance to that of a standard Bayesian dynamic stochastic general equilibrium (DSGE) model and time series models.

Ever since the seminal work by Smets and Wouters (2003, 2007), New Keynesian DSGE models that employ Bayesian estimation techniques have been shown to exhibit a similar forecast performance as comparable time series models (Del Negro and Schorfheide, 2013). These DSGE models have become the workhorse framework for central banks and other institutions to engage in economic forecasting and policy analysis on a sound theoretical basis, and should be regarded as a minimal standard when it comes to studying business cycles in a general equilibrium framework (Christiano et al., 2018; Brunnermeier et al., 2013). However, in light of the financial crisis of 2007-2008, that at that time was not predicted by DSGE models (Christiano et al., 2018), and the subsequent Great Recession, that could not be described sufficiently with DSGE models (Lindé et al., 2016), the DSGE approach has been criticized by several prominent voices within the economic profession. The limits of the DSGE approach at the core of the New Neoclassical Synthesis have been discussed in detail, for example, in (Vines and Wills, 2018).[1] As an alternative,

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[1] For earlier critiques see e.g., Canova and Sala (2009), Colander et al. (2009), Kirman (2010), Krugman (2011), Stiglitz (2011, 2018), Blanchard (2016), Romer (2016). See also the recent response defending DSGE models by Christiano et al. (2018).

some economists are pushing forward with ABMs—potentially to complement DSGE models—as a new promising direction for economic modelling.[2] Farmer and Foley (2009), in particular, suggest that it might be possible to conduct economic forecasts with a macroeconomic ABM, although they consider this to be ambitious.

DSGE models used to study aggregate business cycles traditionally rely on the representative agent assumption. In response to criticism, a parallel research program addressing some perceived shortcomings of DSGE models by exploring the effects of agent heterogeneity in a general equilibrium framework has led to the development of heterogeneous agent New Keynesian (HANK) models.[3] HANK models have been used to show that household and firm heterogeneity affect macroeconomic aggregates, but have rarely been used to forecast economic aggregates, where representative agent New Keynesian (RANK) models have remained the benchmark (Kaplan and Violante, 2018; Christiano et al., 2018; Del Negro and Schorfheide, 2013). The properties inherent to DSGE models due to their grounding in general equilibrium theory has led to criticism that HANK DSGE models—in contrast to ABMs—are restricted to a mild form of heterogeneity (Fagiolo and Roventini, 2017).[4] In ABMs, in contrast, heterogeneity is fundamental on the micro level, and creates emergent behavior and endogenous macroeconomic dynamics (Hommes and LeBaron, 2018).

ABMs have thus two distinguishing features: they are *"agent-based,"* that is, they model individual agents—households, firms, banks, etc.—and they are *simulation models* because they are too detailed and complex to be handled analytically. The dynamic properties of the aggregate system are derived "from the bottom up," namely, they emerge from the micro-behavior of individual agents and the structure of their interactions. Macroeconomic ABMs typically replicate a number of macroeconomic and microeconomic empirical stylized facts, such as time series properties of output fluctuations and growth, as well as cross-sectional distributional characteristics of firms (Dosi et al., 2017; Axtell, 2018). Macroeconomic ABMs relax two key assumptions at the core of the New Neoclassical Synthesis—the single, representative agent and the rational, or model-consistent, expectations hypothesis (Haldane and Turrell, 2018). Representative agents are replaced by individual "agents" who follow well-defined behavioral rules of thumb according to what has been termed as *ecological rationality* (Gigerenzer, 2015) in decision theory, and rational expectations are relaxed to bounded rationality (i.e., agents make decisions based on partial information and limited computational ability).

ABMs take the route of bounded rationality—a research program that started early on in economics from different perspectives with contributions such as those by Simon (1979), Kahneman and Tversky (1980), and Brock and Hommes (1997). Relaxation of the rational expectations hypothesis allows for greater flexibility in the design of ABMs because the strong consistency requirements entailed in simplistic models—all actions and beliefs must be mutually consistent at all times—are no longer necessary. ABMs occupy a middle ground on a spectrum where micro-founded DSGE models lie at one end and statistical models lie at the other (Haldane and Turrell, 2018).[5] Macroeconomic ABMs, however, suffer from a number of problems that impede major applications in economics, such as economic forecasting and empirically founded policy evaluation. The lack of a commonly accepted basis for the modeling of boundedly rational behavior has raised concerns about the "wilderness of bounded rationality" (Sims, 1980). Research on econometric estimation of ABMs has been growing recently, though most of it still remains at the level of proof of concept (Lux and Zwinkels, 2018). Empirical validation of ABMs remains a difficult task. Due to over-parameterization and the corresponding degrees of freedom, almost any simulation output can be generated with an ABM, and thus replication of stylized facts only represents a weak test for the validity of ABMs (Fagiolo and Roventini, 2017).

[2]Some examples include Freeman (1998), Gintis (2007), Colander et al. (2008), LeBaron and Tesfatsion (2008), Farmer and Foley (2009), Trichet (2010), Stiglitz and Gallegati (2011), and Haldane and Turrell (2018).

[3]A non-exhaustive list of prominent examples includes (Kaplan et al., 2018; Kaplan and Violante, 2014; McKay and Reis, 2016; Khan and Thomas, 2008; Chatterjee et al., 2007).

[4]This may be best explained by the way how HANK models depict agent heterogeneity. A restriction here is the necessity to keep a certain amount of information commonly known to the heterogeneous agents in a HANK model in order to be able to solve it. This so-called "approximate aggregation" result uncovered by Krusell and Smith (1998) assumes that agents know the mean of the wealth distribution in the stationary stochastic equilibrium to solve the underlying dynamic programming problem to derive the long-run equilibrium steady state growth path—which can then be subjected to different exogenous shocks to describe business cycles. The framework of Krusell and Smith (1998) still underlies most HANK models (Fagiolo and Roventini, 2017).

[5]In recent years a large literature has appeared on behavioral macro-models with boundedly rational agents and heterogeneous expectations. See e.g. the recent contribution of De Grauwe and Ji (2020) or the recent overview in Hommes (2020).

The main aim of this paper is to develop an ABM that fits microeconomic data of a small open economy and to validate it by assessing its performance in out-of-sample forecasting of the aggregate macro variables, such as GDP (including its components), inflation and interest rates.[6] The model is based on Assenza et al. (2015) who developed a stylized ABM with households, firms (upstream and downstream), and a bank, that replicates a number of stylized facts. Our ABM includes all institutional sectors (financial firms, non-financial firms, households, and a general government), where the firm sector is composed of 64 industry sectors according to national accounting conventions and the structure of input-output tables. The model is based on micro and macro data from national accounts, sector accounts, input-output tables, government statistics, census data, and business demography data. Model parameters are either taken directly from data or calculated from national accounting identities. For exogenous processes such as imports and exports, parameters are estimated. The model furthermore incorporates all economic activities, as classified by the European System of Accounts (ESA) (productive and distributive transactions) and all economic entities; namely, all juridical and natural persons are represented by heterogeneous agents. The model includes a complete GDP identity, where GDP as a macroeconomic aggregate is calculated from the market value of all final goods and services produced by individual agents and market value emerges from trading or, alternatively, according to the aggregate expenditure or income of individual agents. Markets are fully decentralized and characterized by a continuous search-and-matching process, which allows for trade frictions. Agents' expectations are modeled by parameter-free adaptive learning, where agents act as econometricians who estimate the parameters of their model and make forecasts using their estimates (Evans and Honkapohja, 2001). We follow the approach of Hommes and Zhu (2014), where agents learn the optimal parameters of simple parsimonious autoregressive (AR) rules of lag order one in a complex environment.[7]

The objectives of this paper are twofold. First, we develop the first ABM that fits the microeconomic data of a small open economy and allows out-of-sample forecasting of the aggregate macro variables, such as GDP (including its components), inflation and interest rates. Second, as an empirical validation, we compare the forecast performance of the ABM to that of VAR, AR, and DSGE models. For this purpose, we conduct a series of forecasting exercises where we evaluate the out-of-sample forecast performance of the different model types using a traditional measure of forecast error (root mean squared error). In a first exercise, we validate the ABM against an unconstrained VAR model that is estimated on the same dataset as the ABM. We find that the ABM delivers a similar forecast performance to the VAR model for short- to medium-term horizons up to two years, and significantly improves on VAR forecasts for longer horizons up to three years. In a second exercise, we compare the forecast performance of the ABM to that of an AR model and a standard DSGE model for the main macroeconomic aggregates, GDP and inflation, as well as to household consumption and investment as main components of GDP. For a DSGE model, we have employed the standard DSGE model of Smets and Wouters (2007), adapted to the Austrian economy by Breuss and Rabitsch (2009).[8] Here, we find that the ABM delivers a similar forecast performance to that of the standard DSGE model. Both the ABM and the standard DSGE model improve on the AR model in forecasting household consumption and investment. In a third forecasting setup, we generate forecasts conditional on exogenous paths for imports, exports, and government consumption, corresponding to a small open economy setting and exogenous policy decisions. In this forecast exercise, the detailed economic structure incorporated into the ABM improves its forecasting ability significantly for longer forecast horizons (three years), especially in comparison with the DSGE model. We perform two more forecasting exercises exploring the detailed sectoral structure of our ABM. With these three forecast exercises, we achieve comparability of the ABM to the forecasting performance of standard modeling approaches, thereby introducing a novel procedure of model validation for ABMs. To the best of our knowledge, this

[6] A related model that does not allow out-of-sample forecasting of macro variables was used for estimating indirect economic losses from natural disasters in (Poledna et al., 2018).

[7] Brayton et al. (1997) discuss the role of expectations in FRB/US macroeconomic models. One approach is that expectations are given by small forecasting models such as a vector autoregressive (VAR) model. Our choice of an AR(1) model is simply the most parsimonious yet empirically relevant choice, where, for each relevant variable, agents learn the parameters of an AR(1) rule consistent with the observable sample mean and autocorrelation. Slobodyan and Wouters (2012) estimated the Smets and Wouters (2007) DSGE model with expectations modelled by a simple AR(2) forecasting rule under time-varying beliefs and show that this leads to an improvement in the empirical fit of the model and its ability to capture the short-term momentum in the macroeconomic variables. Hommes et al. (2019) estimate the benchmark 3 equations New Keynesian model with optimal AR(1) rules for inflation and output gap and find a better fit than under rational expectations.

[8] We opted for a RANK DSGE model since we want to closely adhere to the standards used in the DSGE forecasting literature (Kaplan and Violante, 2018; Del Negro and Schorfheide, 2013; Diebold et al., 2017). Furthermore, we see DSGE models close in spirit to Smets and Wouters (2007) as *the* benchmark DSGE model for forecasting (in a canonical sense).

is the first ABM able to compete in out-of-sample forecasting of macro variables.

The remainder of the manuscript is structured as follows. Section 2 elaborates on the characteristics of ABMs, critiques of them, and gives a brief summary of the related literature. Section 3 provides the details of the model, stating all model equations and descriptions of agents' behavior. Section 4 gives an overview of all parameters used, explaining in detail the choice of their values as well as the procedure of deriving them, and states the relevant datasets. Section 5 explains the choice of the variables' initial values, including our calculations and datasets involved. Section 6 describes the forecast performance of the ABM, where we validate the ABM against VAR, DSGE, and AR models in different forecasting setups, and delivers applications to more detailed decompositions of the ABM forecasts. Section 7 concludes. The details of our ABM are given in Sections 3 to 5.

2. Related literature

Since their beginnings in the 1930s,[9] ABMs have found widespread application as an established method in various scientific disciplines (Haldane and Turrell, 2018), for example, military planning, the physical sciences, operational research, biology, ecology, but less so in economics and finance. The use of ABMs in the latter two fields to date remains quite limited in comparison to other disciplines. An early exception is Orcutt (1957), who constructed a first simple economically motivated ABM to obtain aggregate relationships from the interaction of individual heterogeneous units via simulation. Other examples include topics such as racial segregation patterns (Schelling, 1969), financial markets (Arthur et al., 1997), or more recently the housing market (Geanakoplos et al., 2012; Baptista et al., 2016). Since the financial crisis of 2007–2008, ABMs have increasingly been applied to research in macroeconomics. Furthermore, in recent years, several ABMs have been developed that depict entire national economies and are designed to deliver macroeconomic policy analysis. The European Commission (EC) has in part supported this endeavor. One example of a large research project funded by the EC is the Complexity Research Initiative for Systemic Instabilities (CRISIS),[10] an open source collaboration between academics, firms, and policymakers (Klimek et al., 2015). Another is EURACE,[11] a large micro-founded macroeconomic model with regional heterogeneity (Cincotti et al., 2010).

In a recent overview Dawid and Delli Gatti (2018) identified seven main families of macroeconomic ABMs[12]: (1) the framework developed by Ashraf, Gershman, and Howitt (2017); (2) the family of models proposed by Delli Gatti et al. (2011) in Ancona and Milan exploiting the notion of Complex Adaptive Trivial Systems (CATS); (3) the framework developed by Dawid et al. (2018) in Bielefeld as an offspring of the EURACE project, known as Eurace@Unibi; (4) the EURACE framework maintained by Cincotti et al. (2010) in Genoa; (5) the Java Agent based MacroEconomic Laboratory developed by Seppecher, Salle, and Lavoie (2018); (6) the family of models developed by Dosi et al. (2017) in Pisa, known as the "Keynes meeting Schumpeter" framework; and (7) the LAGOM model developed by Jaeger et. al (2013). What unites all these families of models is their ability to generate endogenous long-term growth and short- to medium-term business cycles. These business cycles are the macroeconomic outcome of the micro-level interaction of heterogeneous agents in the economy as a complex system subject to non-linearities (Dawid and Delli Gatti, 2018). All these models assume bounded rationality for their agents, and thus suppose adaptive expectation in an environment of fundamental uncertainty. Typically, they minimally depict firm, household, and financial (banking) sectors populated by numerous agents of these types (or classes), and agents exhibit additional heterogeneity within one or more of the different classes. All results are obtained by performing extensive Monte Carlo simulations and averaging over simulation outcomes. The great majority of models are calibrated and validated with respect to a (smaller or larger) variety of stylized empirical economic facts (Fagiolo and Roventini, 2017). However, despite their level of sophistication, all these models suffer from one or more impediments: they serve as a theoretical explanatory tool constructed for a hypothetical economy; the choice of the number of agents is arbitrary or left unexplained; time units may have no clear interpretation; validation with respect to stylized empirical facts cannot solve the potential problem of over-parameterization; the choice of parameter values is often not pinned down by

[9]The first ABM reportedly was constructed (by hand) by Enrico Fermi in the 1930s to model the problem of neutron transport.

[10]FP7-ICT grant 288501, http://cordis.europa.eu/project/rcn/101350_en.html. (Last accessed November 30th, 2019)

[11]FP6-STREP grant 035086, http://cordis.europa.eu/project/rcn/79429_en.html. See also: http://www.wiwi.uni-bielefeld.de/lehrbereiche/vwl/etace/Eurace_Unibi/ (Last accessed November 30th, 2019)

[12]For another recent overview on macroeconomic ABMs see Fagiolo and Roventini (2017).

clear-cut empirical evidence; and most of these models exhibit an extended transient or burn-in phase that is discarded before analysis.

To address these concerns we develop an ABM that fits microeconomic data of a small open economy and allows out-of-sample forecasting of the aggregate macro variables, such as GDP (including its components), inflation and interest rates. This model is based on micro and macro data from national accounts, input-output tables, government statistics, census data, and business demography data. Model parameters are either taken directly from data or are calculated from national accounting identities. For exogenous processes, such as imports and exports, parameters are estimated. As an empirical validation, we compare the out-of-sample forecast performance of the ABM to that of AR, VAR, and DSGE models.

3. An agent-based model for a small open economy

In this section we present an ABM for a small open economy. Following the sectoral accounting conventions of the ESA, Eurostat (2013), the model economy is structured into four mutually exclusive domestic institutional sectors: (1) non-financial corporations (firms); (2) households; (3) the general government; and (4) financial corporations (banks), including (5) the central bank. These four sectors make up the total domestic economy and interact with (6) the rest of the world (RoW) through imports and exports. Each sector is populated by heterogeneous agents, who represent natural persons or legal entities (corporations, government entities, and institutions). We use a scale of 1:1 between model and data, so that each agent in the model represents a natural or legal person in reality. This has the advantage that our ABM is directly linked to microeconomic data and that scaling or fine tuning of parameters and size is not needed; rather, parameters are pinned down by data or calculated from accounting identities. All individual agents have separate balance sheets, depicting assets, liabilities, and ownership structures. The balance sheets of the agents, and the economic flows between them, are set according to data from national accounts.

The firm sector is composed of 64 industry sectors according to the NACE/CPA classification by ESA and the structure of input-output tables. The firm population of each sector is derived from business demography data, while firm sizes follow a power law distribution, which approximately corresponds to the firm size distribution in Austria. Each firm is part of a certain industry and produces industry-specific output by means of labor, capital, and intermediate inputs from other sectors—employing a fixed coefficient (Leontief) production technology with constant coefficients. These productivity and technology coefficients are calculated directly from input-output tables. Firms are subject to fundamental uncertainty regarding their future sales, market prices, the availability of inputs for production, input costs, and cash flow and financing conditions. Based on partial information about their current status quo and its past development, firms have to form expectations to estimate future demand for their products, their future input costs, and their future profit margin. According to these expectations—which are not necessarily realized in the future—firms set prices and quantities. We assume that firms form these expectations using simple autoregressive time series models (AR(1) expectations). These expectations are parameter-free, as agents learn the optimal AR(1) forecast rule that is consistent with two observable statistics, the sample mean and the sample autocorrelation (Hommes and Zhu, 2014). Output is sold to households as consumption goods or investment in dwellings and to other firms as intermediate inputs or investment in capital goods, or it is exported. Firm investment is conducted according to the expected wear and tear on capital. Firms are owned by investors (one investor per firm), who receive part of the profits of the firm as dividend income.

The household sector consists of employed, unemployed, investor, and inactive households, with the respective numbers obtained from census data. Employed households supply labor and earn sector-specific wages. Unemployed households are involuntarily idle, and receive unemployment benefits, which are a fraction of previous wages. Investor households obtain dividend income from firm ownership. Inactive households do not participate in the labor market and receive social benefits provided by the government. Additional social transfers are distributed equally to all households (e.g., child care payments). All households purchase consumption goods and invest in dwellings which they buy from the firm sector. Due to fundamental uncertainty, households also form AR(1) expectations about the future that are not necessarily realized. Specifically, they estimate inflation using an optimal AR(1) model to calculate their expected net disposable income available for consumption.

The main activities of the government sector are consumption on retail markets and the redistribution of income to provide social services and benefits to its citizens. The amount and trend of both government consumption and redistribution are obtained from government statistics. The government collects taxes, distributes social as well as other transfers, and engages in government consumption. Government revenues consist of (1) taxes: on wages (income tax), capital income (income and capital taxes), firm profit income (corporate taxes), household consumption (value-added tax), other products (sector-specific, paid by industry sectors), firm production (sector-specific), as well as on exports and capital formation; (2) social security contributions by employees and employers; and (3) other net transfers such as property income, investment grants, operating surplus, and proceeds from government sales and services. Government expenditures are composed of (1) final government consumption; (2) interest payments on government debt; (3) social benefits other than social benefits in kind; (4) subsidies; and (5) other current expenditures. A government deficit adds to its stock of debt, thus increasing interest payments in the periods thereafter.

The banking sector obtains deposits from households as well as from firms, and provides loans to firms. Interest rates are set by a fixed markup on the policy rate, which is determined according to a Taylor rule. Credit creation is limited by minimum capital requirements, and loan extension is conditional on a maximum leverage of the firm, reflecting the bank's risk assessment of a potential default by its borrower. Bank profits are calculated as the difference between interest payments received on firm loans and deposit interest paid to holders of bank deposits, as well as write-offs due to credit defaults (bad debt). The central bank sets the policy rate based on implicit inflation and growth targets, provides liquidity to the banking system (advances to the bank), and takes deposits from the bank in the form of reserves deposited at the central bank. Furthermore, the central bank purchases external assets (government bonds) and thus acts as a creditor to the government. To model interactions with the rest of the world, a segment of the firm sector is engaged in import-export activities. As we model a small open economy, whose limited volume of trade does not affect world prices, we obtain trends of exports and imports from exogenous projections based on national accounts.

3.1. Firms

Each firm i ($i = 1, 2, \ldots, I = \sum_s I_s$) produces a principal product g ($g = 1, 2, \ldots, G$) using labor, capital and intermediate inputs from other firms, and is part of an industry or sector s ($s = 1, 2, \ldots, S$),[13] with a number of I_s firms in each industry. Demand for products of firm i is formed on markets for final consumption goods, capital goods as well as material or intermediate input goods.

Firms face fundamental uncertainty regarding the main determinants of their individual success on the market: future sales, market prices, the availability of inputs for the production process (labor, capital, intermediate inputs), wages, cash flow, and their access to external finance, among others, are unknown. This implies that in each period t, ($t = 1, ..., T$), the firm has no knowledge about its equilibrium position $(\hat{P}_i(t), \hat{Q}_i^{\mathrm{d}}(t))$[14]—given by the equilibrium price $\hat{P}_i(t)$ and equilibrium demand $\hat{Q}_i^{\mathrm{d}}(t)$—at which all its products would be sold and all consumer demand for its products would be satisfied. Therefore, the firm's future input costs, its capacity to produce given input constraints, as well as the corresponding implications for its cash flow and balance sheet are fundamentally uncertain. Firms only have access to partial information: their current status quo—sales, prices, labor, capital and material input costs, cash flow, etc.—and its past development, as well as selected macro time series such as growth, inflation, or index prices. Consequently, each firm has to form expectations about the future that may not correspond to actual realizations.

3.1.1. Sales

Every agent active on a market as a consumer—be it a household h or a government entity j intending to consume, or a firm demanding capital or intermediate input goods—searches for the best bargain, i.e., the lowest price, to satisfy its demand for each of products g it requires. The consumption and supply networks in the model are formed in every period of the model according to a search-and-matching process: in each period, consumers visit a number of randomly chosen firms i that sell the good g in order to ascertain the selling prices. The probability of a firm i being chosen is determined by weighted sampling without replacement. This probability is given (1) by the price charged by firm i according to an exponential distribution, where firms charging a lower price are more likely of being picked, and

[13]We suppose a one-to-one correspondence between the sets of industries s and products g, meaning that the n-th sector produces only the n-th good, and $S = G$; formally, the correspondence between goods g being produced in sector s would be represented by a unity matrix.

[14]In this manuscript subscripts are used for indices referring to an agent in the model, while superscripts generally indicate a behavioral relation for a variable. For example, a quantity X referring to a firm is denoted by X_i, expectations for a quantity X are written as X^{e}, or demand for a quantity X is indicated by X^{d}. Additionally, superscripts in capital letters are used to further distinguish related variables, e.g., $\bar{P}^{\mathrm{HH}}(t)$ denotes the consumer price index while $\bar{P}^{\mathrm{CF}}(t)$ is capital formation price index.

(2) by the relative size of the firm compared to other firms, so that bigger firms have a higher probability to be picked. The total probability of firm i of being selected in this process is then the average of the latter two probabilities:

$$pr_i^{\text{price}}(t) = \frac{e^{-2P_i(t)}}{\sum_{i \in I_{s=g}} e^{-2P_i(t)}}$$

$$pr_i^{\text{size}}(t) = \frac{Y_i(t)}{\sum_{i \in I_{s=g}} Y_i(t)}$$

$$pr_i^{\text{cum}}(t) = \frac{pr_i^{\text{price}}(t) + pr_i^{\text{size}}(t)}{2}$$

where $pr_i^{\text{price}}(t)$ is the probability of firm i of being selected by a consumer due to its offering price, $pr_i^{\text{size}}(t)$ the probability of being chosen due to its size, $pr_i^{\text{cum}}(t)$ the cumulative average probability to be picked according to both of these factors, and $Y_i(t)$ is the production of goods by firm i, see equation (12). If the most preferred firm is in short supply, the consumer resorts to the remaining firms, otherwise it satisfies all its demand with the first firm. If an agent does not succeed in satisfying its demand for a specific product g, it saves involuntarily. Thus realized demand is the endogenous outcome of the model algorithm, which depends mainly on the random-visiting element, that is, whether the agent acting as a customer finds firms to fulfill its demands.

Demand $Q_i^{\text{d}}(t)$ will be determined by consumers only after the firm has set its price and carried out production $Y_i(t)$. It is subject to the search-and-matching mechanism specifying the visiting consumers of firm i:

$$Q_i^{\text{d}}(t) \begin{cases} < S_i(t-1) + Y_i(t) & \text{if demand from visiting consumers is smaller than supply from firm } i\text{, and} \\ = S_i(t-1) + Y_i(t) & \text{if demand from visiting consumers exactly matches supply from firm } i\text{, and} \\ > S_i(t-1) + Y_i(t) & \text{if demand from visiting consumers is larger than supply from firm } i\text{ ,} \end{cases} \tag{1}$$

where $S_i(t-1)$ is the inventory of finished goods. Sales are then the realized demand dependent on the supply available from firm i after the production process has taken place:

$$Q_i(t) = \min(S_i(t-1) + Y_i(t), Q_i^{\text{d}}(t))\,. \tag{2}$$

The difference between production and sales is excess supply

$$\Delta S_i(t) = Y_i(t) - Q_i(t)\,, \tag{3}$$

which is a reflection of firms' expectation error concerning demand. This difference is stored as inventories,

$$S_i(t) = S_i(t-1) + \Delta S_i(t)\,, \tag{4}$$

until the next period, where they are supplied on the goods market together with newly produced goods. We do not assume any depreciation of this inventory of finished goods.

