Supporting Information

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I. THE AGENT BASED MODEL OF A SMALL OPEN ECONOMY

Agent based models (ABMs) have become standard for many scientific applications[1] and in recent years they have also found a number of applications in economics and finance[2] [18]. Here, we use an ABM developed in [19] and [20], which depicts a small open economy based on detailed data sources from national accounts, input-output tables, government statistics, census data and business surveys. It is able to precisely forecast major macroeconomic variables (GDP, inflation, household consumption, investment). The basic structure of the model is depicted in Figure 1.

Following the sectoral accounting conventions of the European System of Accounts (ESA), see [21], the model economy is structured into four mutually exclusive domestic institutional sectors:

1. non-financial corporations (firms);
2. financial corporations (banks);
3. the general government;
4. and households.

The four sectors make up the total domestic economy and interact with the rest of the world through imports and exports. Each sector shown in Figure 1 is populated by a number of heterogeneous agents, who represent natural persons or legal entities (corporations, government entities and institutions). All agents interact with each other in

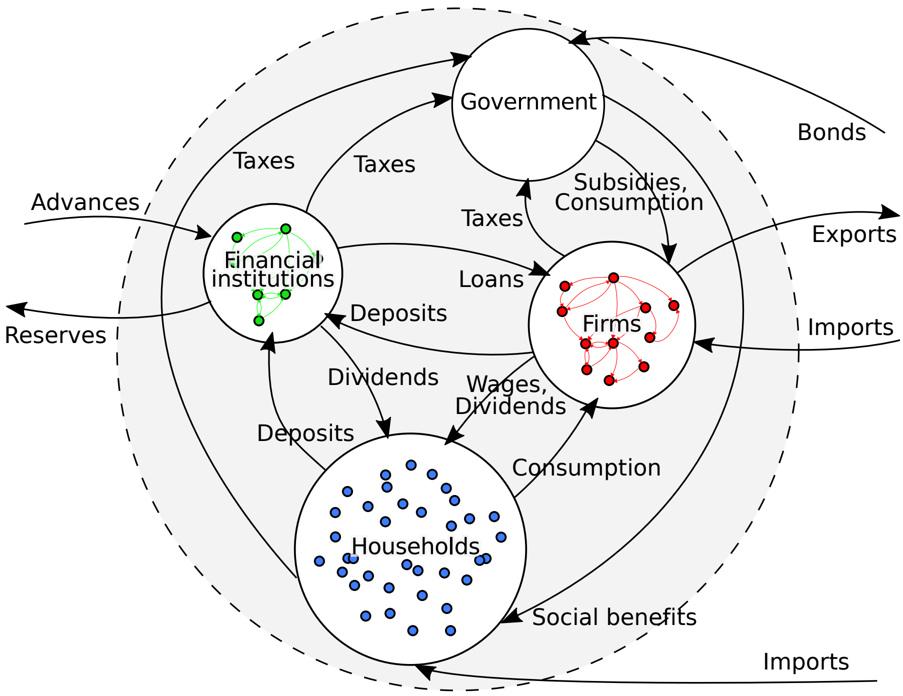

FIG. 1. (a) Schematic overview of the ABM structure showing the institutional sectors (households, non-financial and financial firms and a general government), and their interactions.

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[1] Selected examples are military planning [1–3], the physical sciences [4, 5], operational research [6–8], biology [9–12], and ecology [13–15].
[2] However, the use of ABMs in economics and finance up to date remains rather limited in comparison to other disciplines, or better put, ABMs are confined to a limited audience and selected journals [16, 17]

the following manner. Firms pay dividends to their owners, and wages (financed through income and loans) to their workers. Households consume goods produced by the firms. Households and firms deposit money in banks and banks grant loans to the firms. Government entities are active as consumers on the retail market (government consumption); as a redistributive entity the general government levies taxes and social contributions to provide social services and benefits to its citizens. All individual agents have separate balance sheets, depicting assets, liabilities, and ownership structures. Balance sheets of the agents, and economic flows between them, are set according to data from national accounting.