3.1.2. Price Setting and Supply

Given the importance of accurate forecasts, fundamental uncertainty and imperfect information, firms' have the option of choosing forecasting methods that may closely reflect their economic environment, but that fail to be a complete model of the economy inclusive of every detail. One such forecasting model that meets these requirements is an AR model: this is a simple procedure for projecting past trends into the future, while its forecasting capabilities are comparably high. We therefore assume that an individual firm i in our model uses an autoregressive model to form expectations of demand for its products ($Q_i^{\text{e}}(t)$) and to determine the selling price $P_i(t)$ it will charge. According to these expectations, the firm will set its desired production ($Q_i^{\text{s}}(t)$) as well as its selling price. The information set that the firm uses for these two decisions consists of the previous period's demand for its product, the expected rate of real economic growth, the expected rate of inflation, its expected future input costs based on past prices and expected inflation, and a unit target for attaining an operating surplus.

The supply choice of firm i is thus made based on the expected rate of real economic growth ($\gamma^{\text{e}}(t)$) and the previous period's demand for its product $Q_i^{\text{d}}(t-1)$:

$$Q_i^{\text{s}}(t) = Q_i^{\text{e}}(t) = Q_i^{\text{d}}(t-1)(1 + \gamma^{\text{e}}(t)). \tag{5}$$

Expectations regarding economic growth are formed using an autoregressive model with lag one (AR(1)):[15]

$$\log(Y^{\mathrm{e}}(t)) = \alpha^{\mathrm{Y}}(t)\log\left(\sum_i Y_i(t-1)\right) + \beta^{\mathrm{Y}}(t) + \epsilon^{\mathrm{Y}}(t)\,, \tag{6}$$

where $\alpha^{\mathrm{Y}}(t)$, $\beta^{\mathrm{Y}}(t)$, and $\epsilon^{\mathrm{Y}}(t)$ are re-estimated every period on the time series of aggregate output of firms $\sum_i Y_i(t')$ where $t' = -T', -T'+1, -T'+2, \ldots, 0, 1, 2, \ldots, t-1$. To allow the data to decide on the degree of persistence and cointegration, output is entered in log levels and the growth rate is calculated from the percentage change to the previous period:

$$\gamma^{\mathrm{e}}(t) = \frac{Y^{\mathrm{e}}(t)}{\sum_i Y_i(t-1)} - 1\,. \tag{7}$$

Price setting by the firm evolves according to the expected rate of inflation ($\pi^{\mathrm{e}}(t)$), the cost-structure faced by the firm ("cost-push inflation"), and the unit target for attaining an operating surplus (where again firm i is part of sector s ($i \in I_s$)):

$$\begin{aligned} P_i(t) = {} & \underbrace{\frac{\bar{w}_i(1+\tau^{\mathrm{SIF}})\bar{P}^{\mathrm{HH}}(t-1)(1+\pi^{\mathrm{e}}(t))}{\bar{\alpha}_i}}_{\text{Unit labour costs}} + \underbrace{\frac{1}{\beta_i}\sum_g a_{sg}\bar{P}_g(t-1)(1+\pi^{\mathrm{e}}(t))}_{\text{Unit Material costs}} + \underbrace{\frac{\delta_i}{\kappa_i}\bar{P}^{\mathrm{CF}}(t-1)(1+\pi^{\mathrm{e}}(t))}_{\text{Unit capital costs}} \\ & + \underbrace{\tau_i^{\mathrm{Y}} P_i(t-1)(1+\pi^{\mathrm{e}}(t))}_{\text{Unit net taxes/subsidies products}} + \underbrace{\tau_i^{\mathrm{K}} P_i(t-1)(1+\pi^{\mathrm{e}}(t))}_{\text{Unit net taxes/subsidies production}} + \underbrace{\bar{\pi}_i P_i(t-1)(1+\pi^{\mathrm{e}}(t))}_{\text{Target unit operating surplus}} \quad \forall i \in I_s \end{aligned} \tag{8}$$

where $\bar{\alpha}_i$ indicates the average productivity of labor, w_i are gross wages indexed by the consumer price index $\bar{P}^{\mathrm{HH}}(t)$, see equation (30), and including employers' contribution to social insurance charged at a rate τ^{SIF}; $\frac{1}{\beta_i}\sum_g a_{sg}$ are unit real expenditures on intermediate input by industry s on good g weighted by the average product price index for good g ($\bar{P}_g(t)$), see equation (28), δ_i/κ_i are unit real capital costs due to depreciation (δ_i is the firm's capital depreciation rate and κ_i is the productivity coefficient for capital); $\bar{P}^{\mathrm{CF}}(t)$ is the average price of capital goods as in equation (29), τ_i^{Y} and τ_i^{K} are net tax rates on products and production, respectively, and $\bar{\pi}_i = 1 - \left(1+\tau^{\mathrm{SIF}}\right)\frac{\bar{w}_i}{\bar{\alpha}_i} + \frac{\delta_i}{\kappa_i} + \frac{1}{\beta_i} - \tau_i^{\mathrm{K}} - \tau_i^{\mathrm{Y}}$ is the operating margin. Expectations on inflation are formed using an autoregressive model of lag order one (AR(1)):

$$\log(1+\pi^{\mathrm{e}}(t)) = \alpha^{\pi}(t)\pi(t-1) + \beta^{\pi}(t) + \epsilon^{\pi}(t)\,, \tag{9}$$

where $\alpha^{\pi}(t)$, $\beta^{\pi}(t)$, and $\epsilon^{\pi}(t)$ are re-estimated every period on the time series of inflation $\pi(t')$ where $t' = -T', -T'+1, -T'+2, \ldots, 0, 1, 2, \ldots, t-1$. The inflation rate is calculated from the log difference of the producer price index

$$\pi(t) = \log\left(\frac{\bar{P}(t)}{\bar{P}(t-1)}\right), \tag{10}$$

where the producer price index is defined as

$$\bar{P}(t) = \frac{\sum_i P_i(t)(Y_i(t)+S_i(t)) + \sum_m P_m(t)Q_m(t)}{\sum_i(Y_i(t)+S_i(t)) + \sum_m Q_m(t)}\,, \tag{11}$$

where $P_m(t)$ and $Q_m(t)$ are the price and sales from foreign producers m, for details see Section 3.6.1. With our assumption for firm price setting, we simultaneously incorporate firms' current input cost structure as well as their expectations about future cost, inflation and profit developments.

[15] This is comparable to other adaptive mechanisms such as VAR expectations as used in the US Federal Reserve's FRB/US macroeconomic model (Brayton et al., 1997), or expectations according to an exponential moving average (EMA) model as in Assenza et al. (2015).

3.1.3. Production

In each period t firm i (which is part of industry s) produces output ($Y_i(t)$, in real terms) in form of the principal product g by means of inputs of labor ($N_i(t)$, the number of persons employed), intermediate goods/services and raw materials ($M_i(t)$, in real terms), as well as capital ($K_i(t-1)$, in real terms). We assume a production function with Leontief technology and separate nests for intermediate goods, labour and capital, respectively—all of which represent upper limits to production:

$$Y_i(t) = \min\left(Q_i^{\mathrm{s}}(t), \beta_i M_i(t-1), \alpha_i(t) N_i(t), \kappa_i K_i(t-1)\right), \tag{12}$$

where $\alpha_i(t)$ is the productivity of labor of firm $i \in I_s$, see equation (22), and β_i and κ_i are productivity coefficients for intermediate inputs and capital, respectively. Production by firm i may not equal desired scale of activity ($Q_i^{\mathrm{s}}(t)$). Output could be limited by the amount of available labor force, the quantity of intermediate goods, or the availability of capital needed in the production process. In these cases, the firm has to scale down activity.

3.1.4. Investment

In each period the i-th firm has to decide how much to invest ($I_i^{\mathrm{d}}(t)$, in real terms). Investment allows the firm to adjust the real capital stock $K_i(t)$. Capital adjustment, however, is not immediate and time consuming. New capital goods[16] bought at the time t will be part of the capital stock only in the next period $t+1$. This makes capital a durable and sticky input.

The desired investment in capital stock in period t is

$$I_i^{\mathrm{d}}(t) = \frac{\delta_i}{\kappa_i} Q_i^{\mathrm{s}}(t) = \frac{\delta_i}{\kappa_i} Q_i^{\mathrm{e}}(t) = \frac{\delta_i}{\kappa_i} Q_i^{\mathrm{d}}(t-1)(1+\gamma^{\mathrm{e}}(t)) \quad , \tag{13}$$

where δ_i is the firm's capital depreciation rate. The economic rationale behind this equation is that firms adjust their investment demand to expected wear and tear of capital, and that only capital planned to be used in the production process is expected to depreciate and needs to be replaced by new investment. The latter in turn depends on the future demand estimated by the firm according to past demand and the expected rate of economic growth.

We assume a homogenous capital stock for all firms and thus fixed weights b_g^{CF}, namely, each firm i—irrespective of the sector s firm i is part of—demands $b_g^{\mathrm{CF}} I_i^{\mathrm{d}}(t)$ as its real investment from firms producing good g:

$$I_{ig}^{\mathrm{d}}(t) = b_g^{\mathrm{CF}} I_i^{\mathrm{d}}(t). \tag{14}$$

It may be the case that firms cannot obtain the requested investments goods on the capital goods market, or at an unexpectedly high price. The amount of realized investment therefore depends on the search-and-matching process on the capital goods market, see Section 3.1.1:

$$I_i(t) \begin{cases} = \sum_g I_{ig}^{\mathrm{d}}(t) & \text{if the firm successfully realized the investment plan, and} \\ < \sum_g I_{ig}^{\mathrm{d}}(t) & \text{if all firms visited could not satisfy its demand} \end{cases} \tag{15}$$

In the case where firm i cannot realize its investment plan, it will have to scale down future activity, see equation (12).

The capital stock, as an aggregate over all goods g, evolves according to a depreciation and investment law of motion, where only the amount of capital actually used in the production process depreciates:

$$K_i(t) = K_i(t-1) - \frac{\delta_i}{\kappa_i} Y_i(t) + I_i(t). \tag{16}$$

[16] We assume no difference between investment (or capital) goods, consumption and intermediate-input goods in our model, but rather that each product g is used for all these demand components, according to production needs and consumer preferences.

3.1.5. Intermediate Inputs

Each firm needs intermediate input of goods for production. We assume that firm i holds a stock of input goods $M_i(t)$ (in real terms) for each type of good g. From this stock of intermediate input goods, firm i takes out materials for production as needed, and it keeps these goods in positive supply to avoid shortfalls of material input impeding production. Each period the i-th firm has to decide on the desired amount of intermediate goods and raw materials ($\Delta M^{\mathrm{d}}_{ig}(t)$) that it intends to purchase in order to keep its stock in positive supply. Here also, similar to equation (12), firm i is part of industry s and consumes an intermediate input g according to sector-specific technology coefficients (a_{sg}). We assume a steady use by the firm of its raw materials in production, and hence that the material stock does not depreciate. This is given by

$$\Delta M^{\mathrm{d}}_{ig}(t) = a_{sg}\frac{Q^{\mathrm{s}}_i(t)}{\beta_i} \quad \forall i \in I_s\,. \tag{17}$$

Firms thus try to keep their stock of material input goods within a certain relationship to $Q^{\mathrm{s}}_i(t)$ by accounting for planned material input use in this period. In the intermediate goods market, too, the amount of realized purchases of intermediate goods depends on a search-and-matching process, see Section 3.1.1:

$$\Delta M_i(t) \begin{cases} = \sum_g \Delta M^{\mathrm{d}}_{ig}(t) & \text{if the firm successfully realized its plan, and} \\ < \sum_g \Delta M^{\mathrm{d}}_{ig}(t) & \text{if all firms visited could not satisfy its demand.} \end{cases} \tag{18}$$

If firm i does not succeed in acquiring the materials it intended to purchase, it will be limited in its production possibilities. The stock of good g held by firm i evolves according to the material use in the production process necessary to achieve actual production ($Y_i(t)$) and realized new acquisitions of intermediate goods:

$$M_i(t) = M_i(t-1) - \frac{Y_i(t)}{\beta_i} + \Delta M_i(t)\,. \tag{19}$$

3.1.6. Employment

Each firm i uses employment $N_i(t)$ as labor input for production, which is the number of persons employed. The firm decides on the planned amount of employment $N^{\mathrm{d}}_i(t)$ in each period according to its desired scale of activity ($Q^{\mathrm{s}}_i(t)$) and its average labor productivity ($\bar{\alpha}_i$):

$$N^{\mathrm{d}}_i(t) = \max\left(1, \mathrm{round}\left(\frac{Q^{\mathrm{s}}_i(t)}{\bar{\alpha}_i}\right)\right). \tag{20}$$

Rounding to the nearest integer translates as follows: if the additional labor demand of firm i is less than a half-time position, labor demand is left unchanged. If the additional production needs of firm i exceed a half-time occupation, a new employee is hired.

If the operating workforce at the beginning of period t ($N_i(t-1)$), i.e., the number of persons employed in $t-1$, is higher than the desired work force, the firm fires $N_i(t-1) - N^{\mathrm{d}}_i(t)$ randomly chosen employees (accounting for production constraints due possibly to a shortage of capital). If demand for labor to reach the desired scale of activity is greater than the operating workforce, the firm posts labor vacancies, $V_i(t) = \max\left(N^{\mathrm{d}}_i(t) - N_i(t-1), 0\right)$, which represent a demand for new labor. Whether vacancies are filled or not depends on the search-and-matching mechanism in the labor market (see Section 3.2.1), thus

$$N_i(t) \begin{cases} = N^{\mathrm{d}}_i(t) & \text{if the firm successfully fills all vacancies, and} \\ < N^{\mathrm{d}}_i(t) & \text{if there are unfilled vacancies.} \end{cases} \tag{21}$$

As employees are either employed full-time, part-time, or work overtime, the actual productivity of labor $\alpha_i(t)$ of firm i reflects overtime or part-time employment:

$$\alpha_i(t) = \bar{\alpha}_i \min\left(1.5, \frac{\min\left(Q^{\mathrm{s}}_i(t), \beta_i M_i(t-1), \kappa_i K_i(t-1)\right)}{N_i(t)\bar{\alpha}_i}\right), \tag{22}$$

where the maximum work effort is 150 percent of a full position. To remunerate increased or decreased work effort as compared to a full-time position, the average wage $\bar{w}_i$ of firm i is adapted accordingly:

$$w_i(t) = \bar{w}_i \min\left(1.5, \frac{\min\left(Q_i^{\mathrm{s}}(t), \beta_i M_i(t-1), \kappa_i K_i(t-1)\right)}{N_i(t)\bar{\alpha}_i}\right), \tag{23}$$

where $w_i(t)$ is the real wage paid by firm i. Nominal wage increases accounting for inflation are considered when money wages are paid out to households as part of their disposable income, see Section 3.2.4.

3.1.7. External Finance

Firms may need external financial resources to finance current or future expenditures. Thus, each firm i forms an expectation on its future cash flow $\Delta D_i^{\mathrm{e}}(t)$, that is, the expected change of deposits $D_i(t)$:

$$\Delta D_i^{\mathrm{e}}(t) = \underbrace{\Pi_i^{\mathrm{e}}(t)}_{\text{Exp. profit}} - \underbrace{\theta L_i(t-1)}_{\text{Debt installment}} - \underbrace{\tau^{\mathrm{FIRM}} \max(0, \Pi_i^{\mathrm{e}}(t))}_{\text{Corporate taxes}} - \underbrace{\theta^{\mathrm{DIV}}(1-\tau^{\mathrm{FIRM}}) \max(0, \Pi_i^{\mathrm{e}}(t))}_{\text{Dividend payout}}, \tag{24}$$

where

$$\Pi_i^{\mathrm{e}}(t) = \Pi_i(t-1)(1+\gamma^{\mathrm{e}}(t))(1+\pi^{\mathrm{e}}(t)), \tag{25}$$

is the profit expected by firm i based on the profit in the previous period; θ is the rate of debt installment on firm i's outstanding loans $L_i(t-1)$, τ^{FIRM} is the corporate tax rate, and θ^{DIV} is the dividend payout ratio.

If the internal financial resources of a firm are not adequate to finance its expenditures, the firm will ask for a bank loan, i.e., new credit $\Delta L_i^{\mathrm{d}}(t)$, to cover its financing gap

$$\Delta L_i^{\mathrm{d}}(t) = \max(0, \Delta D_i^{\mathrm{e}}(t) - D_i(t-1)). \tag{26}$$

The availability of credit depends on the capitalization of the banking sector and the arrival of firms to ask for a loan, see Section 3.4.1 for details. If the firm cannot obtain a loan on the credit market, it might become credit constrained, see equation (64). If the firm does not obtain the desired loan, it may become insolvent, see Section 3.1.9.

3.1.8. Accounting

Firm profits $\Pi_i(t)$ are an accounting measure that are defined as revenues from sales plus change in inventories minus expenditures on labor, material, depreciation, interest payments and taxes (all accounted for mark-to-market):

$$\begin{aligned}\Pi_i(t) = {} & \underbrace{P_i(t)Q_i(t)}_{\text{Sales}} + \underbrace{P_i(t)\Delta S_i(t)}_{\text{Inventory change}} - \underbrace{w_i(t)(1+\tau^{\mathrm{SIF}})N_i(t)\bar{P}^{\mathrm{HH}}(t)}_{\text{Labor costs}} - \underbrace{\sum_g a_{sg}\bar{P}_g(t)\frac{Y_i(t)}{\beta_i}}_{\text{Material costs}} - \underbrace{\delta_i \frac{Y_i(t)}{\kappa_i}\bar{P}^{\mathrm{CF}}(t)}_{\text{Depreciation}} \\ & - \underbrace{\tau_i^{\mathrm{Y}} P_i(t)Y_i(t) - \tau_i^{\mathrm{K}} P_i(t)Y_i(t)}_{\text{Net taxes/subsidies on products/production}} - \underbrace{r(t)(L_i(t-1) - \min(0, D_i(t-1)))}_{\text{Interest payments}} + \underbrace{\bar{r}(t)\max(0, D_i(t-1))}_{\text{Interest received}} \quad \forall i \in I_s\end{aligned} \tag{27}$$

where $r(t)$ is the interest rate paid on outstanding loans, see equation (66). $\bar{P}_g(t)$ is the price index for the principal good g:

$$\bar{P}_g(t) = \frac{\sum_{i \in I_{s=g}} P_i(t)(Y_i(t) + S_i(t)) + \sum_{m=g} P_m(t)Q_m(t)}{\sum_{i \in I_{s=g}} (Y_i(t) + S_i(t)) + \sum_{m=g} Q_m(t)}, \tag{28}$$

$\bar{P}^{\mathrm{CF}}(t)$ is the economy-wide capital formation price index defined as

$$\bar{P}^{\mathrm{CF}}(t) = \sum_g b_g^{\mathrm{CF}} \bar{P}_g(t), \tag{29}$$

where b_g^{CF} is the capital formation coefficient for product g, and $\bar{P}^{\mathrm{HH}}(t)$ is the consumer price index:

$$\bar{P}^{\mathrm{HH}}(t) = \sum_g b_g^{\mathrm{HH}} \bar{P}_g(t), \tag{30}$$

where b_g^{HH} is the household consumption coefficient for product g.

Firm net cash flow reflects the amount of liquidity moving in or out of its deposit account:

$$\begin{aligned}\Delta D_i(t) = &\underbrace{P_i(t)Q_i(t)}_{\text{Sales}} - \underbrace{w_i(t)(1+\tau^{\mathrm{SIF}})N_i(t)\bar{P}^{\mathrm{HH}}(t)}_{\text{Labor costs}} - \underbrace{\sum_g a_{sg}P_{ig}(t)\Delta M_i(t)}_{\text{Material costs}} - \underbrace{\tau_i^{\mathrm{Y}}P_i(t)Y_i(t) - \tau_i^{\mathrm{K}}P_i(t)Y_i(t)}_{\text{Net taxes/subsidies on products and production}} \\ &- \underbrace{\tau^{\mathrm{FIRM}}\max(0,\Pi_i(t))}_{\text{Corporate tax payments}} - \underbrace{\theta^{\mathrm{DIV}}(1-\tau^{\mathrm{FIRM}})\max(0,\Pi_i(t))}_{\text{Dividend payments}} - \underbrace{r(t)(L_i(t-1)-\min(0,D_i(t-1)))}_{\text{Interest payments}} \\ &+ \underbrace{\bar{r}(t)\max(0,D_i(t-1))}_{\text{Interest received}} - \underbrace{P_i^{\mathrm{CF}}(t)I_i(t)}_{\text{Investment costs}} + \underbrace{\Delta L_i(t)}_{\text{New credit}} - \underbrace{\theta L_i(t-1)}_{\text{Debt installment}} \quad \forall i \in I_s\,,\end{aligned} \tag{31}$$

where $P_{ig}(t)$ and $P_i^{\mathrm{CF}}(t)$ are the actual prices paid by firm i for intermediate goods of type g and investment in capital goods, respectively, which both are an outcome of the search an matching process. Furthermore, firm i pays interest on outstanding loans and overdrafts on firm i's deposit account (in case $D_i(t) < 0$) at the same rate r, which includes the bank's markup rate. In the opposite case when the firm holds (positive) deposits with the bank, i.e., $D_i(t) > 0$, the interest rate received is lower and corresponds to the policy rate set by the central bank, see Section 3.4.

Firm deposits are then previous deposits plus net cash flow:

$$D_i(t) = D_i(t-1) + \Delta D_i(t)\,. \tag{32}$$

Similarly, overall debt is updated as follows:

$$L_i(t) = (1-\theta)L_i(t-1) + \Delta L_i(t)\,. \tag{33}$$

Finally, firm equity $E_i(t)$ evolves as the balancing item on the firm's balance sheet, where all stocks are again accounted for mark-to-market:

$$E_i(t) = D_i(t) + \sum_g a_{sg}\bar{P}_g(t)M_i(t) + P_i(t)S_i(t) + \bar{P}^{\mathrm{CF}}(t)K_i(t) - L_i(t) \quad \forall i \in I_s\,. \tag{34}$$

3.1.9. Insolvency

If a firm is cash-flow insolvent, i.e., $D_i(t) < 0$, and balance-sheet insolvent, i.e., $E_i(t) < 0$, at the same time, it goes bankrupt and is replaced by a firm that newly enters the market. We assume that the real capital stock of the bankrupt firm is left to the entrant firm at zero costs, but that the new firm has to take over a part of the bankrupt firm's liabilities. Therefore, a part of loans taken out by the bankrupt firm is written off so that the remaining liabilities of firm i amount to a fraction ζ^{b} of its real capital stock. After this partial debt cancellation, the remaining liabilities of the bankrupt firm are transferred to the balance sheet of the entrant firm. In the next period $(t+1)$ liabilities of firm i are initialized with

$$L_i(t+1) = \zeta^{\mathrm{b}}\bar{P}_i^{\mathrm{CF}}(t)K_i(t) \tag{35}$$

and firm deposits with

$$D_i(t+1) = 0\,. \tag{36}$$

Correspondingly, in the next period $(t+1)$ equity of the new firm i is initialized according to equation (34).

3.2. Households

The household sector consists of a total number of H ($h = 1, 2, \ldots, H$) persons. Every person in the household sector has an *activity status*, that is, a type of economic activity from which she receives an income. Each person also participates in the consumption market as a consumer with a certain consumption budget. The activity status is categorized into H^{act} economically active and H^{inact} economically inactive persons. Economically active persons are H^W workers, and I investors (the number of investors equals the number of firms and is constant, see below). The set of workers consists of $H^{\mathrm{E}}(t)$ employed persons and $H^{\mathrm{U}}(t)$ unemployed persons that are actively looking for a job. $H^{\mathrm{E}}(t)$ and $H^{\mathrm{U}}(t)$ are endogenous since we assume that agents may switch between these two sets by being dismissed from their current job or by being hired for a new position. Economically inactive persons include, among others, persons below the age of 15, students, and retirees.

3.2.1. Activity Status

The h-th worker ($h = 1, 2, \ldots, H^{\mathrm{W}}$) supplies labor to the extent of employment (part-time, full, or including overtime). If worker h works for firm i in period t, she receives wage $w_h(t) = w_i(t)$.

If unemployed, the person looks for a job on the labor market by visiting firms with open vacancies in random order and applies for a job (the *search-and-matching* process on the labor market). The unemployed person will accept a job from the first firm with open vacancies that she has the chance to visit. If she does not find a vacancy to fill, that is, when there are no open vacancies left in the economy, she remains unemployed. For simplicity's sake, we do not consider hiring or firing costs for firms, and fired employees become unemployed and start searching for a job in the same period. All unemployed persons receive unemployment benefits, which are a fraction of the labor income that was last received in the period when unemployment starts. In the event that an unemployed person finds a new job, she is remunerated with the wage of firm i that provides the new employment:

$$w_h(t) = \begin{cases} \theta^{\mathrm{UB}} w_h(t-1) & \text{if newly unemployed} \\ w_i(t) & \text{if newly employed by firm } i \\ w_h(t-1) & \text{otherwise, i.e., unemployment continues.} \end{cases} \tag{37}$$

For simplicity's sake, we assume that each firm is owned by one investor, i.e., the number of investors matches that the number of firms overall. Each investor receives income in the form of dividends in the event that the firm she owns makes profits after interest and tax payments. We assume limited liability, i.e., in the case of bankruptcy, the associated losses are borne by the creditor and not the investor household, see Section 3.1.9.

An economically inactive person h receives social benefits $sb^{\mathrm{inact}}(t)$ and does not look for a job:

$$sb^{\mathrm{inact}}(t) = sb^{\mathrm{inact}}(t-1)(1 + \gamma^{\mathrm{e}}(t)) \,. \tag{38}$$

Additionally, each household receives additional social transfers $sb^{\mathrm{other}}(t)$ (related to family and children, sickness, etc.) from the government, which we assume to be constant and the same size for all households:

$$sb^{\mathrm{other}}(t) = sb^{\mathrm{other}}(t-1)(1 + \gamma^{\mathrm{e}}(t)) \,. \tag{39}$$

3.2.2. Consumption

In a bounded rationality setting, consumers' behavior follows a rule of thumb (heuristic) where they plan to consume a fraction of their expected disposable net income including social benefits ($Y^{\mathrm{e}}_h(t)$). The consumption budget (net of VAT) of household h ($C^{\mathrm{d}}_h(t)$) is thus given by:

$$C^{\mathrm{d}}_h(t) = \frac{\psi Y^{\mathrm{e}}_h(t)}{1 + \tau^{\mathrm{VAT}}} \,, \tag{40}$$

where $\psi \in (0, 1)$ is the propensity to consume out of expected income and τ^{VAT} is a value added tax rate on consumption.

Expected disposable net income inclusive of social transfers is determined according to the household's activity status and the associated income from labor, expected profits or social benefits, as well as tax payments, the consumer index price index of the last period, and expectations of the rate of inflation $\pi^{\mathrm{e}}(t)$ formed using an AR(1) model (see equation (9)):

$$Y^{\mathrm{e}}_h(t) = \begin{cases} \left(w_h(t)\left(1 - \tau^{\mathrm{SIW}} - \tau^{\mathrm{INC}}(1 - \tau^{\mathrm{SIW}})\right) + sb^{\mathrm{other}}(t)\right)\bar{P}^{\mathrm{HH}}(t-1)(1 + \pi^{\mathrm{e}}(t)) & \text{if employed} \\ \left(w_h(t) + sb^{\mathrm{other}}(t)\right)\bar{P}^{\mathrm{HH}}(t-1)(1 + \pi^{\mathrm{e}}(t)) & \text{if unemployed} \\ \left(sb^{\mathrm{inact}}(t) + sb^{\mathrm{other}}(t)\right)\bar{P}^{\mathrm{HH}}(t-1)(1 + \pi^{\mathrm{e}}(t)) & \text{if not economically active ,} \\ \theta^{\mathrm{DIV}}(1 - \tau^{\mathrm{INC}})(1 - \tau^{\mathrm{FIRM}})\max(0, \Pi^{\mathrm{e}}_i(t)) + sb^{\mathrm{other}}(t)\bar{P}^{\mathrm{HH}}(t-1)(1 + \pi^{\mathrm{e}}(t)) & \text{if an investor} \\ \theta^{\mathrm{DIV}}(1 - \tau^{\mathrm{INC}})(1 - \tau^{\mathrm{FIRM}})\max(0, \Pi^{\mathrm{e}}_k(t)) + sb^{\mathrm{other}}(t)\bar{P}^{\mathrm{HH}}(t-1)(1 + \pi^{\mathrm{e}}(t)) & \text{if a bank investor} \end{cases} \tag{41}$$

where $\Pi^{\mathrm{e}}_i(t)$ (see equation (25)) and

$$\Pi^{\mathrm{e}}_k(t) = \Pi_k(t-1)(1 + \gamma^{\mathrm{e}}(t))(1 + \pi^{\mathrm{e}}(t)) \tag{42}$$

is the expected profit based on the profit of the previous period of firm i and of the banking sector, respectively; τ^{INC} is the income tax rate, τ^{SIW} is the rate of social insurance contributions to be paid by the employee, θ^{DIV} is the dividend payout ratio, and τ^{FIRM} the corporate tax rate.

Consumers then allocate their consumption budget to purchase different goods from firms. The consumption budget of the h-th household to purchase the g-th good is

$$C^{\mathrm{d}}_{hg}(t) = b^{\mathrm{HH}}_g C^{\mathrm{d}}_h(t)\,, \tag{43}$$

where b^{HH}_g is the consumption coefficient for the g^{th} product of households.[17]

Once they have determined their consumption budget, consumers visit firms in order to purchase goods according to the search-and-matching mechanism, see Section 3.1.1 above. Whether the individual firm can accommodate demand depends (apart from aggregate economic conditions) on its production and inventory stock. Thus realized consumption of household h is another outcome of the search-and-matching process:

$$C_h(t) \begin{cases} = \sum_g C^{\mathrm{d}}_{hg}(t) & \text{if the consumer successfully realized the consumption plan, and} \\ < \sum_g C^{\mathrm{d}}_{hg}(t) & \text{if all firms visited could not satisfy the consumer's demand.} \end{cases} \tag{44}$$

3.2.3. Household Investment

To depict a simple housing market, households use part of their income to invest in dwellings and other durable investment goods. Similar to equation (40) above, we assume household investment occurs according to a fixed rate ψ^{H} on expected disposable net income:

$$I^{\mathrm{d}}_h(t) = \frac{\psi^{\mathrm{H}} Y^{\mathrm{e}}_h(t)}{1+\tau^{\mathrm{CF}}}\,, \tag{45}$$

where τ^{CF} is the tax rate on investment goods.

Investment demand by household h for product g net of taxes ($I^{\mathrm{d}}_{hg}(t)$) is then determined by fixed weights b^{CFH}_g:

$$I^{\mathrm{d}}_{hg}(t) = b^{\mathrm{CFH}}_g I^{\mathrm{d}}_h(t)\,. \tag{46}$$

Again, realized sales of investment goods purchased by households are an outcome of the search-and-matching process on the capital goods market:

$$I_h(t) \begin{cases} = \sum_g I^{\mathrm{d}}_{hg}(t) & \text{if the household successfully realized the investment plan, and} \\ < \sum_g I^{\mathrm{d}}_{hg}(t) & \text{if all firms visited could not satisfy its demand.} \end{cases} \tag{47}$$

The capital stock of household h then follows:

$$K_h(t) = K_h(t-1) + I_h(t)\,. \tag{48}$$

3.2.4. Income

In each period t, all households receive income according to their activity status. Nominal disposable net income $Y_h(t)$ (i.e., realized income after taxes but including unemployment benefits and other social transfers) of the h-th household is different from expected income by the realized inflation in period t, which is represented by the current consumer price index, as well as the realized profits by firms and the bank:

$$Y_h(t) = \begin{cases} \left(w_h(t)\left(1-\tau^{\mathrm{SIW}}-\tau^{\mathrm{INC}}(1-\tau^{\mathrm{SIW}})\right) + sb^{\mathrm{other}}(t)\right)\bar{P}^{\mathrm{HH}}(t) & \text{if employed} \\ \left(w_h(t) + sb^{\mathrm{other}}(t)\right)\bar{P}^{\mathrm{HH}}(t) & \text{if unemployed} \\ \left(sb^{\mathrm{inact}}(t) + sb^{\mathrm{other}}(t)\right)\bar{P}^{\mathrm{HH}}(t) & \text{if not economically active}\,. \\ \theta^{\mathrm{DIV}}(1-\tau^{\mathrm{INC}})(1-\tau^{\mathrm{FIRM}})\max(0,\Pi_i(t)) + sb^{\mathrm{other}}(t)\bar{P}^{\mathrm{HH}}(t) & \text{if an investor} \\ \theta^{\mathrm{DIV}}(1-\tau^{\mathrm{INC}})(1-\tau^{\mathrm{FIRM}})\max(0,\Pi_k(t)) + sb^{\mathrm{other}}(t)\bar{P}^{\mathrm{HH}}(t) & \text{if a bank investor} \end{cases} \tag{49}$$

[17] At this stage we assume all households to buy the same set of goods, independent of the amount they spend on consumption. We also assume that this set of goods is invariant to price changes.

3.2.5. Savings

Savings is the difference between current disposable income $Y_h(t)$ and realized consumption expenditure $C_h(t)$ plus realized investment in housing $I_h(t)$, and is used to accumulate financial wealth:[18]

$$D_h(t) = D_h(t-1) + \underbrace{Y_h(t) - ((1+\tau^{\mathrm{VAT}})C_h(t) + (1+\tau^{\mathrm{CF}})I_h(t))}_{\text{Savings}} + \underbrace{r(t)\min(0, D_h(t-1))}_{\text{Interest payments}} + \underbrace{\bar{r}(t)\max(0, D_h(t-1))}_{\text{Interest received}} . \quad (50)$$

Additionally, the stock of deposits is corrected for interest payments on overdrafts of the household's deposit account ($D_h(t-1) < 0$), and interest received on deposits held with the bank ($D_h(t-1) > 0$).[19]

3.3. The general government

In our model, the government takes two functions: as a consumer on the retail market (government consumption), and as a redistributive entity that levies taxes and social contributions to provide social services and benefits to its citizens. We assume that government consumption is exogenous and attributed to individual government entities. Government expenditures, revenues, deficit and public debt, however, are accounted for at the aggregate level (i.e., for the general government).

3.3.1. Government Consumption

Individual government entities j ($j = 1, 2, \ldots, J$) participate in the goods market as consumers. These entities represent the central government, state government, local governments and social security funds. Analogous to imports and exports, the real final consumption expenditure of the general government ($C^{\mathrm{G}}(t)$) is assumed to follow an autoregressive process of lag order one (AR(1)):

$$\log(C^{\mathrm{G}}(t)) = \alpha^{\mathrm{G}} \log(C^{\mathrm{G}}(t-1)) + \beta^{\mathrm{G}} . \quad (51)$$

Total nominal government consumption demand is attributed to goods g and is uniformly distributed to the J government entities; the consumption budget of the j-th government entity to purchase the g-th good is thus given as

$$C^{\mathrm{d}}_{jg}(t) = \frac{C^{\mathrm{G}}(t)\bar{P}_g(t-1)(1+\pi^{\mathrm{e}}(t))c^{\mathrm{G}}_g}{J} , \quad (52)$$

where c^{G}_g is the fraction of goods of type g demanded by the government.

Realized government consumption is then another outcome of the search-and-matching process on the consumption goods market:

$$C_j(t) \begin{cases} = \sum_g C^{\mathrm{d}}_{jg}(t) & \text{if the government successfully realized the consumption plan, and} \\ < \sum_g C^{\mathrm{d}}_{jg}(t) & \text{if all firms visited could not satisfy its demand.} \end{cases} \quad (53)$$

Other expenditures of the general government include interest payments, social benefits other than social transfers in kind, and subsidies. Interest payments by the general government are made with a fixed average interest rate r^{G} on loans taken out by the government $L^{\mathrm{G}}(t-1)$. Social transfers by the government consist of social benefits for inactive households ($\sum_{h \in H^{\mathrm{inact}}} sb^{\mathrm{inact}}(t)$) such as pension payments or social exclusion benefits, social benefits for any household h ($\sum_h sb^{\mathrm{other}}(t)$) such as relating to family, sickness or housing, and unemployment benefits for unemployed households ($\sum_{h \in H^{\mathrm{U}}(t)} w_h(t)$). Subsidies are paid to firms with subsidy rates (uniform for each industry, but different across industries) on products and production, and are in incorporated in the net tax rates on products (τ^{Y}_i) and production (τ^{K}_i), respectively.[20]

[18]Savings can also be negative in our model, in which case the respective person h would decumulate her financial wealth to finance her consumption needs.

[19]Here, we assume that these interest payments or receipts do not enter the household's consumption decision, and thus we abstract from wealth effects on consumption.

[20]The latter can therefore also have negative values if a sector receives more subsidies on products or production than it has to pay in taxes.

3.3.2. Government Revenues

Revenues of the general government are generated through taxes, social contributions and other transfers from all sectors.

$$
\begin{aligned}
Y^{\mathrm{G}}(t) = & \underbrace{(\tau^{\mathrm{SIF}} + \tau^{\mathrm{SIW}})\bar{P}^{\mathrm{HH}}(t) \sum_{h \in H^{\mathrm{E}}(t)} w_h(t)}_{\text{Social security contributions}} + \underbrace{\tau^{\mathrm{INC}}(1-\tau^{\mathrm{SIW}})\bar{P}^{\mathrm{HH}}(t) \sum_{h \in H^{\mathrm{E}}(t)} w_h(t)}_{\text{Labour income taxes}} + \underbrace{\tau^{\mathrm{VAT}} \sum_h C_h(t)}_{\text{Value added taxes}} \\
& + \underbrace{\tau^{\mathrm{INC}}(1-\tau^{\mathrm{FIRM}})\theta^{\mathrm{DIV}} \left(\sum_i \max(0, \Pi_i(t)) + \max(0, \Pi_k(t)) \right)}_{\text{Capital income taxes}} + \underbrace{\tau^{\mathrm{FIRM}} \left(\sum_i \max(0, \Pi_i(t)) + \max(0, \Pi_k(t)) \right)}_{\text{Corporate income taxes}} \\
& + \underbrace{\tau^{\mathrm{CF}} \sum_h I_h(t)}_{\text{Taxes on capital formation}} + \underbrace{\sum_i \tau_i^{\mathrm{Y}} P_i(t) Y_i(t)}_{\text{Net taxes/subsidies on products}} + \underbrace{\sum_i \tau_i^{\mathrm{K}} P_i(t) Y_i(t)}_{\text{Net taxes/subsidies on production}} + \underbrace{\tau^{\mathrm{EXPORT}} \sum_l C_l(t)}_{\text{Export taxes}} .
\end{aligned}
\tag{54}
$$

3.3.3. Government Deficit

The government deficit (or surplus) resulting from its redistributive activities is

$$
\begin{aligned}
\Pi^{\mathrm{G}}(t) = & \underbrace{\sum_{h \in H^{\mathrm{inact}}} \bar{P}^{\mathrm{HH}}(t) sb^{\mathrm{inact}}(t) + \sum_{h \in H^{\mathrm{U}}(t)} \bar{P}^{\mathrm{HH}}(t) w_h(t) + \sum_h \bar{P}^{\mathrm{HH}}(t) sb^{\mathrm{other}}(t)}_{\text{Social benefits and transfers}} \\
& + \underbrace{\sum_j C_j(t)}_{\text{Government consumption}} + \underbrace{r^{\mathrm{G}} L^{\mathrm{G}}(t-1)}_{\text{Interest payments}} - \underbrace{Y^{\mathrm{G}}(t)}_{\text{Government revenues}} .
\end{aligned}
\tag{55}
$$

3.3.4. Government Debt

The government debt as a stock variable is determined by the year-to-year deficits/surpluses of the government sector:

$$
L^{\mathrm{G}}(t) = L^{\mathrm{G}}(t-1) + \Pi^{\mathrm{G}}(t) . \tag{56}
$$

For reasons of model parsimony, we assume that the government sells its debt contracts to the central bank, which we model as a "clearing house" for capital flows between the national economy and the Rest of the World. Thus, we implicitly assume that the purchase of government bonds is financed by inflows of foreign capital recorded on the liability side of the central bank's balance sheet.

3.4. The bank

For the sake of simplicity we assume that there is one representative bank.[21] The bank takes deposits from firms and households, extends loans to firms, and receives advances from (or deposits reserves at) the central bank.

[21] This assumption of one representative bank is above all due to national accounting conventions. From national annual sector accounts, which determine the logic of financial flows between the aggregate sectors for our model (households, non-financial corporations, financial corporations, government and rest of the world), we obtain balance sheet positions (credit and debts), as well as interest payment flows between firms and the financial sector (banks) on an aggregate level. Since we do not have information on financial relations between individual firms (or industry sectors) and banks for this model, we have no empirically based method to determine credit and debt relations, acquisition and provision of credit, as well as interest payments, between individual firms (or industry sectors) and individual banks. Therefore, we account for credit relations and financial flows between individual firms and banks on an aggregate level for the banking sector, i.e., we assume a representative bank extending credit to individual firms according to the amount of firms' real capital stock, see Section 5 for details, while we account for the value added generated by financial corporations in the real economy according to the logic of IOTs as separate industries within the firm sector.

3.4.1. Provision of Loans

We assume that government regulation imposes a minimum capital requirement on the bank. Thus, the bank can extend loans up to a multiple of its equity base or net worth:

$$\frac{E_k(t)}{\sum_{i=1}^{I} L_i(t)} \geq \zeta\,, \tag{57}$$

where $E_k(t)$ is the equity capital (common equity) of the bank, and $0 < \zeta < 1$ can be interpreted as a minimum capital requirement coefficient. Hence, $1/\zeta$ is the maximum allowable leverage for the bank. However, the bank—like any other agent—has no knowledge of the realized value of either its equity capital or loans extended to the individual firm i, due to fundamental uncertainty prevailing in the model economy. Therefore, the bank has to form expectations both for its equity capital ($E_k^{\mathrm{e}}(t)$) and for the sum of all loans extended to firms in the economy ($\sum_{i=1}^{I} L_i^{\mathrm{e}}(t)$):

$$\frac{E_k^{\mathrm{e}}(t)}{\sum_{i=1}^{I} L_i^{\mathrm{e}}(t)} = \frac{E_k(t-1)}{\sum_{i=1}^{I}(L_i(t-1)+\Delta L_i(t))} \geq \zeta \quad . \tag{58}$$

Here, $\Delta L_i(t)$ is the realized amount of new loans to firm i in period t as given in equation (64), which is either the full amount of new credit demanded by firms ($\Delta L_i^{\mathrm{d}}(t)$, see equation (26)) if the capital requirements for the banks have not been surpassed. However, it is equal to zero if the bank does not have enough equity capital to provide the loan asked for by firm i:

$$\Delta L_i(t) \leq \max\left(0, \frac{E_k(t-1)}{\zeta} - \sum_{i'=1}^{I}(L_{i'}(t-1)+\Delta L_{i'}(t))\right). \tag{59}$$

Furthermore, the bank forms a risk assessment of a potential default on the part of firm i before extending a loan to it. This risk assessment is based on the borrower's leverage as measured by its loan-to-value ratio, i.e., the amount of loans over the market value of its capital stock. Thus, the bank will grant a loan to firm i only up to the point where the borrower's leverage (or loan-to-value) ratio after the loan (including overdrafts on deposit accounts),

$$\frac{L_i(t)}{\bar{P}^{\mathrm{CF}}(t)K_i(t)} \leq \zeta^{\mathrm{LTV}} \tag{60}$$

is below ζ^{LTV}, which is a constant. However, due to fundamental uncertainty, also in this case the bank has to form expectations on both the loans to be provided to firm i ($L_i^{\mathrm{e}}(t)$), as well as on the value of firm i's capital stock ($K_i^{\mathrm{e}}(t)$):

$$\frac{L_i^{\mathrm{e}}(t)}{\bar{P}^{\mathrm{CF}}(t-1)(1+\pi^{\mathrm{e}}(t))K_i^{\mathrm{e}}(t)} \leq \zeta^{\mathrm{LTV}}\,, \tag{61}$$

where

$$L_i^{\mathrm{e}}(t) = (1-\theta)L_i(t-1) + \Delta L_i(t)\,, \tag{62}$$

and

$$K_i^{\mathrm{e}}(t) = K_i(t-1)\,. \tag{63}$$

Altogether, therefore, the amount of new credit extended to firm i by the bank ($\Delta L_i(t)$) is limited by the credit demanded by the firm, the bank's risk assessment regarding the default of its potential borrower, and the minimum capital requirements imposed by the regulator:

$$\begin{aligned}\Delta L_i(t) = \max\Bigg(0, \min\Bigg(&\Delta L_i^{\mathrm{d}}(t), \zeta^{\mathrm{LTV}}\bar{P}^{\mathrm{CF}}(t-1)(1+\pi^{\mathrm{e}}(t))K_i^{\mathrm{e}}(t) - (1-\theta)L_i(t-1),\\ &\frac{E_k(t-1)}{\zeta} - \sum_{i=1}^{I}(L_i(t-1)+\Delta L_i(t))\Bigg)\Bigg).\end{aligned} \tag{64}$$

The order of arrival of firms at the bank is assumed to be random. A financially robust (low leverage) firm, which in principle deserves a large chunk of bank loans, may be denied credit if it arrives "too late" (i.e., after other less robust firms).

3.4.2. Accounting for Profits and Losses

The bank's profits are computed as the difference between revenues from interest payments payable on outstanding loans to firms, including overdrafts on deposit accounts incurred by firms and households ($D_{i,h}(t-1) < 0$), and costs due to interest payments on deposits held with the bank by firms and households ($D_{i,h}(t-1) > 0$):

$$\begin{aligned}\Pi_k(t) = & \underbrace{\bar{r}(t)\max(0, D_k(t-1)) + r(t)\left(\sum_{i=1}^{I} L_i(t-1) - \sum_{i=1}^{I}\min(0, D_i(t-1)) - \sum_{h=1}^{H}\min(0, D_h(t-1))\right)}_{\text{Interest received}} \\ & \underbrace{+ \bar{r}(t)\min(0, D_k(t-1)) - \bar{r}(t)\left(\sum_{i=1}^{I}\max(0, D_i(t-1)) + \sum_{h=1}^{H}\max(0, D_h(t-1))\right)}_{\text{Interest payments}}.\end{aligned} \tag{65}$$

Deposits are remunerated at the policy rate $\bar{r}(t)$, which we assume to be set exogenously by the central bank. The interest rate r for bank credit to firms is then determined by a fixed markup μ over the policy rate $\bar{r}(t)$:

$$r(t) = \bar{r}(t) + \mu\,. \tag{66}$$

Bank equity grows or shrinks according to bank profits or losses, and is given by

$$E_k(t) = E_k(t-1) + \Pi_k(t) - \underbrace{\theta^{\text{DIV}}(1-\tau^{\text{FIRM}})\max(0, \Pi_k(t))}_{\text{Dividend payments}} - \underbrace{\tau^{\text{FIRM}}\max(0, \Pi_k(t))}_{\text{Corporate taxes}} - \underbrace{\sum_{i\in I'}(L_i(t) - D_i(t) - \zeta^{\text{b}}\bar{P}_i^{\text{CF}}(t)K_i(t))}_{\text{Write-off of bad debt}}, \tag{67}$$

where I' is the set of insolvent borrowers, and we assume that outstanding overdraft of firm i's deposit account as well as a fraction $(1-\zeta^{\text{b}})\bar{P}_i^{\text{CF}}(t)K_i(t)$ of loans extended to firm i have to be written off from the bank's balance sheet. The residual and balancing item on the bank's balance sheet ($D_k(t)$),[22] after accounting for loans extended, deposits taken in and its equity capital, are (net) central bank reserves held ($D_k(t) > 0$) or advances obtained by the bank from the central bank ($D_k(t) < 0$).[23]

$$D_k(t) = \sum_{i=1}^{I} D_i(t) + \sum_{h=1}^{H} D_h(t) + E_k(t) - \sum_{i=1}^{I} L_i(t)\,. \tag{68}$$

3.5. The Central Bank

The central bank (CB) sets the policy rate $\bar{r}(t)$ based on implicit inflation and growth targets, provides liquidity to the banking system (advances to the bank), and takes deposits from the bank in the form of reserves deposited at the central bank. Furthermore, the central bank purchases external assets (government bonds) and thus acts as a creditor to the government.

3.5.1. Determination of Interest Rates

The policy rate is determined by a generalized Taylor rule (Taylor, 1993). Following Blattner and Margaritov (2010), we use a "growth" rule specification where the output gap does not enter the equation:[24]

$$\bar{r}(t) = \max\left(0, \rho\bar{r}(t-1) + (1-\rho)\left(r^* + \pi^* + \xi^{\pi}\left(\pi^{\text{EA}}(t) - \pi^*\right) + \xi^{\gamma}\gamma^{\text{EA}}(t)\right)\right), \tag{69}$$

[22] Which also includes currency held by the bank.