The firm sector is composed of 64 industry sectors according to the structure of input-output tables and the NACE/CPA classification by ESA. The firm population of each sector is derived from business demography data, while firm sizes follow a power law distribution. 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 productivity coefficients. Due to this assumption of constant productivity, the "productivity" or "Schumpeter creative destruction effect" - i.e. increasing capital productivity resulting from the technological update of capital stock due to reconstruction of capital destroyed by a natural disaster - is not modelled.[3] Output is sold to households as consumption goods or investments in dwellings, as well as to other firms as intermediate inputs or investments in capital goods. Firm investment is conducted to achieve a desired capacity utilization rate under consideration of capital depreciation. If internal funds (retained profits) are not sufficient to finance investment demand, firms resort to bank loans for residual finance. Firms are owned by investor households (one investor per firm), who receive part of firm profits as dividend income. A segment of the firm sector is engaged in import-export activities. Since we are modelling a small open economy, i.e. its limited volume of trade does not affect world prices, we obtain trends of exports and imports from exogenous projections based on macroeconomic data sources (national accounts times series data).

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 they buy from the firm sector. Households are assumed not to hold private insurance against catastrophic losses due to their reliance on catastrophe relief funds usually provided by the government in case of natural disasters.

The banking sector obtains deposits from households as well as from firms, and provides loans to the latter. Credit creation is limited by minimum capital requirements and loan extension is conditional on a maximum leverage of the firm, reflecting the banks risk assessment of a potential default by its borrower. Bank profits are calculated as the difference of 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 government sector is mainly concerned with consumption on retail markets, as well as with the redistribution of income to provide social services and benefits to its citizens. The amount and trend of both government consumption and redistribution is obtained from macroeconomic data sources (sectoral accounts and symmetric input-output tables) as exogenous trend projections. 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 taxes), 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) of other net transfers such as property income, investment grants, operating surplus, as well as 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. In simulation results below, government spending on catastrophe relief is financed by the issuance of additional amounts of government debt. Therefore, the government is not restrained in its expenditures for other purposes within the simulation period, i.e. there are no opportunity costs for government spending connected with the provision of catastrophe relief in the ABM. In case the government would have to cut back on investments in other sectors or increase taxes to finance catastrophe relief, this would constitute another baseline projection in our model simulations.[4]

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[3] The empirical relevance of this productivity effect is subject to extensive debate in the literature, as different empirical studies present mixed evidence on growth effects and associated increases in capital productivity after a natural disaster. For further discussion on the productivity effect see [22], for empirical studies presenting positive growth effects attributed to the productivity effect see [23] and [24], whose findings are contradicted by several studies such as [25], [26], [27], [28], [29].

[4] Since no reliable data for such an alternative scenario of government spending exists, this issue is left open for further research.

A. 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 ($s = 1, 2, \ldots, S$),[5] 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 $(\hat{P}_i(t), \hat{Q}^d_i(t))$[6] – given by the equilibrium price $\hat{P}_i(t)$ and equilibrium demand $\hat{Q}^d_i(t)$ – at which all its products would be sold and all consumer demand for its products would be satisfied. Furthermore, it entails that 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, i.e. expectations (or expectation mistakes) are a major source of uncertainty in our model.

1. Sales

Another source of uncertainty in our model is the search and matching mechanism we assume for the consumption, capital and intermediate input goods markets. Currently, we abstract from any preferential attachment of an agent to a certain brand or supplier of goods. Thus, our consumption and supply networks are formed in every period of the model, i.e. the firms visited are chosen randomly each period. The goods market are efficient in the sense that there is no "frictional" excess demand or supply, i.e. buyers can exhaust their consumption budget as long as aggregate supply is sufficient to match aggregate demand. However, in the case that aggregate demand exceeds aggregate supply, i.e. when the stocks of all visited firms are not sufficient, (some) individual consumption budgets may not be exhausted and aggregate excess demand is present. The opposite case of course can also be relevant, i.e. that (some) firms cannot sell off all their stock and the firm sector is left with aggregate excess supply. Due to these involuntary savings or inventory accumulation due to excess supply or demand in the aggregate economy or single markets, however, agents' plans regarding demand and supply may not be fulfilled.

Every agent active on a market as a consumer - may it be e.g. 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 its required products g. It visits a number of randomly chosen firms i that sell the good g to ascertain the selling prices. We use weighted sampling without replacement in all goods markets in the model. The weight in the sampling for a firm i to be chosen is determined (1) by the price charged by firm i according to an exponential distribution, where firms charging a lower price are more likely to be picked, and (2) by the relative size of the firm compared to other firms, so that bigger firms have a higher probability to be chosen. The total probability of firm i to be selected in this process is then the average of the latter two probabilities, i.e.:

$$pr^{price}_i(t) = \frac{e^{-P_i(t)}}{\sum_{i \in I_{s=g}} e^{-P_i(t)}}$$
$$pr^{size}_i(t) = \frac{Y_i(t)}{\sum_{i \in I_{s=g}} Y_i(t)}$$
$$pr^{cum}_i(t) = \frac{pr^{price}_i(t) + pr^{size}_i(t)}{2}$$

where $pr^{price}_i(t)$ is the probability of firm i to be selected by firm i due to its offering price, $pr^{size}_i(t)$ the probability to be chosen due to its size, $pr^{cum}_i(t)$ the cumulative average probability to be picked according to both of these

[5] 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.