[23] Note that this variable, if it takes a positive value ($D_k(t) > 0$), signifies that the bank holds positive net reserves, i.e., it holds more reserves than advances and is thus a net creditor to the central bank. On the other hand, in the opposite case of $D_k(t) < 0$, this means that the bank has taken out more central bank advances than it holds central bank reserves, i.e., it is a net debtor to the central bank. The possibility of an inequality of advances and reserves, or, for that matter, an inequality of loans and deposits, is due to the fact that we do not explicitly distinguish between deposits and reserves for reasons of model parsimony. Rather, we use the central bank as a "clearing house" for flows of reserves and deposits between the national economic and the RoW, see equation (76).

[24] Here, we rely on empirical evidence and statements by leading central bankers reported in Blattner and Margaritov (2010) implying that the concept of an output gap does not seem to influence the behavior of the European Central Bank (ECB) to a large extent.

where ρ is a measure for gradual adjustment of the policy rate, r^* is the real equilibrium interest rate, π^* is the inflation target by CB, ξ^π is the weight the CB puts on inflation targeting, and ξ^γ the weight placed on economic growth, respectively. Inflation ($\pi^{\mathrm{EA}}(t)$) and economic growth ($\gamma^{\mathrm{EA}}(t)$) of the monetary union are assumed to follow an autoregressive process of lag order one (AR(1)):

$$\log(1 + \pi^{\mathrm{EA}}(t)) = \alpha^{\pi^{\mathrm{EA}}}(t)\pi^{\mathrm{EA}}(t-1) + \beta^{\pi^{\mathrm{EA}}}(t) \tag{70}$$

and

$$\gamma^{\mathrm{EA}}(t) = \frac{Y^{\mathrm{EA}}(t)}{Y^{\mathrm{EA}}(t-1)} - 1\,, \tag{71}$$

where

$$\log(Y^{\mathrm{EA}}(t)) = \alpha^{Y^{\mathrm{EA}}}(t)\log\left(\sum_i Y^{\mathrm{EA}}(t-1)\right) + \beta^{Y^{\mathrm{EA}}}(t)\,. \tag{72}$$

Note that we assuming here a SoE as part of a monetary union with no influence on interest rates.[25]

3.5.2. Accounting for Profits and Losses

The central bank's profits $\Pi^{\mathrm{CB}}(t)$ are computed as the difference between revenues from interest payments on government debt, as well as revenues ($D_k(t) < 0$) or costs ($D_k(t) > 0$) due to the net position in advances/reserves vis-à-vis the banking system:

$$\Pi^{\mathrm{CB}}(t) = r^{\mathrm{G}}L^{\mathrm{G}}(t-1) - \bar{r}(t)D_k(t-1)\,. \tag{73}$$

The central bank's equity $E^{\mathrm{CB}}(t)$ evolves according to its profits or losses and its past equity, and is given by

$$E^{\mathrm{CB}}(t) = E^{\mathrm{CB}}(t-1) + \Pi^{\mathrm{CB}}(t)\,. \tag{74}$$

The net creditor/debtor position of the national economy to the rest of the world ($D^{\mathrm{RoW}}(t)$)[26] evolves according to the following law of motion

$$D^{\mathrm{RoW}}(t) = D^{\mathrm{RoW}}(t-1) - \underbrace{(1 + \tau^{\mathrm{EXPORT}})\sum_l C_l(t)}_{\text{Exports}} + \underbrace{\sum_m P_m(t)Q_m(t)}_{\text{Imports}}\,. \tag{75}$$

Here, for example, a balance of trade surplus (deficit) enters with a negative (positive) sign, since $D^{\mathrm{RoW}}(t)$ is on the liability side of the CB's balance sheet. Thus a trade surplus (deficit), i.e., an inflow (outflow) money into (out of) the national economy, would reduce (increase) national liabilities versus the RoW.

Inherent stock-flow consistency relating to the accounting principles incorporated in our model implies that our financial system is closed via the accounting identity that connects the change in the amount of deposits in the banking system[27] to the government deficit (surplus)[28] and to the balance of trade:[29]

$$\begin{aligned} E^{\mathrm{CB}}(t) + D^{\mathrm{RoW}}(t) &= L^{\mathrm{G}}(t) - D_k(t) \\ &= L^{\mathrm{G}}(t) - \sum_{i=1}^{I} D_i(t) - \sum_{h=1}^{H} D_h(t) - E_k(t) + \sum_{i=1}^{I} L_i(t)\,. \end{aligned} \tag{76}$$

[25] For example, Austria as part of the EA contributes only about 3 percent of total GDP of the monetary union.

[26] If $D^{\mathrm{RoW}}(t) < 0$, the national economy is a net creditor of the RoW, if $D^{\mathrm{RoW}}(t) > 0$, the national economy is a net debtor to the RoW.

[27] These changes in the amount of deposits in the banking system directly correspond to changes in net central bank reserves $D_k(t)$, which in turn depend the private sector's surplus or deficit in relation to both the government and the RoW.

[28] Financial flows relating to a deficit (surplus) on the part of the government sector either accrue to (are paid by) the private sector (households and firms), or have to flow to (in from) the RoW, in the first case increasing (decreasing) deposits, in the second case increasing (decreasing) D^{ROW}.

[29] A positive (negative) balance of trade will either increase (decrease) deposits held by the private sector, or reduce (increase) the amount of government debt by e.g. reducing (increasing) the amount of government deficit.

3.6. Imports and Exports

To depict trade with the RoW, we include a set of agents that are based abroad and trade with the domestic economy. For simplicity's sake, a representative foreign firm for each sector supplies goods on domestic markets for intermediate, capital and consumption goods (imports), while foreign consumers demand products on these domestic markets (exports). As we assume a small open economy (SoE) setting, we suppose exports and imports to be exogenously given.

3.6.1. Imports

Following this approach, the total amount of imports $Y^{\mathrm{I}}(t)$ (in real terms) is assumed to follow an autoregressive process of lag order one (AR(1)):[30]

$$\log(Y^{\mathrm{I}}(t)) = \alpha^{\mathrm{I}} \log(Y^{\mathrm{I}}(t-1)) + \beta^{\mathrm{I}} \tag{77}$$

and a representative foreign firm for each sector imports goods from the RoW and supplies them to domestic markets. Thus the m-th, $(m = 1, 2, \ldots, S)$, foreign firm representing an industry s imports the principal product g:[31]

$$Y_m(t) = c^{\mathrm{I}}_{g=s} Y^{\mathrm{I}}(t)\,, \tag{78}$$

where c^{I}_g is the fraction of imported goods of type g as part of total imports.

The prices for these import goods are assumed to develop in line with the average sectoral domestic price level. The foreign firm thus sells its products at the inflation-adjusted average sectoral domestic price level. Consequently,

$$P_m(t) = \bar{P}_g(t-1)(1 + \pi^{\mathrm{e}}(t))\,, \tag{79}$$

where m produces the principal product g. This corresponds to the assumption of a fixed relation between the domestic and international price level, i.e., the same inflation rate at home and abroad.

Sales of imports are then the realized demand as an outcome of the search-and-matching process on the goods markets (see Section 3.1.1):

$$Q_m(t) = \min(Y_m(t), Q^{\mathrm{d}}_m(t))\,, \tag{80}$$

where $Q^{\mathrm{d}}_m(t)$ is the demand by consumers from foreign firm m.

3.6.2. Exports

The l-th $(l = 1, 2, \ldots, L)$ foreign consumer, be it a foreign firm, household, or government entity, participates in the domestic goods market as a consumer. Total sales to these foreign consumers on domestic markets represent exports to the rest of the world. Analogous to imports, real exports $(C^{\mathrm{E}}(t))$ are assumed to follow an autoregressive process of lag order one (AR(1)):

$$\log(C^{\mathrm{E}}(t)) = \alpha^{\mathrm{E}} \log(C^{\mathrm{E}}(t-1)) + \beta^{\mathrm{E}}\,. \tag{81}$$

Total exports are then attributed to goods g and are uniformly distributed to the L foreign consumers; the demand for exported goods by the l-th foreign consumer to purchase the g-th good is thus given by

$$C^{\mathrm{d}}_{lg}(t) = \frac{c^{\mathrm{E}}_g C^{\mathrm{E}}(t) \bar{P}_g(t-1)(1 + \pi^{\mathrm{e}}(t))}{L}\,, \tag{82}$$

where c^{E}_g is the fraction of exports of goods of type g.

Realized consumption by foreign consumers is then an outcome of the search-and-matching process on goods markets (see Section 3.1.1):

$$C_l(t) \begin{cases} = \sum_g C^{\mathrm{d}}_{lg}(t) & \text{if the foreign consumer successfully realized the consumption plan, and} \\ < \sum_g C^{\mathrm{d}}_{lg}(t) & \text{if all firms visited could not satisfy its demand.} \end{cases} \tag{83}$$

[30] As a simplifying assumption, this implies that imports to the domestic economy are not demand-driven, but rather subject to a supply constraint.

[31] As for domestic firms, we assume that there is a one-to-one correspondence between the sets of industries s and products g, meaning that the n-th sector produces only the n-th good, and $S = G$.

4. Parameters for the Austrian economy

Parameters for the model presented in Section 3 are set for the Austrian economy, so that each agent in the model represents a natural person or legal entity, such as a corporation, a government entity or any other institution, in Austria. Austria is a typical example of an advanced small open economy with about 8.8 million inhabitants and more than half a million registered businesses[32]: it is closely integrated into the European economy by extensive trade (the export quota, i.e. the share of exports in GDP, is slightly more than 52 percent, the import quota about 48 percent). Austria's well-developed service sector constitutes about 71 percent of total GDP, while the industry sector takes a smaller share with about 28 percent in GDP and the agricultural sector contributes much less (about 1.5 percent of GDP). Austria has a well-developed social and welfare system, primarily based on social security contributions, as well as taxation of income and consumption. Correspondingly, the ratio of public spending to GDP is about 52 percent, while the overall tax burden, that is, the ratio of total taxes and social security contributions to GDP, reaches 43 percent.

The parameters of the model are summarized in Table 1. For the forecasting exercise in Section 6, parameters were initially calculated and estimated over the sample 1997:Q1 to 2010:Q1 and then, respectively, re-estimated and recalculated, every quarter until 2013:Q4. Here we show, as an example, parameter values for 2010:Q4. Data sources include micro and macro data from national accounts, sector accounts, input-output tables, government statistics, census data, and business demography data and are collected in Table 2.[33] Model parameters are either taken directly from data or calculated from national accounting identities. Parameters that specify the number of agents are taken directly from census and business demography data. Model parameters concerning productivity and technology coefficients, as well as capital formation and consumption coefficients, are taken directly from input-output tables, or are derived from them. Tax rates and marginal propensities to consume or invest are calculated from national accounting identities. These rates are set such that the financial flows observed in input-output tables, government statistics, and sector accounts are matched. Capital ratios and the inflation target of the monetary authority are set according to the literature. For exogenous processes such as imports and exports, parameters are estimated from national accounts (main aggregates).

4.1. Firms

Parameters that specify the number of firms are taken directly (or derived from) business demography data. Specifically we use data from business demography by legal form (from 2004 onwards, NACE Rev. 2) (bd_9ac_l_form_r2) to set the number of firms in industries (I_s) according to the population of active enterprises in t (V.11910). Business demography tables do not include the agriculture, forestry and fishing sector (A01-A03), or the public administration, defense, and compulsory social security sector (O64). The number of firms in industries A01-A03 is set according to the *"Grüner Bericht"*,[34] and the number of firms in industry O64 (i.e. generic administrative government units) is set at $10,000$. The amount L of foreign firms that import and export goods is not available from business demography data. As a first simplifying assumption, this number is assumed to be 50 percent of domestically producing firms, which approximately corresponds to the share of exports in total value added. For the classification of industries (s) we use the statistical classification of economic activities in the European Community (NACE). Products (g) are classified according to the classification of products by activity (CPA), which is fully aligned with NACE. Several consolidated tables including input-output tables, demographic data and cross-classification tables are compiled for the EA and European Union with a breakdown of 64 activities/products (NACE*64, CPA*64). We, therefore, set the number of industries (S) and the number of products (G) at 64 ($S = 64, G = 64$).

[32] For facts and figures about the Austrian economy see e.g. the Austrian Statistical Agency, `http://statistik.at/web_en/statistics/index.html` (Last accessed November 30th, 2018). All data for the Austrian economy is provided for the year 2016.

[33] Data are obtained from the Eurostat bulk download facility where it is freely available, see `http://ec.europa.eu/eurostat/estat-navtree-portlet-prod/BulkDownloadListing?sort=1&dir=data` (Last accessed November 30th, 2018). The codes under which the respective datasets are available from Eurostat (such as, e.g., naio_10_cp1700) at this download facility are given in brackets in the description below.

[34] In English the *Green report*, which is a yearly report on agricultural development in Austria, as well as on the social and economic situation of Austrian farmers and forest workers. For further reference, see `http://www.awi.bmlfuw.gv.at/index.php?id=gruenerbericht` (Last accessed November 30th, 2018).

Table 1: Model parameters

Parameter	Description	Value	Source
G/S	Number of products/industries	62	census data, business demography data
H^{act}	Number of economically active persons	4729215	
H^{inact}	Number of economically inactive persons	4130385	
J	Number of government entities	152820	
L	Number of foreign consumers	305639	
I_s	Number of firms/investors in the s^{th} industry	see Table 3	
$\bar{\alpha}_i$	Average productivity of labor of the i^{th} firm	see Section 4.1	input-output tables
κ_i	Productivity of capital of the i^{th} firm	see Section 4.1	
β_i	Productivity of intermediate consumption of the i^{th} firm	see Section 4.1	
δ_i	Depreciation rate for capital of the i^{th} firm	see Section 4.1	
$\bar{w}_i$	Average wage rate of firm i	see Section 4.1	
a_{sg}	Technology coefficient of the g^{th} product in the s^{th} industry	see Section 4.1	
b_g^{CF}	Capital formation coefficient of the g^{th} product (firm investment)	see Table 3	
b_g^{CFH}	Household investment coefficient of the g^{th} product	see Table 3	
b_g^{HH}	Consumption coefficient of the g^{th} product of households	see Table 3	
c_g^{G}	Consumption of the g^{th} product of the government in mln. Euro	see Table 3	
c_g^{E}	Exports of the g^{th} product in mln. Euro	see Table 3	
c_g^{I}	Imports of the g^{th} product in mln. Euro	see Table 3	
τ_i^{Y}	Net tax rate on products of the i^{th} firm	see Section 4.3	
τ_i^{K}	Net tax rate on production of the i^{th} firm	see Section 4.3	
τ^{INC}	Income tax rate	0.2134	government statistics, sector accounts
τ^{FIRM}	Corporate tax rate	0.0779	
τ^{VAT}	Value-added tax rate	0.1529	
τ^{SIF}	Social insurance rate (employers' contributions)	0.2122	
τ^{SIW}	Social insurance rate (employees' contributions)	0.1711	
τ^{EXPORT}	Export tax rate	0.003	
τ^{CF}	Tax rate on capital formation	0.2521	
τ^{G}	Tax rate on government consumption	0.0091	
r^{G}	Interest rate on government bonds	0.0087	
μ	Risk premium on policy rate	0.0256	
ψ	Fraction of income devoted to consumption	0.9079	
ψ^{H}	Fraction of income devoted to investment in housing	0.0819	
θ^{UB}	Unemployment benefit replacement rate	0.3586	
θ^{DIV}	Dividend payout ratio	0.7953	
θ	Rate of installment on debt	0.05	literature
ζ	Banks' capital requirement coefficient	0.03	
ζ^{LTV}	Loan-to-value (LTV) ratio	0.6	
ζ^{b}	Loan-to-capital ratio for new firms after bankruptcy	0.5	
π^*	Inflation target of the monetary authority	0.02	
α^{G}	Autoregressive coefficient for government consumption	0.9832	national accounts (exogenous estimated)
β^{G}	Scalar constant for government consumption	0.1644	
α^{E}	Autoregressive coefficient for exports	0.9679	
β^{E}	Scalar constant for exports	0.3436	
α^{I}	Autoregressive coefficient for imports	0.9736	
β^{I}	Scalar constant for imports	0.2813	
$\alpha^{\text{Y}^{\text{EA}}}$	Autoregressive coefficient for euro area GDP	0.9681	
$\beta^{\text{Y}^{\text{EA}}}$	Scalar constant for euro area GDP	0.4706	
$\alpha^{\pi^{\text{EA}}}$	Autoregressive coefficient for euro area inflation	0.3198	
$\beta^{\pi^{\text{EA}}}$	Scalar constant for euro area inflation	0.0028	
ρ	Adjustment coefficient of the policy rate	1.0028	
r^*	Real equilibrium interest rate	-0.0617	
ξ^{π}	Weight of the inflation target	-17.7004	
ξ^{γ}	Weight of economic growth	-40.9463	

Note: Model parameters are calculated for 2010:Q4. Exogenous autoregressive parameters are estimated starting in 1997:Q1.

Table 2: Eurostat data tables

Name	Code
GDP and main components - output, expenditure and income (quarterly time series)	namq_10_gdp
Symmetric input-output table (IOT) at basic prices (product by product)	naio_10_cp1700
Cross-classification of fixed assets by industry and by asset (stocks)	nama_10_nfa_st
Balance sheets for financial assets	nasa_10_f_bs
Non-financial transactions	nasa_10_nf_tr
Business demography by legal form (from 2004 onwards, NACE Rev. 2)	bd_9ac_l_form_r2
Government revenue, expenditure and main aggregates	gov_10a_main
Government deficit/surplus, debt and associated data	gov_10dd_edpt1
Government expenditure by function - COFOG	gov_10a_exp
Population by current activity status, NACE Rev. 2 activity and NUTS 2 region	cens_11an_r2
Money market interest rates - annual data	irt_st_a
Money market interest rates - quarterly data	irt_st_q

Note: The codes under which the respective datasets are available from Eurostat (such as, e.g., naio_10_cp1700) are shown in the second column.

Several model parameters concerning the firm agents are directly taken from input-output tables (IOTs), or are derived from them. The input-output framework of the ESA consists of supply and use tables in current prices and the prices of the previous year. Supply and use tables are matrices describing the values of transactions in products for the national economy categorized by product type and industry; see (Eurostat, 2013). We use the symmetric input-output table at basic prices (product by product) (naio_10_cp1700) to set the technology, consumption and capital formation coefficients (a_{sg}, b_g^{HH}, b_g^{CF}, c_g^{G}, c_g^{E} and c_g^{I}). Specifically, we use intermediate consumption (P.2)[35] of 64 (CPA*64) products for the technology coefficient of the g^{th} product in the s^{th} industry a_{sg}. To obtain the technology coefficient, the entries are normalized column-wise. Real estate services (CPA_L68) also include imputed rents. Entries of "services of households as employers, undifferentiated goods and services produced by households for own use" (CPA_T) and "Services provided by extraterritorial organizations and bodies" (CPA_U) contain zeros only and are excluded. The capital formation coefficient of the g^{th} product b_g^{CF} is set according to the gross fixed capital formation (P.51G) as given in the symmetric input-output table. The consumption coefficient of the g^{th} product of households b_g^{HH} is set according to final consumption expenditure by households (P.3) plus final consumption expenditure by non-profit organizations serving households (NPISH). Again, entries are normalized to obtain capital formation and consumption coefficients. The consumption of the g^{th} product of the government c_g^{G}, imports of the g^{th} product c_g^{I} and exports of the g^{th} product (c_g^{E}) are taken directly from the symmetric input-output table by using the final consumption expenditure by government (P.3), as well as total exports (P.6) and imports (P.7).

For some parameters we need to combine the logic of annual sectoral accounts and IOTs. The information by institutional sector in the sector accounts and the information by industry or product in the supply and use tables can be linked by cross-classification tables. We use the cross-classification tables and structural business statistics (business demography) to complement symmetric IOTs. Specifically we are using statistics on population by current activity status, NACE Rev. 2 activity and NUTS 2 region (cens_11an_r2) to set the average productivity of labor for firm i ($\bar{\alpha}_i$), which is assumed to be equal across firms in each industry s, but different between industries ($\bar{\alpha}_i = \alpha_s \quad \forall i \in I_s$). It is defined by output (P.1) in the industry divided by the number of persons employed in the population of active enterprises in t (V.16910) in the industry.[36] The average wage that employees receive from firm i ($\bar{w}_i = \frac{w_s}{N_s} \quad \forall i \in I_s$)

[35]The accounting code of the European System of Accounts (ESA) data source is given in brackets. In this coding system, the capital letter D represents a figure from the distributive transactions account, while a P indicates data from the transactions in products and non-produced asset account. The letter B generally stands for a balancing item, i.e. the subtraction of one side of an account from the other. Balancing items carry much of the most vital information in these data. For example, operating surplus/mixed income (B.2A3N) is obtained by subtracting the cost factors compensation of employees and taxes on products from value added. The capital letter F indicates a financial asset/liability for financial balance sheets, e.g. F.2 indicates currency and deposits. The numbers after the letters indicate the type of transaction/balancing item/asset class, in a similar coding system as IO classification with increasing amount of detail in the classification as the amount of digits increases. This means that e.g. D.41 (interest payments) is a sub-category of D4 (property income).

[36]In the context of the Labour Force Survey (LFS), an employed person is a person aged 15 and over (or 16 and over in Iceland and Norway)

Table 3: Sectoral parameters

	I_s	N_s	α_s	β_s	κ_s	δ_s	w_s	τ_s^{Y}	τ_s^{K}	b_g^{CF}	b_g^{CFH}	b_g^{HH}	c_g^{G}	c_g^{E}	c_g^{I}
A01	47901	123068	0.0111	1.6632	0.044	0.0114	0.0003	0.0095	-0.2611	0.0033	0.0006	0.0113	0	0.0051	0.0174
A02	1867	18107	0.0307	1.9507	0.2048	0.0131	0.0023	0.0088	-0.0398	0	0	0.002	0	0.0006	0.0047
A03	234	283	0.0379	1.5267	0.0335	0.0076	0.0018	0.023	0.0036	0	0	0.0003	0	0	0.0004
B	448	6395	0.0701	1.8244	0.1908	0.0279	0.0078	0.0124	-0.0073	0.0008	0.0044	0.0003	0	0.0073	0.0569
C10-12	4842	79431	0.0527	1.3946	0.498	0.025	0.0059	0.002	-0.0112	0	0	0.0631	0	0.0544	0.0495
C13-15	2254	21660	0.0336	1.5409	0.3738	0.0201	0.0058	0.0042	-0.0035	0.0033	0	0.0307	0	0.0214	0.0469
C16	3802	34971	0.0496	1.3227	0.4361	0.017	0.0058	0.0047	0.0033	0.0031	0.0671	0.0004	0	0.0239	0.0104
C17	1019	18789	0.0772	1.3819	0.4108	0.0246	0.0088	0.0035	-0.0017	0	0	0.002	0	0.0281	0.0172
C18	463	12444	0.053	1.5943	0.3205	0.0266	0.0091	0.003	0.0056	0	0	0	0	0.0059	0.0005
C19	7	1544	0.6413	1.0612	0.8256	0.0328	0.0143	0.0091	-0.0027	0	0	0.0191	0	0.0119	0.0405
C20	459	16812	0.1828	1.1085	0.7932	0.019	0.0075	0.0021	0.0005	0	0.0017	0.0077	0	0.0765	0.0909
C21	104	10505	0.0666	1.8145	0.2156	0.0241	0.0073	0.0033	0.0054	0	0	0.0054	0.0236	0.0212	0.03
C22	679	27163	0.046	1.5616	0.4311	0.0262	0.0081	0.004	0.0085	0.0028	0.0103	0.0034	0	0.0269	0.0306
C23	1697	33127	0.041	1.6122	0.2614	0.0213	0.0079	0.0091	0.0087	0.0026	0.026	0.0011	0	0.015	0.0132
C24	2639	37414	0.0862	1.3083	0.5286	0.0262	0.008	0.0071	0.0042	0.0053	0	0	0	0.0686	0.0602
C25	2127	65597	0.0396	1.5823	0.4002	0.0236	0.0081	0.0037	0.0054	0.0132	0.0116	0.0021	0	0.0381	0.0332
C26	461	21164	0.049	1.7646	0.19	0.0374	0.0075	0.0023	0.0013	0.046	0	0.0106	0.0005	0.0384	0.0608
C27	838	41492	0.0454	1.8096	0.3523	0.0293	0.0072	0.0014	0.002	0.0209	0	0.0068	0	0.0507	0.042
C28	1519	69049	0.0539	1.4923	0.5642	0.0287	0.0086	0.002	0.0076	0.1155	0.0022	0.0008	0	0.0995	0.0848
C29	365	26418	0.1012	1.2977	0.4055	0.0294	0.0088	0.0016	0.0029	0.071	0	0.0193	0	0.079	0.0809
C30	115	9932	0.0848	1.3929	0.9523	0.0495	0.0086	0.0019	0.0058	0.0155	0	0.0018	0.0002	0.0197	0.0131
C31_32	6147	48442	0.0321	1.5459	0.479	0.0199	0.0058	0.0081	0.0109	0.031	0	0.0205	0.0039	0.0294	0.0341
C33	2219	24758	0.0729	1.7116	1.9659	0.001	0.017	0.0027	0.0125	0.042	0	0	0	0.0069	0.0046
D	2923	29577	0.1908	1.2803	0.2477	0.0193	0.0103	0.0044	0.0076	0	0	0.0265	0	0.013	0.0064
E36	319	1860	0.0988	2.5567	0.0399	0.0095	0.0134	0.0071	0.0266	0	0	0	0	0	0
E37-39	2660	13748	0.1116	1.8111	0.0698	0.0125	0.0131	0.0133	0.0082	0	0	0.0005	0	0.0065	0.0118
F	40541	289349	0.0388	1.6356	0.4075	0.0131	0.0074	0.0045	0.0117	0.2993	0.7263	0.0096	0	0.0046	0.0037
G45	12773	79935	0.0225	2.0223	0.4369	0.0131	0.006	0.0048	0.0182	0.0135	0	0.0257	0	0.0039	0.0002
G46	35476	211081	0.037	2.4179	0.4586	0.0224	0.0086	0.0051	0.013	0.0391	0.0127	0.0405	0.0088	0.0676	0.0035
G47	54533	367771	0.0135	2.9497	0.3531	0.0159	0.0041	0.0085	0.0188	0.0041	0.0458	0.1216	0.009	0	0
H49	15527	130956	0.0272	2.0273	0.1591	0.0188	0.0061	0.0255	0.019	0.0015	0.0017	0.0261	0.0307	0.0353	0.0273
H50	194	650	0.0356	1.2557	0.165	0.0524	0.004	0.0018	0.006	0	0.0001	0.0002	0	0.0029	0.0083
H51	315	8345	0.0939	1.2358	0.4242	0.0549	0.0106	0.0043	0.0084	0	0	0.0089	0	0.007	0.0069
H52	1681	51360	0.0403	2.7059	0.0467	0.0112	0.0091	0.0054	0.0206	0.0008	0.0006	0.0049	0.0259	0.0133	0.0121
H53	681	27422	0.022	2.1974	1.0186	0.026	0.0077	0.014	0.0255	0	0	0.0019	0	0.0027	0.0015
I	58156	297890	0.0177	2.7159	0.2627	0.0103	0.0042	0.0161	0.0049	0	0	0.1177	0.0002	0.0164	0.0121
J58	1635	13604	0.0601	1.5738	1.5796	0.0591	0.0107	0.0017	0.0009	0.0074	0	0.0076	0.0009	0.0064	0.0115
J59_60	3754	13894	0.0384	1.5732	0.5471	0.0521	0.0074	0.0033	-0.0297	0.0027	0	0.0063	0	0.0019	0.0047
J61	407	11480	0.1414	1.7194	0.1377	0.0319	0.0158	0.003	0.0087	0	0	0.017	0	0.0051	0.0046
J62_63	20232	61985	0.0429	2.0445	1.1036	0.0912	0.0117	0.0031	0.0183	0.0865	0	0	0	0.014	0.0106
K64	2242	80368	0.0442	2.5271	0.2425	0.0186	0.0125	0.0385	0.0165	0	0	0.0172	0.0001	0.0131	0.0075
K65	451	30324	0.0474	1.7555	0.3369	0.0105	0.0121	0.0464	0.0216	0	0	0.024	0	0.0065	0.0036
K66	11338	24314	0.0296	1.551	2.1919	0.0428	0.0049	0.0252	0.0121	0	0	0.002	0	0.0007	0.0007
L68A	12043	29579	0.3389	3.1659	0.0808	0.0251	0.011	0.0138	0.0111	0.0046	0.0053	0.1743	0.0006	0.0009	0.0006
M69_70	42306	127617	0.0312	1.9971	0.9796	0.01	0.0081	0.0051	0.0169	0.0008	0.0013	0.0025	0	0.0112	0.0092
M71	21944	65354	0.0301	2.1107	0.4376	0.0253	0.0072	0.0031	0.0165	0.0213	0.0783	0	0.0019	0.0087	0.0033
M72	2351	14252	0.1473	3.7771	1.4741	0.1967	0.0544	0.0136	0.0018	0.138	0	0	0.0022	0.0116	0.0045
M73	14055	36513	0.0368	1.3863	1.4981	0.0327	0.0042	0.0106	0.0076	0	0	0	0.0002	0.0055	0.0065
M74_75	14077	21981	0.0242	2.1125	0.7877	0.0334	0.0037	0.0082	0.0051	0	0	0.0022	0.0002	0.001	0.0004
N77	3578	12244	0.1527	3.2182	0.0886	0.0594	0.0064	0.0051	0.0034	0	0	0.0076	0.0014	0.0058	0.0063
N78	1437	82828	0.0129	8.2179	5.9181	0.0465	0.0083	0.0009	0.0453	0	0	0	0	0.0005	0.0007
N79	2692	14603	0.0375	1.2591	0.9812	0.0207	0.0047	0.0073	0.0073	0	0	0.0126	0.0018	0.0003	0.0004
N80-82	14290	113132	0.0144	2.7553	0.6078	0.0177	0.0044	0.0059	0.0223	0.0018	0.0042	0.0056	0.0086	0.0015	0.0018
O	10000	251139	0.021	3.3616	0.1005	0.0116	0.0092	0.043	0.0182	0	0	0.0004	0.3324	0.0009	0.0004
P	12573	115507	0.0347	7.5534	0.1459	0.0168	0.02	0.0258	0.0267	0	0	0.0144	0.2207	0.0001	0.0003
Q86	40749	166917	0.0301	3.484	0.2014	0.0131	0.0116	0.0449	0.0125	0	0	0.0351	0.2371	0.001	0.0007
Q87_88	20452	138958	0.011	3.3889	0.2302	0.0121	0.0057	0.0306	-0.0348	0	0	0.0249	0.0478	0	0.0029
R90-92	16239	35610	0.0229	3.4512	0.235	0.0236	0.008	0.0211	-0.0063	0.0023	0	0.0133	0.0129	0.0013	0.0021
R93	6525	22679	0.019	2.7802	0.0663	0.0089	0.0041	0.0165	0.0022	0	0	0.0097	0.0047	0.0001	0.0001
S94	7182	57121	0.014	2.6605	0.151	0.0088	0.0057	0.0659	0.0316	0	0	0.0111	0.0218	0	0
S95	1979	4947	0.0509	2.3756	2.3287	0.1374	0.0116	0.0193	0.0149	0	0	0.0021	0	0	0
S96	18762	60330	0.0123	3.476	0.1833	0.0128	0.0028	0.0104	0.0134	0	0	0.0172	0.002	0	0.0002

Note: Sectoral parameters are calculated for 2010:Q4.

who during the reference week performed work—even if just for one hour a week—for pay, profit or family gain. For further information, see

Table 4: Statistical classification of economic activities in the European Community (NACE Rev. 2)

NACE	Description
A01	Crop and animal production, hunting and related service activities
A02	Forestry and logging
A03	Fishing and aquaculture
B	Mining and quarrying
C10-12	Manufacture of food products, beverages and tobacco products
C13-15	Manufacture of textiles, wearing apparel and leather products
C16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
C17	Manufacture of paper and paper products
C18	Printing and reproduction of recorded media
C19	Manufacture of coke and refined petroleum products
C20	Manufacture of chemicals and chemical products
C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
C22	Manufacture of rubber and plastic products
C23	Manufacture of other non-metallic mineral products
C24	Manufacture of basic metals
C25	Manufacture of fabricated metal products, except machinery and equipment
C26	Manufacture of computer, electronic and optical products
C27	Manufacture of electrical equipment
C28	Manufacture of machinery and equipment n.e.c.
C29	Manufacture of motor vehicles, trailers and semi-trailers
C30	Manufacture of other transport equipment
C31_32	Manufacture of furniture; other manufacturing
C33	Repair and installation of machinery and equipment
D35	Electricity, gas, steam and air conditioning supply
E36	Water collection, treatment and supply
E37-39	Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services
F	Construction
G45	Wholesale and retail trade and repair of motor vehicles and motorcycles
G46	Wholesale trade, except of motor vehicles and motorcycles
G47	Retail trade, except of motor vehicles and motorcycles
H49	Land transport and transport via pipelines
H50	Water transport
H51	Air transport
H52	Warehousing and support activities for transportation
H53	Postal and courier activities
I	Accommodation and food service activities
J58	Publishing activities
J59_60	Motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities
J61	Telecommuni-cations
J62_63	Computer programming, consultancy and related activities; information service activities
K64	Financial service activities, except insurance and pension funding
K65	Insurance, reinsurance and pension funding, except compulsory social security
K66	Activities auxiliary to financial services and insurance activities
L68B	Real estate activities excluding imputed rents
M69_70	Legal and accounting activities; activities of head offices; management consultancy activities
M71	Architectural and engineering activities; technical testing and analysis
M72	Scientific research and development
M73	Advertising and market research
M74_75	Other professional, scientific and technical activities; veterinary activities
N77	Rental and leasing activities
N78	Employment activities
N79	Travel agency, tour operator reservation service and related activities
N80-82	Security and investigation activities; services to buildings and landscape activities; office administrative, office support and other business support activities
O84	Public administration and defence; compulsory social security
P85	Education
Q86	Human health activities
Q87_88	Social work activities
R90-92	Creative, arts and entertainment activities; libraries, archives, museums and other cultural activities; gambling and betting activities
R93	Sports activities and amusement and recreation activities
S94	Activities of membership organisations
S95	Repair of computers and personal and household goods
S96	Other personal service activities

(which is industry-specific) is defined by wages and salaries (D.11) in the industry divided by the number of persons employed in the population of active enterprises in t (V.16910) in the industry. The average productivity of capital

`http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Employed_person_-_LFS` (Last accessed November 30^{th}, 2018).

Table 5: Statistical classification of economic activities in the European Community (NACE Rev. 2)

NACE	Description
A	Agriculture, forestry and fishing
B, C, D and E	Industry (except construction)
F	Construction
G, H and I	Wholesale and retail trade, transport, accomodation and food service activities
J	Information and communication
K	Financial and insurance activities
L	Real estate activities
M and N	Professional, scientific and technical activities; administrative and support service activities
O, P and Q	Public administration, defence, education, human health and social work activities
R and S	Arts, entertainment and recreation; other service activities; activities of household and extra-territorial organizations and bodies

in the i^{th} firm (κ_i) is set using cross-classification of fixed assets by industry and by asset (stocks) (nama_10_nfa_st) and is again assumed to be equal across firms by industries ($\kappa_i = \kappa_s \quad \forall i \in I_s$), and different across industries s. It is defined by output (P.1) in the industry divided by total fixed assets (net) (N11N)[37] in the industry multiplied by the desired capacity utilization rate (ω, see the Section 5.1). An exception is the sector L68 (real estate services), where the stock of household dwellings ($K_h(0)$) is included that has no productive use in the economy regarding the output of goods and services on markets, and thus has to be treated differently. We remove the stock of dwellings from sector L68 and attribute it to the household sector, see Section 5.2. The productivity of intermediate consumption goods of firm i (β_i) is again the same for each firm in industry s, but differs across industries ($\beta_i = \beta_s \quad \forall i \in I_s$). It is defined by output (P.1) in the industry divided by total intermediate consumption (P.2) of the industry from symmetric input-output tables. The average depreciation of capital in the i^{th} firm (δ_i) is again heterogenous across industries and homogenous across firms by industry ($\delta_i = \delta_s \quad \forall i \in I_s$). It is defined by consumption of fixed capital (P.51C1) in the industry divided by total fixed assets (net) (N11N) in the industry multiplied by the desired capacity utilization rate.

Firms' dividend payout ratio θ^{DIV} is set to match interest and dividend receipts (D.4 received) plus mixed income (B.2A3N)[38] by the household sector in national accounting data (non-financial transactions (nasa_nf_tr)) in relation to total net operating surplus and mixed income (B.2A3N) as obtained from IOTs. As these payments also include interest payments to the household sector, the dividend payout ratio can be seen as the total return property rights ownership in non-financial and financial firms by the household sector, and is set accordingly for each individual firm.

4.2. Households

Parameters that specify the number of households (persons) are taken directly (or derived from) census data. We use the register-based census and the register-based labor market statistics in Austria conducted by Statistik Austria, and supplied via Eurostat. Specifically we are using statistics on population by current activity status, NACE Rev. 2 activity and NUTS 2 region (cens_11an_r2) to set the constant number of inactive persons (H^{inact}). The total number of economically active persons (H^{act}) is set to the total number of persons employed in the population of active enterprises in t (V16910) plus the total number of unemployed and one investor for each firm. The total number of unemployed (plus the labor reserve) is taken from the European Labour Force Survey (LFS).[39]

Households' marginal propensity to consume out of initial disposable income (ψ) is chosen such that consumption out of disposable income ($\psi Y_h(0)$) equals actual household and NPISH consumption in IOTs (P.3 in sectors S.14,

[37]We use total fixed assets (net) because the gross capital stock includes the values of the accumulated consumption of fixed capital. Most fixed assets can be recorded in balance sheets at current purchasers' prices reduced for the accumulated consumption of fixed capital; this is known as the written-down replacement cost. The sum of the reduced values of all fixed assets still in use is described as the net capital stock. The gross capital stock includes the values of the accumulated consumption of fixed capital.

[38]In the logic of IOTs, the self-employed are attributed to firm sectors. Thus, operating surplus of IO sectors includes mixed income, which directly flows to households in the depiction of our model and is thus treated as dividend income.

[39]The number of unemployed and employed persons extracted from the Labour Force Survey (LFS) complies with the ILO definition. According to the ILO definition, unemployed persons are defined as persons who are without work during the reference week, are currently available to work and have either actively been seeking work during the past four weeks or have already found a job to start within the next three months. The LFS also provides information on persons who do not meet the ILO criteria for unemployment but who are willing and available to work within short notice (labor reserve).

S.15). The parameter ψ^{H} capturing the fraction of household expected disposable income $Y_h(0)$ which is invested gross of taxes every period is set according to IOTs. We set ψ^{H} such that investment by the firm sector (in line with our investment function) plus investment by the household sector equals total gross fixed capital formation (P.51G). The household investment coefficients b_g^{CFH} are set such that investment in dwellings as obtained from IOTs for Austria provided by Statistik Austria[40] and gross fixed capital by sector from IOTs are mutually consistent. The replacement rate for unemployment benefits θ^{UB} is chosen according to the statutory replacement rate of 55 percent of net income, which amounts to a replacement rate on gross income of $\theta^{\mathrm{UB}} = 0.55(1 - \tau^{\mathrm{INC}})(1 - \tau^{\mathrm{SIW}})$.

4.3. The general government

The number of government entities (J) is set to 25 percent of domestically producing firms, which roughly equals the share of government consumption in total value added. This corresponds to a realistic depiction of public entities comprising municipalities, public schools, social insurance carriers, and districts, among others, in Austria according to their participation in the Austrian economy.

Tax and subsidy rates are set such that these rates approximate the actual financial flows observed in national accounting data, i.e. non-financial transactions (nasa_10_nf_tr), as well as government revenue, expenditure and main aggregates (gov_10a_main). In the context of the model, we define an average tax rate as the aggregate tax flow paid by an institutional sector (firms in CPA classification, households, etc.) divided by the corresponding aggregate monetary flow that serves as the base for the tax and that is received by the same institutional sector (such as income, profit, output, fixed assets, etc.). This average tax rate obtained from macroeconomic aggregates is then applied to every individual unit/person in our model in the corresponding economic context. The income tax rate τ^{INC} on income from both labor and capital is particularly chosen such that tax payments on wages received by employees and taxes on dividends received by investors add up to total income tax payments by the household sector taken from government expenditure data (gov_10a_main, D.5REC and D.91REC).[41] For reasons of model parsimony we abstract from the progressivity of the Austrian tax system (e.g. regarding income taxes), and secondly from other tax regulations (deductions, exemptions, etc.) relevant for some agents due to specific features of the Austrian tax code.

Firm profit taxes τ^{FIRM} are specified by the ratio of total corporate tax flows (D.51, paid by sectors S.11 and S.12), which are obtained from national accounting data (non-financial transactions (nasa_nf_tr)), to total operating surplus and mixed income (sum over all firm sectors), which we directly take from IOTs (B.2A3N). Value added tax rates τ^{VAT} are specified as total value added taxes net of subsidies (D.21X31) from IOTs divided by consumption by households and NPISH (P.3 in sectors S.14 and S.15). Rates for social security contributions both for employers (τ^{SIF}) and employees (τ^{SIW}) are levied on gross wage income of households (D.11) as given in IOTs. Employers' social security contributions are taken from IOTs by subtracting total gross wage income (D.11) from total compensation of employees (D.1). Employees' social contributions include actual social security contributions (D.613) as well as social security supplements to be paid by employees (D.614), and are obtained by subtracting employers' social contributions from total social contributions received by the government according to government statistics (gov_10a_main, D.61REC). Finally, sector-specific net rates for other taxes and subsidies on products ($\tau_i^{\mathrm{Y}} = \tau_s^{\mathrm{Y}} \quad \forall i \in I_s$) as well as on production ($\tau_i^{\mathrm{K}} = \tau_s^{\mathrm{K}} \quad \forall i \in I_s$) are taken from IOTs: sectoral product tax (D.21X31) and production tax (D.29X39) payments. Tax rates on exports (τ^{EXPORT}), which are levied on total firms' exports as in IOTs (P.6 total) as a uniform tax rate according to total net export tax flows in IOTs (D.21X31 for final use export, P.6). Taxes on capital formation (τ^{CF}) payable on firm investments are determined by dividing tax flows on investments as IOTs (D.21X31) by total investments in dwellings (obtained from IOTs provided by Statistik Austria, see footnote 40).

4.4. The Bank

Banks' capital requirement coefficient (ζ) is set at 3 percent. A capital requirement of 3 percent corresponds to the maximum leverage ratio (tier 1 capital in relation to total exposure) as recommended in the Basel III framework.

[40] See `https://www.statistik.at/web_en/statistics/Economy/national_accounts/input_output_statistics/index.html` (Last accessed November 30^{th}, 2018) for more information on IOTs provided by Statistik Austria. More detailed IOTs for Austria, which include a breakdown of investment into different investment purposes (dwellings, other buildings and structures, machinery, transport equipment, cultivated assets, and intangible fixed assets), can be purchased. This is the only case where we do not rely on publicly and freely available data from the Eurostat bulk download facility.

[41] From national accounting data alone, it is not possible to distinguish between the amount of income taxes due to incomes from labor and capital, respectively. For this distinction, it would be necessary to resort to the Austrian tax code and household surveys.

The rate of debt installment (θ) is set such that firms repay 5 percent of their total outstanding debt every quarter. The risk premium μ paid on firms' outstanding debt is obtained from national accounting data. It is set such that total interest payments in our model financial market, where firm debt constitutes the only financial asset held by the banking sector, matches empirically observed interest payments (D.41) paid by non-financial (S.11) and financial corporations (S.12) in national accounting data (non-financial transactions (nasa_nf_tr)). Therefore, the risk premium by the banking sector μ is calculated by the difference between the 3-month Euribor interest rate obtained from money market interest rates (irt_st_a) and the observed interest payments (D.41) divided by the initial amount of firm debt L^{I}, which is obtained from national accounting data, see Section 5. In order to obtain a quarterly risk premium, μ is converted to a quarterly rate. The bank's maximum loan-to-value (LTV) ratio (ζ^{LTV}) is set to 60 percent. LTV is one of the most common ratios considered for secured loans, and loans with an LTV ratio below 60 percent are typically considered as low- or medium-risk loans. Finally, the loan-to-value ratio for a new firm replacing a bankrupt firm ζ^{b} is set to be equal to 0.5.

5. Initial conditions for the Austrian economy

We set initial conditions for the model presented in Section 3 to represent the Austrian economy. All initial conditions in the model are collected in Table 6. For the forecasting exercise in Section 6, initial conditions were initially calculated and set according to 2010:Q1 and then, respectively, recalculated and reset, every quarter until 2013:Q4. Here we show and discuss, as an example, initial conditions for 2010:Q4.

Table 6: Initial conditions

Initial condition	Description	Value
$P_i(0)$	Initial price of the i^{th} firm	see Section 5.1
$Y_i(0)/Q^{\mathrm{d}}_i(0)$	Initial production/demand of the i^{th} firm (in mln. Euro)	see Section 5.1
$K_i(0)$	Initial capital of the i^{th} firm (in mln. Euro)	see Section 5.1
$M_i(0)$	Initial stocks of raw materials, consumables, supplies of the i^{th} firm (in mln. Euro)	see Section 5.1
$S_i(0)$	Initial stocks of finished goods of the i^{th} firm (in mln. Euro)	see Section 5.1
$N_i(0)$	Initial number of employees of the i^{th} firm	see Section 5.1
$D_i(0)$	Initial liquidity (deposits) of the i^{th} firm (in mln. Euro)	see Section 5.1
$L_i(0)$	Initial debt of the i^{th} firm (in mln. Euro)	see Section 5.1
$\Pi_i(0)$	Initial profits of the i^{th} firm (in mln. Euro)	see Section 5.1
$D_h(0)$	Initial personal assets (deposits) of the h^{th} household (in mln. Euro)	see Section 5.2
$K_h(0)$	Initial household capital (in mln. Euro)	see Section 5.2
$w_h(0)$	Initial wage of the h^{th} household (in mln. Euro)	see Section 5.2
$sb^{\mathrm{inact}}(0)$	Initial pension/social benefits in mln. Euro	0.0022
$sb^{\mathrm{other}}(0)$	Initial social benefits received by all households in mln. Euro	0.0007
$L^{\mathrm{G}}(0)$	Initial government debt (in mln. Euro)	243871.1
$\Pi_k(0)$	Initial banks' profits (in mln. Euro)	see Section 5.4
$E_k(0)$	Initial banks' equity (in mln. Euro)	97802.3
$E^{\mathrm{CB}}(0)$	Initial central banks' equity (in mln. Euro)	115947.6
$D^{\mathrm{RoW}}(0)$	Initial net creditor/debtor position of the national economy to RoW (in mln. Euro)	0

Note: Initial condition are shown for 2010:Q4.

5.1. Firms

The distribution of firm sizes in industrial countries is well-known to be highly skewed, with large numbers of small firms coexisting with small numbers of large firms (Ijiri and Simon, 1977; Axtell, 2001). Initial employment of firm i ($N_i(0) \quad \forall i \in I_s$) is therefore drawn from a power law distribution with exponent -2 (where $\sum_{i \in I_s} N_i(0) = N_s$ and $N_i(0) > 0$), which approximately corresponds to firm size distribution in Austria.[42] To determine initial production

[42]The firm size distribution is obtained from the SABINA database.

Table 7: Initial conditions for the institutional sectors

Initial condition	Description	Value
D^{I}	Initial liquidity (deposits) of the firm sector (in mln. Euro)	52141.2
L^{I}	Initial debt of the firm sector (in mln. Euro)	244953.2
ω	Desired capacity utilization rate	0.85
w^{UB}	Initial unemployment benefits (in mln. Euro)	0.0038
D^{H}	Initial personal assets (deposits) of the household sector (in mln. Euro)	222933.2
K^{H}	Initial capital (dwellings) of the household sector (in mln. Euro)	401079.7

Note: Initial condition are shown for 2010:Q4.

$Y_i(0)$ of the i^{th} firm, we use the initial employment by firm $N_i(0)$, and compute the corresponding amount of production by the productivity of labour per unit of output $\bar{\alpha}_i$:

$$Y_i(0) = Q_i^{\mathrm{d}}(0) = \bar{\alpha}_i N_i(0)\,.$$

Initial capital of firm i, $K_i(0)$, (i is part of industry s) is then obtained by dividing firm i's initial level of production $Y_i(0)$ by the productivity of capital κ_i and the desired rate of capacity utilization ω.

$$K_i(0) = \frac{Y_i(0)}{\kappa_i \omega}\,.$$

Thus, it is the share of capital of the i^{th} firm in sector s as measured by production, accounting for the reserve capacity of its capital stock targeted by firm i. The initial stocks of raw materials, consumables, supplies, and spare parts (i.e. intermediate inputs) of the i^{th} firm ($M_i(0)$) are set such that—given the initial level of production by firm i, the productivity of intermediate inputs β_i and a buffer stock of material inputs $1/\omega$—firms hold enough intermediate inputs to be able to provide for expected use of these inputs as well as accounting for their desired buffer stock:

$$M_i(0) = \frac{Y_i(0)}{\omega \beta_i}\,.$$

Regarding financial and current assets cross-classification tables are not available. Correspondingly, a breakdown of financial and current assets for the 64 economic activities (NACE*64) is not available in macroeconomic data. Thus, we apportion initial debt $L_i(0)$ to the i^{th} individual firm by disaggregating total firm debts according to the share of the firms' capital stock $K_i(0)$ in the total capital stock $\sum_i K_i(0)$:

$$L_i(0) = L^{\mathrm{I}} \frac{K_i(0)}{\sum_i K_i(0)}\,,$$

where the total amount of firm debt L^{I} is obtained from national accounting data (financial balance sheets (nasa_10_f_bs), loans (F.4) of non-financial corporations (S.11), non-consolidated liability position). The total initial liquidity (deposits) of all firms as an aggregate, D^{I}, is set according to national accounting data (financial balance sheets (nasa_10_f_bs), non-consolidated deposits (F.2) held by the non-financial corporations sector (S.11)). This aggregate is broken down onto single firms by the share of firm i's operating surplus in the overall operating surplus, where we assume that firm liquidity (deposits) moves in line with its production as a liquid form of working capital used for current expenditures:

$$D_i(0) = D^{\mathrm{I}} \frac{\max(\bar{\pi}_i Y_i(0), 0)}{\sum_i \max(\bar{\pi}_i Y_i(0), 0)}\,,$$

where $\bar{\pi}_i = 1 - \left(1 + \tau^{\mathrm{SIF}}\right) \frac{\bar{w}_i}{\bar{\alpha}_i} + \frac{\delta_i}{\kappa_i} + \frac{1}{\beta_i} - \tau_i^{\mathrm{K}} - \tau_i^{\mathrm{Y}}$ is the operating margin. Initial profit of the i^{th} firm is given by the initial operating surplus and the initial income from interest less interest payments:

$$\Pi_i(0) = \bar{\pi}_i Y_i(0) - r(0) L_i(0) + \bar{r}(0) D_i(0)\,.$$

The initial inventories of finished goods $S_i(t)$ of firm i is assumed to be equal to zero due to a lack of reliable data sources. The initial price of the i^{th} firm $P_i(0)$ is set to one.