[6] In this manuscript subscripts are used for indices and superscripts generally means something related to or derived from a variable, e.g. expectations for a quantity X are written as X^e. Additionally, superscripts in capital letters are used to further distinguish related variables, e.g. $\bar{P}^{HH}(t)$ denotes the consumer price index while $\bar{P}^{CF}(t)$ is capital formation price index.

factors, and $Y_i(t)$ is the production of goods by firm i, see equation (A.8). If the most preferred firm is in short supply, the consumer resorts to the remaining firms, otherwise 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, i.e. whether the agent acting as a customer finds firms to fulfill its demands.

Demand $Q_i^d(t)$ 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:

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

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:

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

The difference between production and sales is excess supply

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

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

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

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.

2. Price and quantity decisions

In any period t, the firm bases its price-quantity decision on two key signals: the previous price charged by competitors $\bar{P}_g(t-1)$ and its own excess supply $\Delta_i(t-1)$. These two signals relate the actual position of the firm, i.e. the last available status quo $(P_i(t-1), Y_i(t-1))$ given by last period's price $P_i(t-1)$ and actual production $Y_i(t-1)$, to its equilibrium position in the market $(\hat{P}_i(t), \hat{Q}_i^d(t))$, at which it would face neither excess supply nor excess demand. On the basis of these two signals the firm decides whether to change the price or expected demand and therefore the desired quantity, but not both. Adjustment is in fact partial and asymmetric.

The difference between actual production (supply choice) and actual demand is excess supply:

$$\Delta_i(t-1) = Y_i(t-1) - Q_i^d(t-1),$$

which is a reflection of firms' expectation error concerning demand. The firm decides to raise its price with respect to the status quo, if there was excess demand in the last period and the price was below the average price. It will lower its price in the case of excess supply and a price above average.

$$P_i(t) = \begin{cases} P_i(t-1)(1+\eta_i(t)) & \text{if } \Delta_i(t-1) \leq 0 \text{ and } P_i(t-1) < \bar{P}_g(t-1) \\ P_i(t-1)(1-\eta_i(t)) & \text{if } \Delta_i(t-1) > 0 \text{ and } P_i(t-1) > \bar{P}_g(t-1) \\ P_i(t-1) & \text{otherwise.} \end{cases} \tag{A.5}$$

where $\eta_i(t)$ is a positive parameter drawn from a time invariant uniform distribution with support (η^a, η^b). The firm cannot set the price below a certain threshold, which covers average cost faced by the firm ("cost-push inflation"), and a unit target for attaining an operating surplus (where again firm i is part of sector s $(i \in I_s)$):

$$\begin{aligned} P_i(t) \geq\ & \overbrace{\frac{w_i(t)(1+\tau^{SIF})\bar{P}^{HH}(t-1)}{\bar{\alpha}_i}}^{\text{Unit labour costs}} + \overbrace{\frac{1}{\beta_i}\bar{P}_i^M(t-1)}^{\text{Unit Material costs}} + \overbrace{\frac{\delta_i}{\kappa_i}\bar{P}_i^{CF}(t-1)}^{\text{Unit capital costs}} \\ & + \underbrace{\tau_i^Y \bar{P}_g(t-1)}_{\text{Unit net taxes/subsidies products}} + \underbrace{\tau_i^K \bar{P}_g(t-1)}_{\text{Unit net taxes/subsidies production}} + \underbrace{\bar{\pi}_i \bar{P}_g(t-1)}_{\text{Target unit operating surplus}} \end{aligned} \tag{A.6}$$

where w_i are gross wages indexed by the consumer price index $\bar{P}^{HH}$, see equation (A.27), and including employers' contribution to social insurance charged with 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 ($\bar{P}_i^M(t)$), see equation (A.25), $\bar{P}_g(t)$ is the price index for good g as in equation (A.12), δ_i/κ_i are unit real capital costs due to depreciation (δ_i is the firm's capital depreciation rate and κ_i the productivity coefficient for capital), $\bar{P}_i^{CF}(t)$ is the average (historical) price of capital goods as in equation (A.26), τ_i^Y and τ_i^K are net tax rates on products and production, respectively, and $\bar{\pi}_i = \frac{\Pi_i(0)+r(L_i(0)-\min(0,D_i(0)))-\bar{r}\max(0,D_i(0))}{Y_i(0)P_i(0)}$ is the operating margin where $Y_i(0)P_i(0)$ is the initial value of production and $\Pi_i(0)+r(L_i(0)-\min(0,D_i(0)))-\bar{r}\max(0,D_i(0))$ is the initial operating surplus, see equation (A.24).