5.2. Households

Initial personal assets (deposits) of the h^{th} household ($D_h(0)$) are obtained from national accounting data (financial balance sheets (nasa_10_f_bs), F.2, currency and deposits held by the household and NPISH sectors, S14_S15, non-consolidated asset position), which is disaggregated onto the individual level according to the share of each household's income in total income as a proxy for the household's wealth:

$$D_h(0) = D^{\text{H}} \frac{Y_h(0)}{\sum_h Y_h(0)} ,$$

where D^{H} are the initial personal assets (deposits) of the household sector and $Y_h(0)$ is determined according to equation (49). Initial capital (dwellings) of the h^{th} household ($K_h(0)$) is set to match dwellings (N111N) as obtained from balance sheets for non-financial assets (nama_10_nfa_st) and is again disaggregated onto the individual level according to the share of each household's income in total income as a proxy for the household's wealth:

$$K_h(0) = K^{\text{H}} \frac{Y_h(0)}{\sum_h Y_h(0)} ,$$

where K^{H} is the initial capital (dwellings) of the household sector.

The initial wage of the h^{th} household ($w_h(0)$) is equal to the initial wage paid by firm i ($\bar{w}_i$), if i is the employer of household h; or it is equal to the initial unemployment benefits w^{UB}, if the household is unemployed. Initial unemployment benefits are set by dividing the total flow of unemployment payments (GF.1005), as obtained from the Eurostat data set government expenditure by funcion (gov_10a_exp), by the amount of unemployed persons (wstatus=UNE), which is determined according to the statistics on population by current activity status, NACE Rev. 2 activity and NUTS 2 region (cens_11an_r2). Thus, $w_h(0)$ is determined as follows:

$$w_h(0) = \begin{cases} w^{\text{UB}} & \text{if unemployed} \\ \bar{w}_i & \text{if employed by firm } i \end{cases} .$$

Transfers other than consumption, savings, taxes and subsidies[43] are netted out for the government and household sectors, and treated as a net transfer from the government to the household sector. Government transfers to households in the form of social benefits (D.62) are attributed to the different household (consumer) types according to their employment status. The data are taken from national accounting statistics on general government expenditures by function (COFOG classification, Eurostat table gov_10a_exp), which are used to allocate the total flow of the different social benefits ($sb^{\text{inact}}(0)$, $sb^{\text{other}}(0)$) from the government to persons to whom this transfer applies. To break the overall economic flows of social benefits down onto an individual household level, we follow the following procedure: all social benefits are given in equal proportion to the different household types such that the sum of individual flows adds up to total macroeconomic flows.

5.3. The general government

Initial government debt ($L^{\text{G}}(0)$) is set according to the Austrian government's (sector S.13) consolidated gross debt (GD) as obtained from the Eurostat data set government deficit/surplus, debt and associated data (gov_10dd_edpt1).

5.4. The Bank

Initial bank's equity ($E_k(0)$) is obtained from national accounting data (financial balance sheets (nasa_10_f_bs), F.5 and BF.90, non-consolidated equity and financial net worth of monetary financial institutions other than the central bank (S122_S123)). Initial bank's profits are given by the initial income from interest less interest payments:

$$\Pi_k(0) = r(0) \sum_i L_i(0) + \bar{r}(0) \left(\sum_i D_i(0) + \sum_h D_h(0) - D_k(0) \right),$$

where initial advances from the central bank ($D_k(0)$) are set according to equation (68).

[43] In particular property and interest income (D.4) in the government sector, other current transfers (D.7), adjustments for changes in pension entitlements (D.8), as well as capital transfers other than capital taxes (D.9 - D.91)

5.5. The Central Bank

Initial central bank's equity ($E^{CB}(0)$) is the residual on the central bank's passive side, obtained by deducting initial bank reserves held ($D_k(0)$) and the initial net creditor/debtor position with the rest of the world ($D^{RoW}(0)$) from the central bank's assets (initial government debt ($L^G(0)$)). Thus, the initial central bank's equity ($E^{CB}(0)$) is set according to equation (76) where the initial balance of trade with the rest of the world ($D^{RoW}(0)$) is assumed to be zero and the initial bank reserves held ($D_k(0)$) are set according to equation (68).

6. Forecast performance

To validate the ABM, we conduct a series of forecasting exercises in which we evaluate the out-of-sample forecast performance of the ABM in comparison with standard macroeconomic modeling approaches.[44] The purpose of the first comparison in Section 6.1 is to compare the ABM to VAR models estimated on the same set of time series as the ABM. The purpose of the second comparison in Section 6.2 is to benchmark the ABM to a DSGE model as an alternative modelling paradigm that is rooted in econonomic theory.[45] Here, the AR model serves as a benchmark model for the forecast performance of both the ABM and the DSGE model. In the third forecast exercise in Section 6.3, we test the ABM against the DSGE model in a conditional forecasting setup.

6.1. Comparison with VAR models

In this section, we compare the out-of-sample forecast performance of the ABM to that of an unconstrained (non-theoretical) VAR model estimated on the same observable macro time series as the ABM in a traditional out-of-sample root mean squared error (RMSE)[46] forecast exercise. To test whether the ABM forecasts are significantly different in accuracy than the VAR(1) forecasts, we conduct Diebold and Mariano (1995) tests. Observable time series include real GDP, inflation, real government consumption, real exports and real imports of Austria, real GDP and inflation of the euro area (EA), and the Euro Interbank Offered Rate (Euribor). Both the VAR model and the ABM were initially estimated over the sample 1997:Q1 to 2010:Q1, and were then used to forecast the eight time series from 2010:Q2 to 2016:Q4; the models were re-estimated every quarter for the time periods 2010:Q2 to 2013:Q4. ABM results are obtained as an average over 500 Monte Carlo simulations. To determine the optimal lag length of the VAR models, we use Akaike's and the Bayesian Information Criterion (AIC and BIC). For the entire time period from 2010:Q1 to 2013:Q4 VAR models of lag order one minimize both the AIC and BIC. For the optimized log likelihoods and the forecast performance of VAR models of different lag orders, see Tables C.1 and C.2 in the appendix. To allow the data to decide on the degree of persistence and cointegration, in the VAR model we enter GDP, government consumption, exports, imports, and GDP of the EA in log levels.

Table 8 reports the out-of-sample RMSEs for different forecast horizons of 1, 2, 4, 8, and 12 quarters over the period 2010:Q2 to 2016:Q4. In parentheses we show the p-values of Diebold and Mariano (1995) tests, where we test whether the ABM forecasts are significantly different in accuracy than the VAR(1) forecasts (the null hypothesis of the test is that there is no difference between two competing forecasts). These out-of-sample forecast statistics demonstrate the good forecast performance of the ABM relative to the VAR(1) model. For GDP and inflation, the

[44]This out-of-sample prediction performance evaluation is constructed along the lines of Smets and Wouters (2007), who compare a Bayesian DSGE model to unconstrained VAR as well as Bayesian VAR (BVAR) models. As Smets and Wouters (2007) and for reasons of data availability, we are restricted to use final-revised data as available from Eurostat at the time of model estimation. For example, it is a well-known fact that input-output tables are produced with a lag of usually several years (for Austria, the lag is about 4 to 5 years). Clearly, vintage data, that is, data that was available at the period to which the model is estimated, would in general be preferable for a pseudo-out-of-sample forecast exercise with expanding sample as we conduct below in Section 6. However, similar to Smets and Wouters (2007), in this study we are primarily interested in how well the ABM fits data of the Austrian economy, and not in benchmarking the forecast performance of the ABM with potentially inconsistent real-time data. Conducting a real-time forecast evaluation along the lines of e.g. Diebold et al. (2017) is subject to future research.

[45]As discussed above, to benchmark the forecasting performance of our ABM, we choose a DSGE model based on Smets and Wouters (2007) which is the canonical DSGE model used for forecasting. Furhermore, we use a DSGE model of the representative agent type as means of comparison because (RANK) DSGE models typically exhibit a better forecast performance than their heterogeneous agent counterpart (HANK) DSGE models.

[46]The root mean squared error is defined as follows: $RMSE = \sqrt{\frac{1}{n}\sum_{t=1}^{T}(\hat{x}_t - x_t)^2}$, where $\hat{x}_t$ is the forecast value and x_t is the observed data point for time period t.

Table 8: Out-of-sample forecast performance

	GDP	Inflation	Government consumption	Exports	Imports	GDP EA	Inflation EA	Euribor
VAR(1)	*RMSE-statistic for different forecast horizons*							
1q	0.66	0.39	0.98	1.88	2.16	0.58	0.15	0.09
2q	0.89	0.38	1.35	2.35	2.82	0.89	0.13	0.15
4q	1.29	0.36	2.05	2.67	3.02	1.49	0.17	0.24
8q	1.55	0.36	3.13	3.22	3.22	2.77	0.21	0.26
12q	1.99	0.42	3.5	5.7	4.66	4.05	0.27	0.2
ABM	*Percentage gains (+) or losses (-) relative to VAR(1) model*							
1q	4.3 (0.71)	4.3 (0.61)	30.2 (0.19)	13.4 (0.42)	27 (0.16)	28.1 (0.05)	27.1 (0.14)	-89.5 (0.03)
2q	-1 (0.95)	2.2 (0.77)	59.5 (0.07)	9.8 (0.50)	22.2 (0.19)	21.1 (0.19)	-21.4 (0.47)	-18.8 (0.67)
4q	-2.6 (0.86)	5.3 (0.29)	61.6 (0.11)	-12.8 (0.40)	-4.2 (0.72)	20.3 (0.10)	7.9 (0.67)	22.2 (0.50)
8q	10.3 (0.34)	-0.6 (0.89)	60.2 (0.00)	-10.4 (0.59)	-14.1 (0.38)	35.3 (0.00)	27.3 (0.01)	65.3 (0.00)
12q	37.3 (0.00)	20.8 (0.00)	44.5 (0.00)	34.5 (0.00)	5.1 (0.31)	41.3 (0.00)	29.9 (0.01)	74.1 (0.00)

Note: All models are estimated starting in 1997:Q1. The forecast period is 2010:Q2 to 2016:Q4. All models are re-estimated each quarter. ABM results are obtained as an average over 500 Monte Carlo simulations. The values in brackets indicate the p-values of Diebold and Mariano (1995) tests, where we test whether the ABM forecasts are significantly different in accuracy than the VAR(1) forecasts (the null hypothesis of the test is that there is no difference between two competing forecasts).

ABM delivers a similar forecast performance to that of the VAR(1) for short- to medium-term horizons up to two years, and significantly improves on it for longer horizons up to three years. For all variables (GDP, inflation, government consumption, exports, GDP and inflation of the EA, and the Euribor), the ABM does better than the VAR(1) model by a considerable margin for longer horizons, with statistically significantly more accurate forecasts for all variables except for imports at a horizon of 12 quarters.

6.2. *Comparison with DSGE and AR models*

In this section, we benchmark the ABM to a standard DSGE model by comparing their out-of-sample forecast performances. In this comparison, the ABM and the DSGE model are estimated on different time series due to the inherent methodological differences between these model types. Therefore, we choose as variables for comparison the major macroeconomic aggregates: real GDP, inflation, and the main components of GDP—real household consumption and real investment, as well as interest rates. As discussed above, to conduct this comparison, we employ a version of the standard DSGE model of Smets and Wouters (2007), which is a widely cited New Keynesian DSGE model for the US economy with sticky prices and wages, adapted to the Austrian economy. Specifically, we use the two-country model of Breuss and Rabitsch (2009), which is a New Open Economy Macro model for Austria as part of the European Monetary Union (EMU).[47] The DSGE model is estimated on the following set of 13 variables for the same time period as the ABM (1997:Q1-2010:Q1): log difference of real GDP, real consumption, real investment and the real wage, log hours worked, the log difference of the GDP deflator (six each for Austria and the EA), as well as the three-month Euribor.

As a benchmark model for the forecast performance of both the ABM and the DSGE model we use AR models. As above, we use the AIC and BIC to determine the optimal lag length for the AR models, for details see Tables C.3 and C.4 in the appendix. For the entire time period from 2010:Q1 to 2013:Q4 and for all variables, AR models of lag order one minimize both the AIC and BIC. Thus, as standard time series model for comparing the forecast performance of the ABM and DSGE models, we estimate AR(1) models on the log levels of real GDP, real household consumption, real investment, the log difference of the GDP deflator (inflation), and the Euribor. All models are initially estimated over the sample 1997:Q1 to 2010:Q1, and the models are then used to forecast the four time series from 2010:Q2 to 2016:Q4, with the models being re-estimated every quarter for the time periods 2010:Q2 to 2013:Q4. ABM results are obtained as an average over 500 Monte Carlo simulations and the DSGE model is estimated using Bayesian methods.[48]

[47] See the supplementary material for additional information on the DSGE model. We would like to thank Katrin Rabitsch for providing us with the improved version of the DSGE model in Breuss and Rabitsch (2009) for this manuscript.

[48] DSGE estimations are done with Dynare, see `http://www.dynare.org/` (Last accessed November 30^{th}, 2018). A sample of 250,000 draws

Table 9: Out-of-sample forecast performance in comparison to DSGE model

	GDP	Inflation	Household consumption	Investment	Euribor
AR(1)	*RMSE-statistic for different forecast horizons*				
1q	0.62	0.37	0.66	1.4	0.05
2q	0.89	0.36	0.93	2.21	0.1
4q	1.33	0.34	1.32	3.5	0.16
8q	1.48	0.37	1.57	4.34	0.21
12q	1.31	0.33	2	6.09	0.26
DSGE	*Percentage gains (+) or losses (-) relative to AR(1) model*				
1q	-5.7 (0.62)	5.3 (0.59)	7.9 (0.31)	22.1 (0.24)	-16 (0.06)
2q	-3.4 (0.80)	-20 (0.17)	7.2 (0.43)	31.4 (0.28)	-39.1 (0.01)
4q	15.1 (0.17)	-8.2 (0.00)	25.3 (0.13)	37.9 (0.26)	-70.2 (0.00)
8q	39 (0.08)	1.7 (0.43)	10.9 (0.32)	36.1 (0.16)	-132.2 (0.00)
12q	28.5 (0.00)	-4.3 (0.63)	7.1 (0.37)	50.8 (0.00)	-139.2 (0.00)
ABM	*Percentage gains (+) or losses (-) relative to AR(1) model*				
1q	-1.7 (0.02)	0 (0.96)	0.5 (0.94)	8.9 (0.13)	-235.7 (0.00)
2q	-1.8 (0.30)	-1.2 (0.29)	0.5 (0.96)	10.2 (0.20)	-90.3 (0.19)
4q	0.2 (0.93)	1.1 (0.14)	7.1 (0.62)	9.2 (0.28)	-15.9 (0.78)
8q	5.9 (0.13)	0.4 (0.78)	21.6 (0.04)	29.8 (0.00)	58 (0.00)
12q	4.6 (0.54)	-0.3 (0.10)	29.8 (0.00)	39.6 (0.00)	79.6 (0.00)

Note: All models are estimated starting in 1997:Q1. The forecast period is 2010:Q2 to 2016:Q4. All models are re-estimated each quarter. ABM results are obtained as an average over 500 Monte Carlo simulations. The values in brackets indicate the p-values of Diebold and Mariano (1995) tests, where we test whether the ABM and DSGE forecasts are significantly different in accuracy than the AR(1) forecasts (the null hypothesis of the test is that there is no difference between two competing forecasts).

Table 9 shows comparisons between the ABM, and the DSGE and AR(1) models for forecast horizons of 1, 2, 4, 8, and 12 quarters over the period 2010:Q2 to 2016:Q4. Regarding forecasts of GDP and inflation, the performance of the ABM and AR(1) models is relatively similar, which is also reflected in the p-values of the Diebold and Mariano (1995) tests. The DSGE model, which is applying more filtering than the other models, also shows a similar forecasting performance as the AR(1) for inflation and improves on the other models by forecasting GDP significantly better for longer horizons. Both the ABM and the DSGE model show their strengths in terms of forecasts of household consumption, and especially investment, as theory-driven economic models. Both these models explicitly incorporate the behavior of different agents in the economy, as well as constraints due to the consistency requirements of national accounting—for example, they take into consideration that household consumption and investment are major components of GDP. While the improvement for investment is clearly noticeable both for the ABM and for the DSGE model, whose sophisticated assumptions about agents' behavior seem to make the greatest difference for this variable, there is also quite a pronounced improvement for forecasts of household consumption by the ABM (significantly more accurate forecasts for 12q). For investment forecasts, both the ABM and the DSGE model clearly do better than the AR(1) model, especially for longer horizons, where both the DSGE and the ABM significantly outperform the AR(1) model at 8q and 12q (ABM) or at 12q (DSGE).[49]

was created (neglecting the first 50,000 draws).

[49] At this point we would like to comment on the limited performance of the DSGE model with regard to interest rate forecasts. This is mostly due to the time period we are focusing on, where policy rates set by the ECB and growth rates were especially downward trending. In particular, the Taylor rule of the DSGE model that targets the output gap seems to underestimate the output gap in the EA and thus does not accurately predict the downward trending policy rate. This corresponds to the fact, which is e.g. noted by Lindé et al. (2016), that DSGE models generally exhibit difficulties in explaining the depth of the Great Recession and the slow recovery thereafter. In contrast, in the ABM the policy rate is determined by a generalized Taylor rule targeting inflation and growth that does not seem to severely underestimate the fall in interest rates.

6.3. *Conditional forecasts*

As a further validation exercise, we test the conditional forecast performance of the different model classes (ABM, DSGE, and ARX models).[50] In this exercise, we generate forecasts from the three models conditional on the paths realized for the following three variables: real exports, real imports, and real government consumption (as government consumption is an exogenous shock in the DSGE model, conditional forecasts in the DSGE models are subject to exogenous paths for exports and imports). The exogenous predictors can be included in the ARX model and the ABM (conditional forecasts) in a straightforward way; for details, see Appendix A. Conditional forecasts in the DSGE model are achieved by controlling certain shocks to match the predetermined paths of the exogenous predictors. In particular, we control the consumption preference shocks for Austria and the EA, which are the major drivers for Austrian exports and imports in the two-country setting of the DSGE model; see the supplementary material on the DSGE model for details. Again, we use the period 1997:Q1-2010:Q1 to initially estimate our models. We then forecast real GDP, inflation, and nominal household consumption and investment from 2010:Q2 to 2016:Q4, with the models being re-estimated every quarter for the time periods 2010:Q2 to 2013:Q4. Thus, together with the real exports, real imports, and real government consumption, we account for all main components of GDP.[51]

Table 10: Conditional forecast performance

	GDP	Inflation	Household consumption	Investment
ARX(1)	*RMSE-statistic for different forecast horizons*			
1q	0.34	0.38	0.58	1.11
2q	0.37	0.34	0.75	1.49
4q	0.41	0.35	0.96	1.25
8q	0.53	0.35	1.22	1.07
12q	0.58	0.41	1.43	1.35
DSGE	*Percentage gains (+) or losses (-) relative to ARX(1) model*			
1q	-60.7 (0.05)	1.4 (0.91)	-200.3 (0.08)	-1.1 (0.96)
2q	-105.8 (0.00)	-17.1 (0.28)	-196.7 (0.09)	-3.5 (0.90)
4q	-105.4 (0.00)	-12.4 (0.59)	-242.2 (0.12)	-86.2 (0.00)
8q	-144.4 (0.12)	-7.7 (0.56)	-287.6 (0.00)	-117.5 (0.00)
12q	-160.2 (0.00)	-33.9 (0.00)	-354 (0.00)	-71.9 (0.00)
ABM	*Percentage gains (+) or losses (-) relative to ARX(1) model*			
1q	3.3 (0.12)	-0.9 (0.21)	-22.1 (0.19)	-1.8 (0.94)
2q	-0.9 (0.90)	-1.1 (0.34)	-8.4 (0.62)	-11.8 (0.74)
4q	-23.1 (0.51)	0.8 (0.51)	-12.8 (0.55)	-107.1 (0.10)
8q	-1 (0.94)	-1 (0.00)	18.8 (0.05)	-142.3 (0.03)
12q	18.5 (0.00)	-1.6 (0.00)	6.6 (0.33)	-120.5 (0.06)

Note: All models are estimated starting in 1997:Q1. The forecast period is 2010:Q2 to 2016:Q4. All models are re-estimated each quarter. ABM results are obtained as an average over 500 Monte Carlo simulations. The values in brackets indicate the *p*-values of Diebold and Mariano (1995) tests, where we test whether the ABM conditional forecasts and DSGE conditional forecasts are significantly different in accuracy than the ARX(1) forecasts (the null hypothesis of the test is that there is no difference between two competing forecasts).

Table 10 shows that the forecast performance of the ABM and AR models improves pronouncedly for GDP and household consumption and investment when exogenous predictors are included. Again, the performance of the ABM (conditional forecasts) and ARX(1) model is relatively similar for GDP and inflation. However, compared to the unconditional case, the ABM as a theory-driven model seemingly does better in forecasting GDP at longer horizons,

[50] Again, we use the AIC and BIC to determine the optimal lag length for the ARX models, for details see Tables C.5 and C.6 in the appendix. As above, for the entire time period from 2010:Q1 to 2013:Q4 and for all variables, models of lag order one minimize both the AIC and BIC.

[51] Another note on interest rate forecasts: since interest rates are determined exogenously for the Austrian economy (which makes up only 3 percent of total GDP of the EA) and are assumed to remain constant in the conditional forecasting setup, we do not report on Euribor forecasts here. For readers interested in the interest rate forecast performance of the two-country DSGE model in the conditional forecasting setup, please refer to the supplementary material on the DSGE model.

where it delivers a forecast performance significantly better than the ARX(1) model. The forecast performance of the DSGE model (conditional forecasts) clearly deteriorates for all variables and horizons as compared to unconditional forecasting. This is due to methodological reasons, that is, the need to control exogenous shocks such that the exogenous paths of the predictors are matched in the DSGE model. This clearly has the most pronounced implications for the forecast of household consumption in the DSGE model, where forecast errors increase to a large extent when compared to the ARX(1) model.

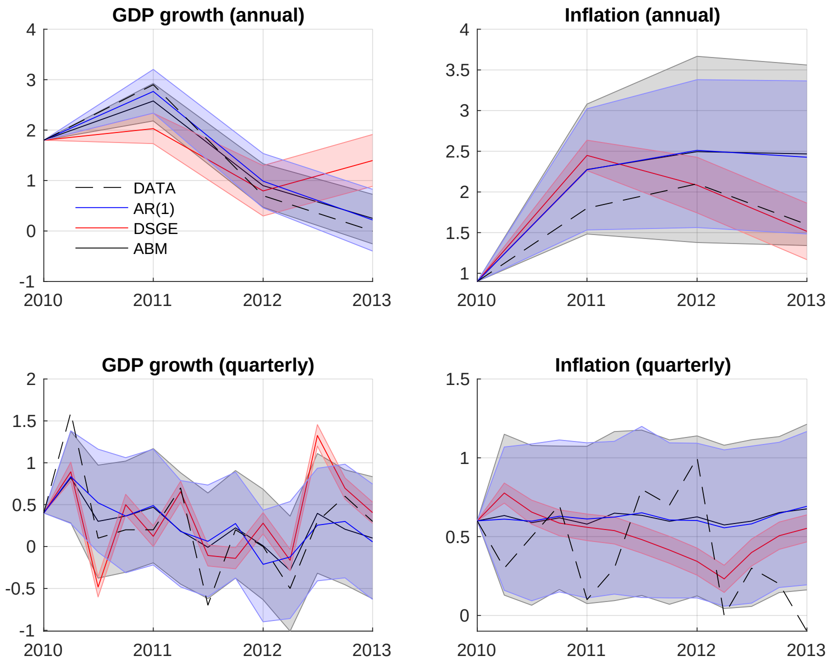

Figure 1: Forecast performance from 2011:Q1-2013:Q4. ABM conditional forecasts (black line), DSGE conditional forecasts (red line), ARX(1) forecasts (blue line) and observed Eurostat data for Austria (dashed line). Top figures show growth and inflation on an annualized basis; bottom figures depict quarterly growth and inflation rates. A 90 percent confidence interval is plotted around the mean trajectory. Model results are obtained as an average over 500 Monte Carlo simulations.