Concerning its supply choice, the firm similarly updates its expectation of this period's demand and thus the desired scale of activity $Q_i^s(t)$. It raises output in the case of excess demand and a price above average, and reduces output in the case of excess supply and a price below average as follows:

$$Q_i^s(t) = \begin{cases} Y_i(t-1) + \rho|\Delta_i(t-1)| & \text{if } \Delta_i(t-1) \leq 0 \text{ and } P_i(t-1) \geq \bar{P}_g(t-1) \\ Y_i(t-1) - \rho|\Delta_i(t-1)| & \text{if } \Delta_i(t-1) > 0 \text{ and } P_i(t-1) \leq \bar{P}_g(t-1) \\ Y_i(t-1) & \text{otherwise.} \end{cases} \tag{A.7}$$

where $\rho \in (0,1)$ is the quantity adjustment parameter.

The four cases and the according adjustment are displayed in the following table:

	if $P_i(t-1) < P_g(t-1)$	if $P_i(t-1) \geq P_g(t-1)$
if $\Delta_i(t-1) \leq 0$	$P_i(t) \uparrow$	$Q_i^s(t) \uparrow$
if in period t $\Delta_i(t-1) > 0$	$Q_i^s(t) \downarrow$	$P_i(t) \downarrow$

Given this simple adjustment mechanism, the firm tends to circle around the equilibrium position.[7]

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 - which all represent upper limits to production:

$$Y_i(t) = \min\left(Q_i^s(t), \beta_i M_i(t-1), \alpha_i(t) N_i(t), \kappa_i K_i(t-1)\right), \tag{A.8}$$

where $\alpha_i(t)$ is the productivity of labor of firm $i \in I_s$, see equation (A.21), and β_i and κ_i are its productivity coefficients for intermediate inputs and capital, respectively. Production by firm i may not equal desired scale of activity ($Q_i^s(t)$). Output could be limited by the amount of available labor force, or a firm might be short on intermediate goods or does not have the amount of capital needed in the production process. In these cases the firm has to scale down activity.

4. Investment

Each period the i-th firm has to decide how much to invest ($I_i^d(t)$, 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[8] 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 real capital stock in period t is:

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[7] This assumption on firm behavior is based on the evidence of survey data on price and quantity adjustment of firms over the business cycle (Kawasaki et al., 1982; Bhaskar et al., 1993).

[8] 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.

$$I_i^d(t) = \min\Bigg(\overbrace{\underbrace{\frac{\bar{Y}_i(t-1)}{\kappa_i \omega}}_{\text{desired capital stock}} + \underbrace{\delta_i \min\left(\frac{Q_i^s(t)}{\kappa_i}, K_i(t-1)\right)}_{\text{replacement investment}} - \underbrace{K_i(t-1)}_{\text{existing capital stock}}}^{\text{credit-unconstrained case}}, \\ \overbrace{\underbrace{\delta_i \min\left(\frac{Q_i^s(t)}{\kappa_i}, K_i(t-1)\right)}_{\text{replacement investment}} + \underbrace{\frac{\Delta L_i(t) + \max(0, D_i(t-1))}{\bar{P}^{CF}(t-1)}}_{\text{investment financed by credit and cash available to firm } i}}^{\text{credit-constrained case}} \Bigg) . \tag{A.9}$$

Here δ_i is the firm's capital depreciation rate, $\omega \in (0,1)$ represents the desired rate of capacity utilization of firm i, and $\bar{Y}_i(t-1)$ is the weighted average of past production of firm i,

$$\bar{Y}_i(t) = (1-\nu)\bar{Y}_i(t-1) + \nu Y_i(t) , \tag{A.10}$$

where $\nu \in (0,1)$ is a memory parameter. $\bar{Y}_i(t)$ is thus a weighted average of current and past production with exponentially decaying weights. Furthermore, $\Delta L_i(t)$ is the amount of new credit extended to firm i by the bank, see equation (E.6), $D_i(t-1)$ is the amount of cash available to firm i ($D_i(t-1) > 0$), or the amount of outstanding overdraft on firm $i's$ deposit account with the bank ($D_i(t-1) < 0$), see equations (A.28) and (A.29), and $\bar{P}^{CF}(t-1)$ is the economy-wide capital formation price index from period $t-1$, which is used as the expected price for the investment goods bundle by firms above and is defined as