Figures 1, 2 and 3 provide a graphical comparison between conditional forecasts with the ABM and results from an ARX(1) model, and between conditional forecasts with the DSGE model and actual time series data reported by Eurostat. Figure 1 shows aggregate GDP growth and inflation (measured by GDP deflator) rates—annually (top) and quarterly (bottom). One can see at first glance that the ABM tracks the data very well for GDP growth (left panels). For annualized (top left) and quarterly (bottom left) model results, almost all data points are within the 90 percent confidence interval (gray shaded area)—except for two outliers (2011:Q1,2012:Q2), where the Austrian growth rate either picked up quite sharply (2011:Q1) or decreased considerably, despite an upward trend before (2012:Q2). It is especially interesting to note how the ABM catches trends in the data somewhat better than the ARX(1) model. In particular, the ABM reacts directly to a fall in exports in 2013:Q1 (see Figure 3)—which reflects a slowdown in economic growth for some of Austria's European trading partners during the European debt crisis—that drags down GDP growth in the ABM. In contrast to this, the ARX(1) model simply extrapolates the past trend into the future. Similar to the ABM, the DSGE in a conditional forecasting setup seems to catch upward and downward trends in the data quite well, but tends to "overreact" by taking the trend too far. This certainly deteriorates the forecast performance of the DSGE, and is most probably connected to the way in which controlling the shocks for the conditional forecasting procedure influences the mechanics of the DSGE model.

A similar picture arises when the conditional forecasts for the main macroeconomic aggregates in levels (GDP, household consumption, investment) of the ABM are compared to the other models; see Figures 2 (annual) and 3 (quarterly). Looking at GDP at annual levels (top left in Figure 2) and quarterly levels (top left in Figure 3), it is evident that the ABM closely follows the data, as do the growth rates in Figure 1, and that all data points, except

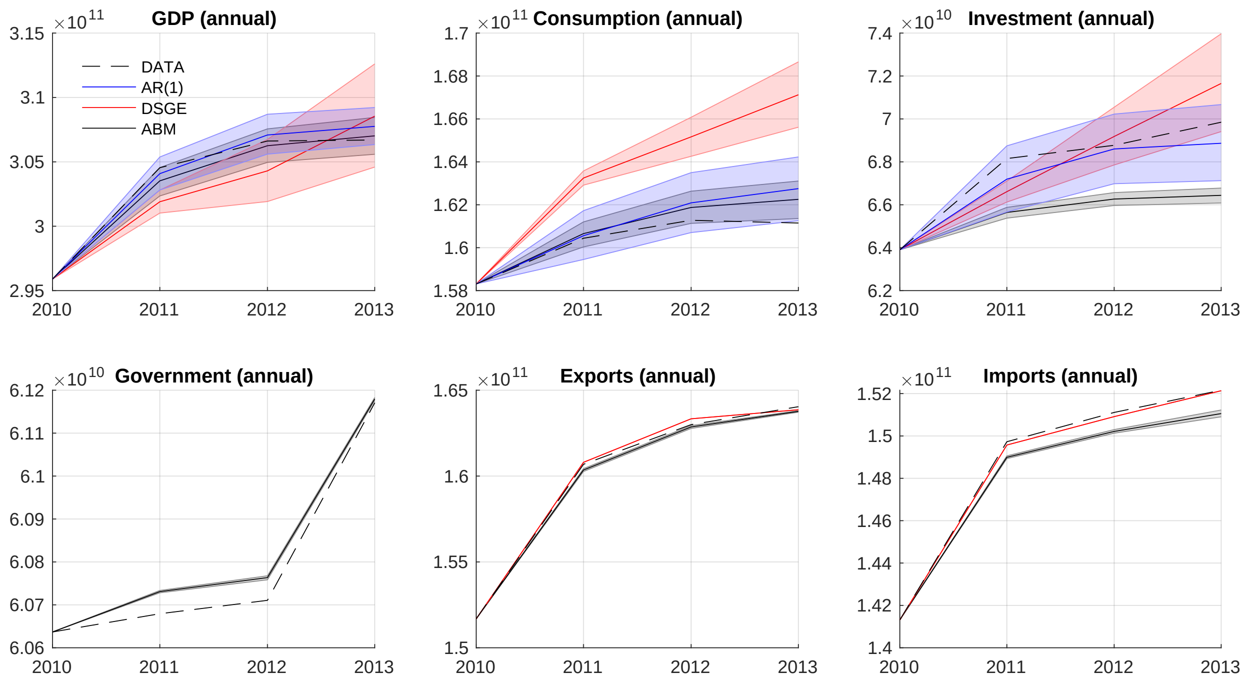

Figure 2: Forecast performance from 2011:Q1-2013:Q4. GDP (annually, in euro and in real terms with base year 2010), household consumption (annually, in euro and in real terms with base year 2010), fixed investment (annually, in euro and in real terms with base year 2010), government consumption (annually, in euro and in real terms with base year 2010), exports (annually, in euro and in real terms with base year 2010), and imports (annually, in euro and in real terms with base year 2010). ABM conditional forecasts (black line), DSGE conditional forecasts (red line), ARX(1) forecasts (blue line), and observed Eurostat data for Austria (dashed line). A 90 percent confidence interval is plotted around the mean trajectory. Model results are obtained as an average over 500 Monte Carlo simulations.

for the two outliers referred to above, are within the confidence interval. The ARX(1) model delivers a comparable forecasting performance, but smooths the trends more than the ABM does. The DSGE model at first consistently underestimates both annual and quarterly GDP levels, and then overestimates the upward trend starting in 2013:Q2. Again, the influence on quarterly GDP of the drop in exports in 2013:Q1, due to overall economic developments in Europe during the European debt crisis (Figure 3, bottom middle panel), remains visible, and the ABM captures this trend quite well. Both the ABM and the ARX(1) model seem to smooth out the changes in household consumption to approximately match the average trend, with the ABM being somewhat closer to the data. Again, the DSGE model seems to follow the trends in the data quite accurately, but consistently overestimates the level, which might be responsible for the overall poor forecasting performance of the DSGE model for household consumption. As to be expected, the volatility of investment in the data is the highest of all these variables. The ARX(1) smoothes this volatility out on average, and is thus very successful in tracking both annual and quarterly investment data (Figures 2 and 3, top right). The DSGE model, while catching the initial trend in the data, overshoots in its forecast at the end, whereas the ABM consistently underestimates investment levels.

6.4. Sectoral decomposition

The previous sections have demonstrated that the size and detailed structure of the ABM tend to improve its forecasting performance of macroeconomic aggregates compared to standard models. Another important advantage of our approach is that the detailed structure of the ABM allows macroeconomic forecasts to be disaggregated with varying levels of detail, offering insights into the composition of overall macroeconomic trends. Thus, as a last validation exercise, we test the sectoral out-of-sample forecast performance of the ABM. In this exercise we decompose ABM forecasts from Sections 6.1 and 6.2 for different sectors by economic activities. Specifically, sectoral gross value added (GVA) is disaggregated for 10 economic activities (NACE*10) according to the statistical classification of economic activities in the European Community (NACE Rev. 2), see Table 5 in the appendix for details. As a benchmark

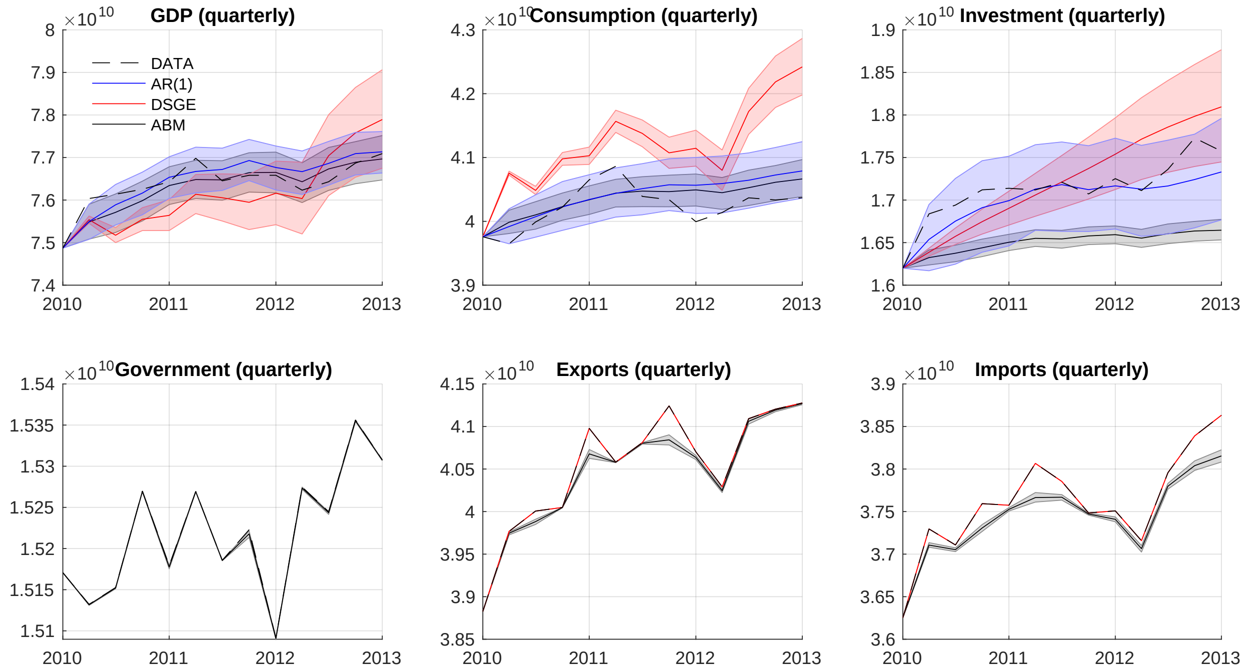

Figure 3: Forecast performance from 2011:Q1-2013:Q4. GDP (quarterly, in euro and in real terms with base year 2010), household consumption (quarterly, in euro and in real terms with base year 2010), fixed investment (quarterly, in euro and in real terms with base year 2010), government consumption (quarterly, in euro and in real terms with base year 2010), exports (quarterly, in euro and in real terms with base year 2010), and imports (quarterly, in euro and in real terms with base year 2010). ABM conditional forecasts (black line), DSGE conditional forecasts (red line), ARX(1) forecasts (blue line), and observed Eurostat data for Austria (dashed line). A 90 percent confidence interval is plotted around the mean trajectory. Model results are obtained as an average over 500 Monte Carlo simulations.

we again use AR models estimated on the log difference of sectoral GVA, where we determine the optimal lag length with the AIC and BIC, for details see Tables C.7 and C.8 in the appendix. For the entire time period from 2010:Q1 to 2013:Q4 and for all variables, models of lag order one minimize both the AIC and BIC. All models are initially estimated over the sample 1997:Q1 to 2010:Q1, and the models are then used to forecast the four time series from 2010:Q2 to 2016:Q4, with the models being re-estimated every quarter for the time periods 2010:Q2 to 2013:Q4. ABM results are obtained as an average over 500 Monte Carlo simulations.

Table 11 shows the sectorally disaggregated forecast performance of the ABM in comparison to sectoral AR(1) models. At first glance, it becomes apparent that the ABM improves in its forecast performance for longer time horizons, where the Diebold and Mariano (1995) tests indicate significantly improved forecast accuracy for several larger sectors (F, G, H, I, J, K; to some extent also B, C, D and E). Results have confirmed our intuition that ABM forecasts would tend to perform better for larger sectors and for sectors that are closer connected to real economic activity in Austria. The ABM performs best in forecasting for sectors that are not so much subject to other factors such as exports, imports, or policy decisions, which are all exogenous to our model. Particular, but non-exhaustive examples, for such sectors driven by exogenous factors are: (1) the agricultural sector (A), which is to a large extent dominated by the subsidy policies of the Austrian government and the EU, (2) the real estate sector (L), which reflects how rents are imputed for national accounting data, or (3) activities of head offices (M), which might reflect changes in ownership structures of large companies (holdings) more than real economic developments in Austria.

Finally, we decompose ABM forecasts from Sections 6.1 and 6.2 into 64 economic activities (NACE*64) according to the statistical classification of economic activities in the European Community (NACE Rev. 2), see table 4 in the appendix for details. This level of disaggregation represents the most detailed decomposition for which main aggregates for Austria (but only as annual time series, which are published with a considerable lag of about 5 years), are available. Therefore, for these highly disaggregated forecasts, we are restricted to a graphical analysis of the forecast performance. Thus, in Figure 4 we show ABM forecasts for GVA disaggregrated by 64 economic activities

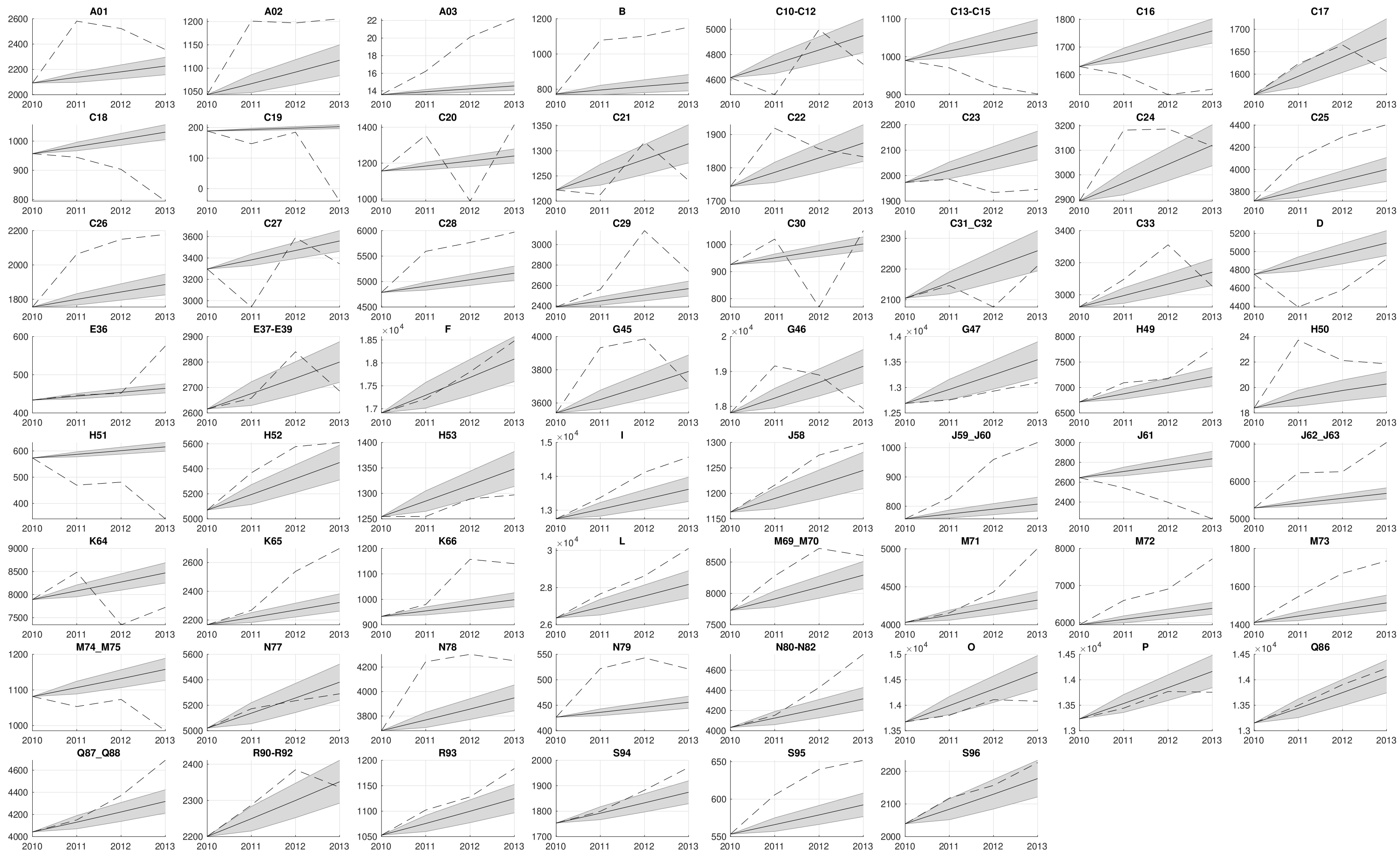

Figure 4: Comparison of sectoral gross value added (GVA) for model simulations and observed data of Austria. GVA generated by one representative time period (500 Monte Carlo simulations) is shown by a solid line (a 90 percent confidence interval is plotted around the mean trajectory), and observed GVA in Austria from 2010 to 2013 is indicated by a dashed line. GVA is disaggregated for 64 economic activities/products (NACE*64, CPA*64) according to the statistical classification of economic activities in the European Community (NACE Rev. 2).

Table 11: Out-of-sample forecast performance of sectoral gross value added (GVA)

	A	B, C, D and E	F	G, H and I	J	K	L	M and N	O, P and Q	R and S
AR(1)	*RMSE-statistic for different forecast horizons*									
1q	10.97	1.29	1.39	0.98	2.37	3.95	0.37	1.68	0.55	0.34
2q	14.29	1.75	1.81	1.48	2.93	4.94	0.61	1.94	0.71	0.58
4q	14.13	2.62	2.74	2.46	4.77	6.79	1	2.28	1.01	0.99
8q	12.95	3.46	4.33	3.69	7.03	8.12	1.45	2.81	1.63	1.75
12q	9.6	3.5	6.62	3.47	10.01	11.57	1.98	2.77	2.06	2.63
ABM	*Percentage gains (+) or losses (-) relative to AR(1) model*									
1q	0 (1.00)	4.5 (0.41)	5.2 (0.55)	-6.9 (0.15)	4.4 (0.17)	0.8 (0.92)	-65.8 (0.00)	-6 (0.52)	10 (0.31)	-1.5 (0.92)
2q	-5.6 (0.65)	12.7 (0.22)	15.8 (0.11)	-3.9 (0.67)	13 (0.06)	2 (0.90)	-95.5 (0.00)	-16.2 (0.30)	20.7 (0.12)	6.9 (0.83)
4q	-10.2 (0.44)	19.8 (0.26)	34.5 (0.00)	2.2 (0.88)	17.9 (0.00)	14.2 (0.52)	-132.2 (0.00)	-40.1 (0.23)	29.8 (0.20)	19.2 (0.60)
8q	-10.5 (0.76)	31.3 (0.24)	64.7 (0.00)	13.9 (0.13)	32.2 (0.00)	41.9 (0.09)	-194.2 (0.00)	-68.3 (0.02)	3.9 (0.92)	25.5 (0.45)
12q	-79.3 (0.00)	41.8 (0.07)	65.7 (0.00)	26.2 (0.00)	37.5 (0.00)	53.7 (0.00)	-215.4 (0.00)	-116.3 (0.00)	-20.9 (0.59)	42 (0.00)

Note: GVA is shown for the sectors Agriculture, forestry and fishing (A); Industry (except construction) (B, C, D and E); Manufacturing (C); Construction (F); Wholesale and retail trade, transport, accommodation and food service activities (G, H and I); Information and communication (J); Financial and insurance activities (K); Real estate activities (L); Professional, scientific and technical activities, as well as administrative and support service activities (M and N); Public administration, defence, education, human health and social work activities (O, P and Q); Arts, entertainment, and recreation, as well as other service activities (R and S). All models are estimated starting in 1997:Q1. The forecast period is 2010:Q2 to 2016:Q4. All models are re-estimated each quarter. ABM results are obtained as an average over 500 Monte Carlo simulations. The values in brackets indicate the p-values of Diebold and Mariano (1995) tests, where we test whether the ABM forecasts are significantly different in accuracy than the AR(1) forecasts (the null hypothesis of the test is that there is no difference between two competing forecasts).

in comparison to observed sectoral GVA in Austria from 2010 to 2013.[52] The projections of the ABM capture the trends in larger sectors particularly well. Most notably, trends in major sectors such as construction and construction works (F), retail trade (G47), accommodation and food services (I), or land transport services (H49) are matched by the ABM in close relation to the data. These sectors tend to follow overall trends in GDP to a large degree, which is one explanation for the good forecasting performance of the ABM for these sectors.

Some of the more pronounced differences are due to sector-specific features such as sizeable export-induced exogenous shocks or an unusually low number of firms in the sector, which can cause sectors to deviate from aggregate macroeconomic trends. This is particularly true for smaller sectors, where deviations of ABM forecasts are higher in relative terms. Examples of such sectors are products of agriculture, hunting and related services (A01), mining and quarrying (B), air transport services (H51), motion picture, video, and television program services (J59), and telecommunication services (J61), among others. For manufacturing sectors, which are potentially influenced more by trends exogenous to the ABM, such as the structure of Austrian exports, the forecasts are within an acceptable range, which is often also the case for larger sectors. Indicative examples for such sectors are wood and products of wood (C16), fabricated metal products (C25), and machinery and equipment (C28).

6.5. Components of GDP

In the previous sections we have shown that the detailed structure of the ABM does not only improve its forecasting performance compared to standard models for macroewconomic aggegates, but also allows macroeconomic forecasts to be broken down with varying levels of detail. Another important advantage of our approach is that forecasts are decomposed in a stock-flow consistent way according to the rules and conventions of national accounting (ESA). In particular, we are able to forecast *all* economic activities depicted in the model consistent with national accounting rules and relate them to the main macroeconomic aggregates. Most importantly, for all forecasts, our model preserves the principle of double-entry bookkeeping. This implies that all financial flows within the model are made explicit and are recorded as an outflow of money (use of funds) for one agent in the model in relation to a certain economic activity, and as an inflow of money (source of funds) for another agent. In principle, we can thus consistently report on the economic activity of every single agent at the micro-level. A more informative aggregation is on a meso-level according to the NACE/CPA classification into 64 industries, which encompasses many variables. This multitude of results consists of all components of GDP on a sectoral level: among others, wages, operating surplus, investment,

[52]Note the varying scales for the sectors of different sizes.

taxes and subsidies of different kinds, intermediate inputs, exports, imports, final consumption of different agents (household, government), employment, and also economic indicators such as productivity coefficients for capital, labor, and intermediate inputs.

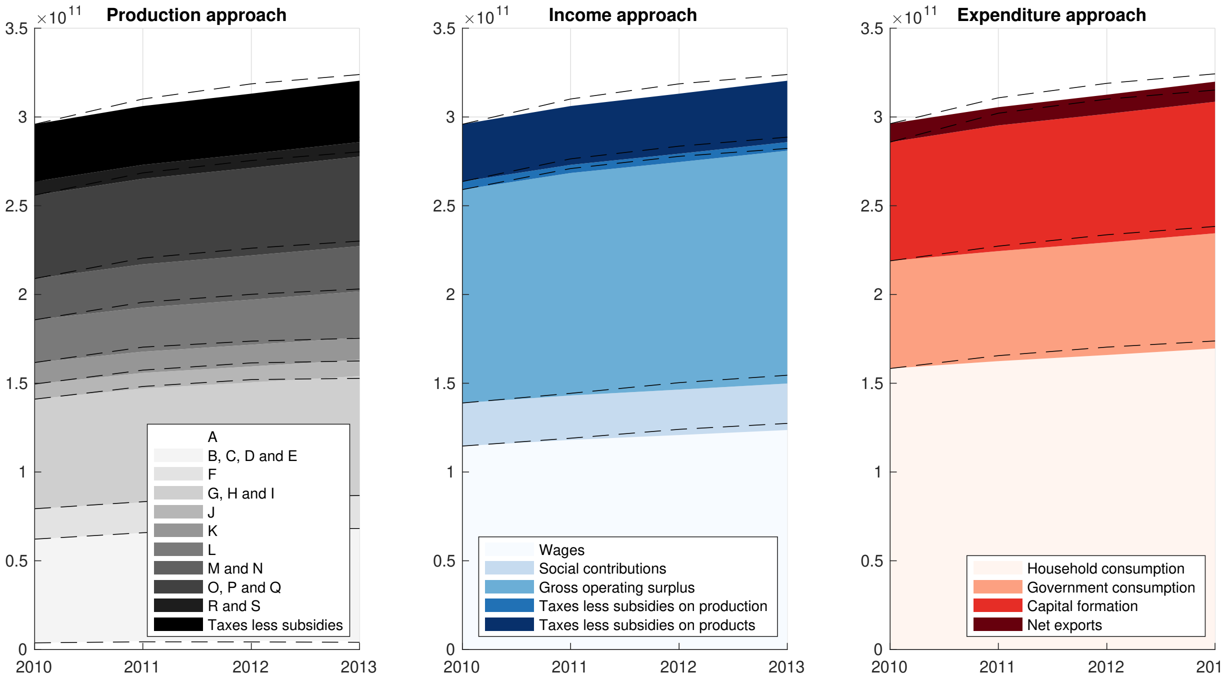

Figure 5: Composition of GDP according to production, income and expenditure approaches. The colored areas indicate ABM simulation results for one selected time period (2011:Q1-2013:Q4), again as an average over 500 Monte Carlo simulations. The dashed line shows the corresponding values obtained from the data.