$$\bar{P}^{CF}(t) = \sum_g b_g^{CF} \bar{P}_g(t) , \tag{A.11}$$

where b_g^{CF} are the fixed weights of capital formation (CF) for the products g demanded in the formation of the capital stock by each firm $\bar{P}_g(t)$ is the price index for the principal good g:

$$\bar{P}_g(t) = \frac{\sum_{i \in I_{s=g}} P_i(t) Y_i(t)}{\sum_{i \in I_{s=g}} Y_i(t)} . \tag{A.12}$$

Faced with fundamental uncertainty as regarding to whether its production plans will match demand, firm i determines a desired capital stock and corresponding investment as in equation (A.9), possibly subject to credit and liquidity constraints limiting its capability to invest. In the credit-unconstrained case - abstracting from short run fluctuations in its output - firm i uses $\bar{Y}_i(t)$ as an indicator for its average production level and ascertains the related amount of average capital stock needed by means of the productivity of capital. Moreover, firm i sets a desired rate of capacity utilization such that its holds spare production capacity in order to be able to satisfy unexpected rises in demand without major adjustment costs. Firms also account for expected wear and tear of capital in the production process by applying an average depreciation rate on the existing capital stock, thus estimating average replacement investment necessary to reach the desired amount of capital stock. Given that the firm can finance this amount of desired investment out of internal funds, desired investment equals desired capital plus expected future depreciation minus the existing capital stock. The firm, however, may be subject to credit and liquidity constraints. In this case, we assume that the minimal amount of investment is equal to replacement investment, i.e. the wear and tear of capital in the production process, plus the amount of investment that can be financed by additional credit from the bank, which depends on the amount of credit the bank is willing to provide, cash available to firm i and the expected price for the investment goods bundle.

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

$$I_{ig}^d(t) = b_g^{CF} I_i^d(t) . \tag{A.13}$$

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 I A 1:

$$I_i(t) \begin{cases} = \sum_g I_{ig}^d(t) & \text{if the firm successfully realized the investment plan, and} \\ < \sum_g I_{ig}^d(t) & \text{if all visited firms could not satisfy its demand} \end{cases} \tag{A.14}$$

In case firm i cannot realize its investment plan, it will have to scale down future activity, see equation (A.8).

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:

$$K_i(t) = K_i(t-1) - \frac{\delta_i}{\kappa_i} Y_i(t) + I_i(t)\,. \tag{A.15}$$

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 which it takes out materials for production as needed, and which it keeps in positive supply to avoid shortfalls of material input impeding their production.

Each period the i-th firm has to decide on the desired amount of intermediate goods and raw materials ($\Delta M_{ig}^d(t)$) that it intends to purchase in order to keep its stock in positive supply. Also here, similar to equation (A.8), firm i is part of industry s and consumes intermediate input g according to sector-specific technology coefficients a_{sg}. We assume that the firm steadily uses its raw materials in production, and that the material stock does hence not depreciate. It is given as

$$\Delta M_{ig}^d(t) = \left(\frac{\bar{Y}_i(t-1)}{\omega \beta_i} + \frac{\min(Q_i^s(t), \kappa_i K_i(t-1))}{\beta_i} - M_i(t-1) \right) a_{sg} \quad \forall i \in I_s\,, \tag{A.16}$$

where $\bar{Y}_i(t-1)$ is the weighted average of past production of firm i, and a_{sg} are intermediate-input or technology coefficients of products g necessary for production in industry s (we assume equal production technologies for all firms in the same sector s). This equation relates to the assumption that firms try to keep their stock of material input goods in a certain relationship to to its weighted average of past production: $\bar{Y}_i(t-1)/\omega\beta_i$ indicates the size of material stock firm i wants to hold after the current period given the productivity of intermediate inputs and the desired rate of capacity utilization. Similarly, $\min(Q_i^s(t), \kappa_i K_i(t-1))/\beta_i$ is the amount of material stock the firm anticipates to use for production this period, considering both the firm's supply decision as well as possible production constraints due to a shortage of capital that could e.g. be due to catastrophic losses in the previous period.

Also in the intermediate goods market, the amount of realized purchases of intermediate goods depends on a search and matching process, see section I A 1:

$$\Delta M_i(t) \begin{cases} = \sum_g \Delta M_{ig}^d(t) & \text{if the firm successfully realized its plan, and} \\ < \sum_g \Delta M_{ig}^d(t) & \text{if all visited firms could not satisfy its demand.} \end{cases} \tag{A.17}$$

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 necessary in the production process to achieve actual production ($Y_i(t)$) and realized new acquisitions of intermediate goods:

$$M_i(t) = M_i(t-1) - \frac{Y_i(t)}{\beta_i} + \Delta M_i(t)\,. \tag{A.18}$$

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 $N_i^d(t)$ in each period according to its desired scale of activity ($Q_i^s(t)$) and its average labor productivity ($\bar{\alpha}_i$):

$$N_i^d(t) = \max\left(1, \text{round}\left(\frac{\min(Q_i^s(t), \kappa_i K_i(t-1))}{\bar{\alpha}_i}\right)\right). \tag{A.19}$$

Rounding to the nearest integer translates as follows: in case the additional labor demand of firm i is less than a half-time position, labor demand is left unchanged. In case 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 $N_i(t-1) - N_i^d(t)$ randomly chosen employees (again accounting for production constraints possibly due 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, $V_i(t) = \max\left(N_i^d(t) - N_i(t-1), 0\right)$, which are demand for new labor. Whether vacancies are filled or not depends on the search and matching mechanism in the labor market (see paragraph regarding unemployed households in section I C below), thus

$$N_i(t) \begin{cases} = N_i^d(t) & \text{if the firm successfully fills all vacancies, and} \\ < N_i^d(t) & \text{if there are unfilled vacancies.} \end{cases} \tag{A.20}$$

Since 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:

$$\alpha_i(t) = \bar{\alpha}_i \min\left(1.5, \frac{\min(Q_i^s(t), \kappa_i K_i(t-1))}{N_i(t)\bar{\alpha}_i}\right), \tag{A.21}$$

where the maximum work effort is 150% 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:

$$w_i(t) = \bar{w}_i \min\left(1.5, \frac{\min(Q_i^s(t), \kappa_i K_i(t-1))}{N_i(t)\bar{\alpha}_i}\right), \tag{A.22}$$

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 I C 4.

7. *External Finance*

If internal financial resources of a firm are not enough to finance its expenditures, the firm will ask for a bank loan, i.e. new credit $\Delta L_i^d(t)$, to cover its financing gap. The latter is determined by deducting depreciation of existing capital and available cash reserves (internal funds) $D_i(t-1)$ from the amount of desired nominal investment in capital stock:

$$\Delta L_i^d(t) = \max\left(0, \bar{P}^{CF}(t-1)I_i^d(t) - \bar{P}_i^{CF}(t-1)\delta_i \min\left(\frac{Q_i^s(t)}{\kappa_i}, K_i(t-1)\right) - D_i(t-1)\right). \tag{A.23}$$

The availability of credit depends on the capitalization of the banking sector and the arrival of firms to ask for a loan, see section I E 1 for details. In case the firm cannot obtain a loan on the credit market, it might become credit constrained, see equation (E.6). If the firm does not get the desired loan, it may become insolvent, see section I A 9.

8. *Accounting*

Firm profits $\Pi_i(t)$ are an accounting figure that we define as revenues from sales plus change in inventories minus expenditures on labor, material, depreciation, interest payments and taxes (all accounted for at historical costs):

$$\begin{aligned}\Pi_i(t) = {} & \overbrace{P_i(t)Q_i(t)}^{\text{Sales}} + \overbrace{P_i(t)\Delta S_i(t)}^{\text{Inventory change}} - \overbrace{w_i(t)(1+\tau^{SIF})N_i(t)\bar{P}^{HH}(t)}^{\text{Labor costs}} - \overbrace{\bar{P}_i^M(t-1)\frac{Y_i(t)}{\beta_i}}^{\text{Material costs}} - \overbrace{\bar{P}_i^{CF}(t-1)\frac{\delta_i Y_i(t)}{\kappa_i}}^{\text{Depreciation}} \\ & - \underbrace{\tau_i^Y P_i(t)Y_i(t) - \tau_i^K P_i(t)Y_i(t)}_{\text{Net taxes/subsidies on products/production}} - \underbrace{r(L_i(t-1) - \min(0, D_i(t-1)))}_{\text{Interest payments}} + \underbrace{\bar{r}\max(0, D_i(t-1))}_{\text{Interest received}}\end{aligned} \tag{A.24}$$