Probably the simplest example indicative of this model structure is that it breaks down simulation results into the larger components of GDP according to the different approaches for determining GDP. Figure 5 is a graphical representation of ABM out-of-sample forecasts from Section 6.4. The components are shown according to the production, income, and expenditure approaches to determine GDP, which are defined within the framework of our model along ESA lines, as laid out in Appendix B. With the fine-grained detail incorporated into our model, we can demonstrate how the development of macroeconomic aggregates such as GDP relates to trends in different industry sectors (production approach), the distribution of national income (income approach), and the composition of final uses in the economy (expenditure approach). Here, the colored fields indicate ABM simulation results for the different components of GDP, while the dashed line refers to the values reported in the data. Our results show that ABM forecasts of these components of GDP, where the ABM does not predict major structural changes for the Austrian economy, correspond closely to the developments in the data.

7. Conclusion

We have developed an ABM of a small open economy that fits micro and macro data from national accounts, sector accounts, input-output tables, government statistics, census data, and business demography data. Although the model is very detailed, it is the first ABM that can compete with standard VAR, AR, and DSGE models in out-of-sample forecasting. An advantage of our detailed ABM is that it allows for a breakdown of the forecasts of aggregate variables in a stock-flow consistent manner to generate forecasts of disaggregated sectoral variables and the main components of GDP.

At this point, we would like to stress again that the purpose of this study was not to show whether an ABM at such a high resolution as ours can forecast better or worse than an AR or DSGE model for a particular variable or time horizon. Much more, we believe that the benchmarking and validation procedure for an ABM as presented here is a first major and necessary step to turn ABMs into a mature forecasting and policy evaluation tool.

The ABM is tailor-made for the small open economy of Austria, but the model can easily be adapted to other economies of larger countries such as the UK and the US or to larger regions such as the EU. Additionally, it would be interesting to estimate it also to other time periods than the ones presented here, e.g. for the run-up to the financial crisis 2007-2008, and to find out whether parameter values and forecasts change significantly for other time periods.[53] Our model can be used for stress-testing exercises or for predicting the effect of changes in monetary, fiscal, and other macroeconomic policies. Such extensions and applications are currently being explored.

In a recent application, our model has been used to forecast the medium-run macroeconomic effects of different scenarios for lockdown measures taken in Austria to combat the COVID-19 crisis (Poledna et al., 2020). The dynamical properties and the detailed structure of our model enabled us to assess the overall macroeconomic impact including labour market effects of the COVID-19 crisis, to make detailed projections on sectoral impacts, and to give a realistic outlook on the timing and shape of economic recovery thereafter.

A grand challenge and long-term objective for future work would be a "big data ABM" research program to develop ABMs for larger economies and regions based on available micro and macro data to eventually monitor the macro economy in real time on supercomputers. Such detailed "big data ABMs" have the potential for improved macro forecasting and more reliable policy scenario analysis, and could revolutionize the way we monitor and forecast economic activity.

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[53]For this study, we were restricted by the data availability as discussed above. Most notably for our present analysis, the sectoral definitions for input-output tables were changed between the years 2009 and 2010.

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Appendix A. Conditional forecasts with the agent-based model

We generate forecasts conditional on exogenous paths for imports, exports and government consumption, corresponding to a small open economy setting and exogenous policy decisions. In this setup, we assume that imports and exports, as well as government consumption, are exogenously given from data. Thus, in this setup we replace equations (77), (81), and (51) and set imports, exports and government consumption according to observed data.

Furthermore, in this setup we assume that agents' forecasts take into account expectations on imports, exports and government consumption. Thus, we replace equations (6) and (9), and assume expectations on economic growth and inflation to be formed using an autoregressive model with exogenous predictors and lag order one (ARX(1)). Thus, in this setup expectations on economic growth are formed according to an ARX(1) rule:

$$\log(Y^{\mathrm{e}}(t)) = \alpha^{\mathrm{Y}}(t)\log\left(\sum_i Y_i(t-1)\right) + \gamma^{\mathrm{I}}(t)\log(Y^{\mathrm{I}}(t)) + \gamma^{\mathrm{G}}(t)\log(C^{\mathrm{G}}(t)) + \gamma^{\mathrm{E}}(t)\log(C^{\mathrm{E}}(t)) + \beta^{\mathrm{Y}}(t) + \epsilon^{\mathrm{Y}}(t)\,, \quad \text{(A.1)}$$

where $\alpha^{\mathrm{Y}}(t)$, $\gamma^{\mathrm{I}}(t)$, $\gamma^{\mathrm{E}}(t)$, $\gamma^{\mathrm{G}}(t)$, $\beta^{\mathrm{Y}}(t)$, and $\epsilon^{\mathrm{Y}}(t)$ are re-estimated every period on the time series of aggregate output of firms $\sum_i Y_i(t')$ and the exogenous predictors imports $Y^{\mathrm{I}}(t')$, exports $C^{\mathrm{E}}(t')$ as well as government consumption $C^{\mathrm{G}}(t')$, where $t' = -T', -T'+1, -T'+2, \ldots, 0, 1, 2, \ldots, t-1$. To allow the data to decide on the degree of persistence and cointegration, output, imports and exports as well as government consumption are entered in log levels.

Similarly, in this setup expectations on inflation are formed using an autoregressive model with exogenous predictors and lag order one (ARX(1)):

$$\log(1+\pi^{\mathrm{e}}(t)) = \alpha^{\pi}(t)\pi(t-1) + \gamma^{\mathrm{I}}(t)\log(Y^{\mathrm{I}}(t)) + \gamma^{\mathrm{G}}(t)\log(C^{\mathrm{G}}(t)) + \gamma^{\mathrm{E}}(t)\log(C^{\mathrm{E}}(t)) + \beta^{\pi}(t) + \epsilon^{\pi}(t)\,, \quad \text{(A.2)}$$

where $\alpha^{\pi}(t)$, $\gamma^{\mathrm{I}}(t)$, $\gamma^{\mathrm{E}}(t)$, $\gamma^{\mathrm{G}}(t)$, $\beta^{\pi}(t)$, and $\epsilon^{\pi}(t)$ are re-estimated every period on the time series of inflation $\pi(t')$, and the exogenous predictors are imports $Y^{\mathrm{I}}(t')$, exports $C^{\mathrm{E}}(t')$ and government consumption $C^{\mathrm{G}}(t')$, where $t' = -T', -T'+1, -T'+2, \ldots, 0, 1, 2, \ldots, t-1$. Again, imports and exports as well as government consumption are entered in log levels.

Appendix B. Macroeconomic variables

Appendix B.1. Gross domestic product

GDP in our model can be defined by the production, expenditure and income approaches:

$$
\begin{aligned}
GDP(t) = & \underbrace{\sum_i \tau_i^{\mathrm{Y}} P_i(t) Y_i(t) + \sum_h \tau^{\mathrm{VAT}} C_h(t) + \sum_h \tau^{\mathrm{CF}} I_h(t) + \sum_j \tau^{\mathrm{G}} C_j(t) + \sum_l \tau^{\mathrm{EXPORT}} C_l(t)}_{\text{Taxes on products}} \\
& + \underbrace{\sum_i (1-\tau_i^{\mathrm{Y}}) P_i(t) Y_i(t)}_{\text{Total sales of goods and services}} - \underbrace{\sum_{g,s,i\in I_s} \bar{P}_g(t) a_{sg} \frac{Y_i(t)}{\beta_i}}_{\text{Intermediate inputs}} \quad \text{(Production approach)} \\
= & \underbrace{\sum_h (1+\tau^{\mathrm{VAT}}) C_h(t)}_{\text{Household consumption}} + \underbrace{\sum_j (1+\tau^{\mathrm{G}}) C_j(t)}_{\text{Government consumption}} + \underbrace{\sum_h (1+\tau^{\mathrm{CF}}) I_h(t) + \sum_i \bar{P}^{\mathrm{CF}}(t) I_i(t)}_{\text{Gross fixed capital formation}} \\
& + \underbrace{\sum_i P_i(t) \Delta S_i(t) + \sum_{g,s,i\in I_s} \bar{P}_g(t) \left(\Delta M_{ig}(t) - a_{sg} \frac{Y_i(t)}{\beta_i} \right)}_{\text{Changes in inventories}} \\
& + \underbrace{\sum_l (1+\tau^{\mathrm{EXPORT}}) C_l(t)}_{\text{Exports}} - \underbrace{\sum_m P_m(t) Q_m(t))}_{\text{Imports}} \quad \text{(Expenditure approach)} \\
= & \underbrace{\sum_i \tau_i^{\mathrm{Y}} P_i(t) Y_i(t) + \sum_h \tau^{\mathrm{VAT}} C_h(t) + \sum_h \tau^{\mathrm{CF}} I_h(t) + \sum_j \tau^{\mathrm{G}} C_j(t) + \sum_l \tau^{\mathrm{EXPORT}} C_l(t)}_{\text{Taxes on products}} + \underbrace{(1+\tau^{\mathrm{SIF}}) \bar{P}^{\mathrm{HH}}(t) \sum_h w_h(t)}_{\text{Compensation of employees}} \\
& + \underbrace{\sum_i \left(\Pi_i(t) + r(t) L_i(t) + \bar{P}^{\mathrm{CF}}(t) \frac{\delta_i}{\kappa_i} Y_i(t) \right)}_{\text{Gross operating surplus and mixed income}} + \underbrace{\sum_i \tau_i^{\mathrm{K}} P_i(t) Y_i(t)}_{\text{Net taxes on production}} \quad \text{(Income approach)}
\end{aligned}
$$

Appendix B.2. Inflation

Inflation, which is measured by the GVA deflator, is the economy-wide average price of all goods and services produced and sold:

$$
GVA\ deflator(t) = \frac{\sum_i (1-\tau_i^{\mathrm{Y}}) P_i(t) Y_i(t) - \sum_{g,s,i\in I_s} \bar{P}_g(t) a_{sg} \frac{Y_i(t)}{\beta_i}}{\sum_i (1-\tau_i^{\mathrm{Y}}) Y_i(t) - \sum_{g,s,i\in I_s} a_{sg} \frac{Y_i(t)}{\beta_i}}
$$

where $P_i(t)$ and $Y_i(t)$ are price and production of firm i, respectively.

Appendix B.3. Household Consumption

Household consumption is the sum of the realized consumption of all individual households, i.e. $\sum_h (1+\tau^{\mathrm{VAT}}) C_h(t)$.

Appendix B.4. Investment

Total fixed investment in the model is the sum of realized investment by individual firms plus the sum of realized investment by individual households, that is, $\sum_h (1+\tau^{\mathrm{CF}}) I_h(t) + \sum_i \bar{P}^{\mathrm{CF}}(t) I_i(t)$.

Appendix B.5. Government Consumption

Government consumption is the sum of the realized consumption of all government entities, i.e. $\sum_{h=1}^{\mathrm{H}} C_h(t)$.

Appendix B.6. Exports

Export is the sum of the realized consumption of all foreign consumers, i.e. $\sum_l (1+\tau^{\mathrm{EXPORT}}) C_l(t)$.

Appendix B.7. Imports

Import is defined as the total sales of all goods and services produces by foreign firms, i.e. $\sum_m P_m(t) Q_m(t))$.

Appendix C. Forecast performance

Table C.1: Optimized log-likelihood of VAR models of different lag orders

Order of the VAR	Log-likelihood
VAR(1)	1844.24
VAR(2)	1832.44
VAR(3)	1821.22

Note: All models are estimated using the period 1997:Q1 to 2010:Q4.

Table C.2: Out-of-sample forecast performance of VAR models of different lag orders

	GDP	Inflation	Government consumption	Exports	Imports	GDP EA	Inflation EA	Euribor
VAR(1)	*RMSE-statistic for different forecast horizons*							
1q	0.66	0.39	0.98	1.88	2.16	0.58	0.15	0.09
2q	0.89	0.38	1.35	2.35	2.82	0.89	0.13	0.15
4q	1.29	0.36	2.05	2.67	3.02	1.49	0.17	0.24
8q	1.55	0.36	3.13	3.22	3.22	2.77	0.21	0.26
12q	1.99	0.42	3.5	5.7	4.66	4.05	0.27	0.2
VAR(2)	*Percentage gains (+) or losses (-) relative to VAR(1) model*							
1q	13.5 (0.15)	-22.4 (0.17)	6.1 (0.65)	2.9 (0.87)	17.9 (0.07)	12.5 (0.21)	-14.3 (0.39)	23.3 (0.09)
2q	4.5 (0.68)	-19.6 (0.21)	13.9 (0.41)	-17.2 (0.26)	9.5 (0.46)	-8.2 (0.61)	-26 (0.35)	11.3 (0.27)
4q	-18.7 (0.39)	-8.9 (0.00)	1.9 (0.81)	-32.8 (0.19)	-19.8 (0.29)	-31.7 (0.24)	-24.7 (0.01)	-4.1 (0.51)
8q	-73.1 (0.09)	1 (0.83)	-21.1 (0.00)	-80.3 (0.09)	-63.7 (0.09)	-37.5 (0.12)	1.3 (0.91)	-52.8 (0.06)
12q	-63.9 (0.02)	-15 (0.00)	-42.9 (0.00)	-38.9 (0.01)	-40.7 (0.00)	-20.7 (0.02)	-9.5 (0.00)	-76.9 (0.00)
VAR(3)	*Percentage gains (+) or losses (-) relative to VAR(1) model*							
1q	-24.7 (0.38)	-50.3 (0.01)	-17.2 (0.35)	-7 (0.71)	3.9 (0.64)	-29.3 (0.21)	-27.6 (0.22)	23.4 (0.21)
2q	-57.2 (0.17)	-37.6 (0.04)	-8.6 (0.62)	-62.8 (0.01)	-19.1 (0.38)	-46 (0.20)	-58.5 (0.17)	7.9 (0.58)
4q	-92.2 (0.17)	-11.8 (0.10)	-17 (0.07)	-135.2 (0.11)	-87.6 (0.18)	-81.3 (0.15)	-58.1 (0.00)	-34.3 (0.10)
8q	-128.5 (0.04)	-19.3 (0.08)	-57.5 (0.00)	-136.2 (0.00)	-103.1 (0.00)	-68.8 (0.00)	-25.8 (0.12)	-100.1 (0.11)
12q	-92.2 (0.00)	-41.3 (0.00)	-100.6 (0.00)	-76.1 (0.00)	-72.9 (0.00)	-53 (0.00)	-49.7 (0.00)	-94.4 (0.01)

Note: All models are estimated starting in 1997:Q1. The forecast period is 2010:Q2 to 2016:Q4. All models are re-estimated each quarter. The values in brackets indicate the *p*-values of Diebold and Mariano (1995) tests, where we test whether the VAR forecasts are significantly different in accuracy than the VAR(1) forecasts (the null hypothesis of the test is that there is no difference between two competing forecasts).

Table C.3: Optimized log-likelihood of AR models of different lag orders

Order of the AR	GDP	Inflation	Household consumption	Investment	Euribor
AR(1)	207.53	229.98	213.65	139.15	310.56
AR(2)	202.02	222.87	206.18	133.25	305.01
AR(3)	190.32	214.86	194.98	124.77	287.13

Note: All models are estimated using the period 1997:Q1 to 2010:Q4.

Table C.4: Out-of-sample forecast performance of AR models of different lag order

	GDP	Inflation	Household consumption	Investment	Euribor
AR(1)	*RMSE-statistic for different forecast horizons*				
1q	0.62	0.37	0.66	1.4	0.05
2q	0.89	0.36	0.93	2.21	0.1
4q	1.33	0.34	1.32	3.5	0.16
8q	1.48	0.37	1.57	4.34	0.21
12q	1.31	0.33	2	6.09	0.26
AR(2)	*Percentage gains (+) or losses (-) relative to AR(1) model*				
1q	-15.8 (0.29)	0.4 (0.81)	-1.1 (0.74)	-3.4 (0.32)	0.6 (0.96)
2q	-16.1 (0.29)	2.1 (0.29)	-0.5 (0.90)	0 (1.00)	-24.8 (0.14)
4q	-11.4 (0.26)	0.3 (0.49)	1.1 (0.63)	2.2 (0.45)	-69 (0.00)
8q	-19.7 (0.20)	-0.2 (0.00)	-3.2 (0.10)	7.2 (0.00)	-151.6 (0.00)
12q	-29.9 (0.02)	-0.1 (0.33)	-3.5 (0.00)	7.8 (0.01)	-151.9 (0.00)
AR(3)	*Percentage gains (+) or losses (-) relative to AR(1) model*				
1q	-13.3 (0.28)	0.7 (0.83)	-5.2 (0.54)	-5.4 (0.21)	1.5 (0.91)
2q	-12.2 (0.46)	1.3 (0.73)	-3.9 (0.71)	-1.8 (0.69)	-24 (0.15)
4q	-12.7 (0.07)	-2.1 (0.37)	1.6 (0.69)	2.4 (0.46)	-67.6 (0.00)
8q	-27.4 (0.05)	0.6 (0.00)	-5.4 (0.27)	8.1 (0.00)	-148.1 (0.00)
12q	-49.6 (0.02)	0.2 (0.48)	-6.9 (0.00)	8.8 (0.01)	-146.8 (0.00)

Note: All models are estimated starting in 1997:Q1. The forecast period is 2010:Q2 to 2016:Q4. All models are re-estimated each quarter. The values in brackets indicate the *p*-values of Diebold and Mariano (1995) tests, where we test whether the AR forecasts are significantly different in accuracy than the AR(1) forecasts (the null hypothesis of the test is that there is no difference between two competing forecasts).

Table C.5: Optimized log-likelihood of ARX models of different lag orders

Order of the AR	GDP	Inflation	Household consumption	Investment
ARX(1)	236.29	235.19	216.75	144.37
ARX(2)	224.41	226.47	208.32	136.80
ARX(3)	211.18	218.68	197.80	128.36

Note: All models are estimated using the period 1997:Q1 to 2010:Q4.

Table C.6: Conditional forecast performance or ARX models of different lag orders

	GDP	Inflation	Household consumption	Investment
ARX(1)	*RMSE-statistic for different forecast horizons*			
1q	0.34	0.38	0.58	1.11
2q	0.37	0.34	0.75	1.49
4q	0.41	0.35	0.96	1.25
8q	0.53	0.35	1.22	1.07
12q	0.58	0.41	1.43	1.35
ARX(2)	*Percentage gains (+) or losses (-) relative to ARX(1) model*			
1q	-12.9 (0.09)	-0.4 (0.93)	-1.3 (0.35)	3.6 (0.55)
2q	-4.5 (0.51)	1.9 (0.75)	-1.2 (0.51)	3.2 (0.77)
4q	7.6 (0.00)	-0.3 (0.75)	-2 (0.07)	-7.1 (0.06)
8q	5 (0.00)	0.8 (0.04)	-3.3 (0.00)	1.2 (0.88)
12q	6 (0.00)	2.2 (0.04)	-3.1 (0.00)	-2.1 (0.66)
ARX(3)	*Percentage gains (+) or losses (-) relative to ARX(1) model*			
1q	-12.4 (0.08)	-2.4 (0.60)	-5.9 (0.27)	3.2 (0.72)
2q	-4.1 (0.48)	1.1 (0.86)	-5.7 (0.44)	2.3 (0.89)
4q	8.2 (0.01)	-0.3 (0.53)	-5 (0.15)	-16.5 (0.11)
8q	6.6 (0.00)	0.8 (0.03)	-7.5 (0.00)	-0.1 (0.99)
12q	7.8 (0.00)	2.4 (0.05)	-8.5 (0.00)	-7.1 (0.39)

Note: All models are estimated starting in 1997:Q1. The forecast period is 2010:Q2 to 2016:Q4. All models are re-estimated each quarter. The values in brackets indicate the *p*-values of Diebold and Mariano (1995) tests, where we test whether the ARX forecasts are significantly different in accuracy than the ARX(1) forecasts (the null hypothesis of the test is that there is no difference between two competing forecasts).

Table C.7: Optimized log-likelihood of sectoral AR models of different lag orders

Order of the AR	A	B, C, D and E	F	G, H and I	J	K	L	M and N	O, P and Q	R and S
AR(1)	65.40	143.06	135.38	173.30	138.26	85.90	182.56	151.17	211.61	169.80
AR(2)	61.62	134.75	130.33	166.03	132.17	81.87	177.44	143.71	210.84	162.39
AR(3)	56.89	126.64	122.71	155.43	123.98	76.71	166.40	136.91	202.63	153.53

Note: All models are estimated using the period 1997:Q1 to 2010:Q4.

Table C.8: Out-of-sample forecast performance of sectoral gross value added (GVA)

	A	B, C, D and E	F	G, H and I	J	K	L	M and N	O, P and Q	R and S
AR(1)	*RMSE-statistic for different forecast horizons*									
1q	10.97	1.29	1.39	0.98	2.37	3.95	0.37	1.68	0.55	0.34
2q	14.29	1.75	1.81	1.48	2.93	4.94	0.61	1.94	0.71	0.58
4q	14.13	2.62	2.74	2.46	4.77	6.79	1	2.28	1.01	0.99
8q	12.95	3.46	4.33	3.69	7.03	8.12	1.45	2.81	1.63	1.75
12q	9.6	3.5	6.62	3.47	10.01	11.57	1.98	2.77	2.06	2.63
AR(2)	*Percentage gains (+) or losses (-) relative to AR(1) model*									
1q	-3.4 (0.09)	-6 (0.27)	4.7 (0.47)	-0.8 (0.78)	-5.2 (0.03)	0.7 (0.89)	-1.4 (0.88)	5.7 (0.28)	-7.6 (0.45)	-6.6 (0.02)
2q	-3.8 (0.18)	-5.5 (0.22)	8.6 (0.01)	0.1 (0.96)	-5.4 (0.06)	3.6 (0.37)	-5.4 (0.27)	9.3 (0.04)	-7 (0.43)	-3.8 (0.10)
4q	-5.5 (0.08)	-6.7 (0.04)	13.8 (0.00)	-0.1 (0.97)	-7.7 (0.01)	10.1 (0.13)	-14.3 (0.09)	4.1 (0.22)	-2.4 (0.38)	-2.4 (0.03)
8q	-3.3 (0.02)	-8.7 (0.05)	19.3 (0.00)	0.1 (0.92)	-7.9 (0.00)	22.1 (0.00)	-26.2 (0.09)	4.8 (0.39)	-2.8 (0.02)	-1.8 (0.00)
12q	-2.2 (0.00)	-14.5 (0.00)	20.1 (0.00)	0.6 (0.61)	-8.2 (0.00)	22 (0.00)	-36.6 (0.01)	0.3 (0.92)	-1.7 (0.01)	-2.4 (0.00)
AR(3)	*Percentage gains (+) or losses (-) relative to AR(1) model*									
1q	-3.3 (0.16)	-3.7 (0.33)	5.7 (0.41)	-1 (0.73)	-5.2 (0.05)	1.7 (0.80)	-1.9 (0.84)	-16.4 (0.21)	-7.3 (0.44)	-7.4 (0.02)
2q	-2.9 (0.40)	-4.5 (0.51)	9.3 (0.03)	0 (1.00)	-5.4 (0.15)	4.1 (0.62)	-5.9 (0.16)	-7.8 (0.23)	-6.9 (0.48)	-4.8 (0.08)
4q	-2.4 (0.27)	-9.3 (0.01)	16.4 (0.00)	-0.7 (0.84)	-8.8 (0.00)	15.7 (0.14)	-13.2 (0.11)	-19 (0.08)	-1.5 (0.59)	-2.9 (0.03)
8q	-2.1 (0.08)	-15.6 (0.01)	22.6 (0.00)	-0.8 (0.64)	-9.7 (0.00)	33.1 (0.00)	-23.7 (0.11)	-14.6 (0.05)	-2.4 (0.00)	-2.2 (0.00)
12q	-0.7 (0.01)	-28.4 (0.00)	23.6 (0.00)	-0.6 (0.52)	-10.1 (0.00)	37.1 (0.00)	-32 (0.01)	-18.7 (0.03)	-1.6 (0.01)	-2.6 (0.00)

Note: GVA is shown for the sectors Agriculture, forestry and fishing (A); Industry (except construction) (B, C, D and E); Manufacturing (C); Construction (F); Wholesale and retail trade, transport, accommodation and food service activities (G, H and I); Information and communication (J); Financial and insurance activities (K); Real estate activities (L); Professional, scientific and technical activities, as well as administrative and support service activities (M and N); Public administration, defence, education, human health and social work activities (O, P and Q); Arts, entertainment, and recreation, as well as other service activities (R and S). All models are estimated starting in 1997:Q1. The forecast period is 2010:Q2 to 2016:Q4. All models are re-estimated each quarter. The values in brackets indicate the *p*-values of Diebold and Mariano (1995) tests, where we test whether the AR forecasts are significantly different in accuracy than the AR(1) forecasts (the null hypothesis of the test is that there is no difference between two competing forecasts).