where r is the interest rate paid on outstanding loans, see equation (E.8). $\bar{P}_i^M(t)$ is the average (historical) price for the stock of good g held by firm i, where the average is taken over different goods g and past time periods:

$$\bar{P}_i^M(t) = \bar{P}_i^M(t-1)\frac{M_i(t-1)}{M_i(t)} - \bar{P}_i^M(t-1)\frac{Y_i(t)}{\beta_i M_i(t)} + \sum_g P_{ig}(t)\frac{\Delta M_{ig}(t)}{M_i(t)}, \tag{A.25}$$

and $\bar{P}_i^{CF}(t)$ is the average (historical) price for the capital stock of firm i:

$$\bar{P}_i^{CF}(t) = \bar{P}_i^{CF}(t-1)\frac{K_i(t-1)}{K_i(t)} - \bar{P}_i^{CF}(t-1)\frac{\delta_i Y_i(t)}{\kappa_i K_i(t)} + P_i^{CF}(t)\frac{I_i(t)}{K_i(t)}, \tag{A.26}$$

where $P_{ig}(t)$ and $P_i^{CF}(t)$ 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 and matching process. $\bar{P}^{HH}(t)$ is the consumer price index:

$$\bar{P}^{HH}(t) = \sum_g b_g^{HH} \bar{P}_g(t)\,, \tag{A.27}$$

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:

$$\begin{aligned}\Delta D_i(t) = {} & \overbrace{P_i(t)Q_i(t)}^{\text{Sales}} - \overbrace{w_i(t)(1+\tau^{SIF})N_i(t)\bar{P}^{HH}(t)}^{\text{Labor costs}} - \overbrace{\sum_g P_{ig}(t)\Delta M_{ig}(t)}^{\text{Material costs}} - \underbrace{\tau_i^Y P_i(t)Y_i(t) - \tau_i^K P_i(t)Y_i(t)}_{\text{Net taxes/subsidies on products and production}} \\ & - \underbrace{\tau^{FIRM}\max(0,\Pi_i(t))}_{\text{Corporate tax payments}} - \underbrace{\theta^{DIV}(1-\tau^{FIRM})\max(0,\Pi_i(t))}_{\text{Dividend payments}} - \underbrace{r(L_i(t-1) - \min(0,D_i(t-1)))}_{\text{Interest payments}} \\ & + \underbrace{\bar{r}\max(0,D_i(t-1))}_{\text{Interest received}} - \underbrace{P_i^{CF}(t)I_i(t)}_{\text{Investment costs}} + \underbrace{\Delta L_i(t)}_{\text{New credit}} - \underbrace{\theta L_i(t-1)}_{\text{Debt installment}} .\end{aligned} \tag{A.28}$$

Furthermore, firm i pays interest on outstanding loans and overdrafts on firm i's deposit account (in case $D_i(t) < 0$) with the same rate r including 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 I E.

Firm deposits are then previous deposits plus net cash flow:

$$D_i(t) = D_i(t-1) + \Delta D_i(t)\,. \tag{A.29}$$

Similarly, overall debt is updated as follows:

$$L_i(t) = (1-\theta)L_i(t-1) + \Delta L_i(t)\,. \tag{A.30}$$

Finally, firm equity $E_i(t)$ evolves as the balancing item on the firm's balance sheet:

$$E_i(t) = D_i(t) + \bar{P}_i^M(t)M_i(t) + \bar{P}_i(t)S_i(t) + \bar{P}_i^{CF}(t)K_i(t) - L_i(t)\,, \tag{A.31}$$

where $\bar{P}_i(t)$ is the average (historical) price of finished goods in the inventory:

$$\bar{P}_i(t) = \bar{P}_i(t-1)\frac{S_i(t-1)}{S_i(t)} + P_i(t)\frac{\Delta S_i(t)}{S_i(t)}\,. \tag{A.32}$$

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

$$L_i(t-1) = \zeta^b \bar{P}_i^{CF}(t)K_i(t) \tag{A.33}$$

and firm deposits with

$$D_i(t-1) = 0\,. \tag{A.34}$$

Correspondingly, in the next period $(t+1)$ equity of the new firm i is initialized according to equation (A.31).

B. Imports and Exports

To depict trade with the Rest of the World (RoW), we include a set of agents that are based abroad and trade with the domestic economy. For simplicity, 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.

1. Imports

The representative foreign firm for each sector imports goods Y_m (in real terms) from the RoW and supplies them to domestic markets:[9] The m-th, ($m = 1, 2, \ldots, S$), foreign firm representing an industry s produces the principal product g:[10]

$$Y_m = c^I_{g=s} \,, \tag{B.1}$$

where c^I_g is the amount of imported goods of type g.

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,

$$P_m(t) = \bar{P}_g(t-1) \,, \tag{B.2}$$

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 I A 1):

$$Q_m(t) = \min(Y_m, Q^d_m(t)) \,, \tag{B.3}$$

where $Q^d_m(t)$ is the demand by consumers from the foreign firm.

2. Exports

The l-th ($l = 1, 2, \ldots, L$) foreign consumer, may it be e.g. 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. Exports are assumed to stay constant in real terms, but they are adjusted to the domestic price index of good g.

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

$$C^d_{lg}(t) = \frac{\bar{P}_g(t-1)c^E_g}{L} \,, \tag{B.4}$$

where c^E_g is the amount 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 I A 1):

$$C_l(t) \begin{cases} = \sum_g C^d_{lg}(t) & \text{if the foreign consumer successfully realized the consumption plan, and} \\ < \sum_g C^d_{lg}(t) & \text{if all visited firms could not satisfy its demand.} \end{cases} \tag{B.5}$$

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[9] As a simplifying assumption, this implies that imports by the domestic economy are not demand-driven, but rather subject to a supply constraint that we assume to be constant.

[10] As for domestic firms, we suppose there are M_s foreign firms in each industry s and 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 $S = G$.

C. Household Sector

The household sector consists of a total number of H ($h = 1, 2, \dots, H$) persons. On the one hand, every person in the household sector has an *activity status*, i.e. the type of economic activity from which she receives her income. On the other hand, each person 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 employees, and I investors (the number of investors equals the number of firms and is constant, see below). The set of employees consists of $H^E(t)$ employed persons and $H^U(t)$ unemployed persons that are actively looking for a job. $H^E(t)$ and $H^U(t)$ are endogenous since we assume that agents can switch between these two sets by means of hiring and firing. Furthermore, we assume the set of persons to grow at a constant rate of υ, thus accounting for population growth.[11] Not economically active persons include persons below the age of 15, students, persons receiving a pension and other currently not economically active persons.

1. Activity Status

The h-th employee ($h = 1, 2, \dots, H^W$) supplies labor to the extent of employment (part-time, full, or including overtime). If employee 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 she has the chance to visit. If she does not find a vacancy to fill, i.e. when there are no open vacancies in the economy left, she remains unemployed. For simplicity 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 unemployment starts. In case an unemployed person finds a new job, she is remunerated with the wage of firm i that provides the new employment:

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

For simplicity, we assume that each firm is owned by one investor, i.e. the number of investors matches that of overall firms. Each investor receives income in the form of dividends in case the firm she owns makes profits after interest and tax payments. We assume limited liability, i.e. in case of bankruptcy, the associated losses are borne by the creditor and not the investor household, see section I A 9.

Economically inactive person h receives social benefits sb^{inact} and does not look for a job.

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

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 ($Y_h^e(t)$). The consumption budget (net of VAT) of household h ($C_h^d(t)$) is thus given by:

$$C_h^d(t) = \frac{\psi Y_h^e(t)}{1 + \tau^{VAT}}, \tag{C.2}$$

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

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[11] We initialize persons newly entering our model economy with the activity status of unemployed to account for shifts between active and inactive persons in the labor force. This relates e.g. to persons reaching the age of sixteen, students that finish their degree, migrant workers, etc., that newly enter the labor force but still have to acquire a position at a firm seeking to hire new employees.

consumer index price index of last period:

$$Y_h^e(t) = \begin{cases} \left(w_h(t)\left(1-\tau^{SIW}-\tau^{INC}(1-\tau^{SIW})\right)+sb^{other}\right)\bar{P}^{HH}(t-1) & \text{if employed} \\ \left(w_h(t)+sb^{other}\right)\bar{P}^{HH}(t-1) & \text{if unemployed} \\ \left(sb^{inact}+sb^{other}\right)\bar{P}^{HH}(t-1) & \text{if not economically active} \\ \theta^{DIV}(1-\tau^{INC})(1-\tau^{FIRM})\max(0,\Pi_i^e(t))+sb^{other}\bar{P}^{HH}(t-1) & \text{if an investor} \\ \theta^{DIV}(1-\tau^{INC})(1-\tau^{FIRM})\max(0,\Pi_k^e(t))+sb^{other}\bar{P}^{HH}(t-1) & \text{if a bank investor} \end{cases} \quad . \tag{C.3}$$

Here, 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

$$C_{hg}^d(t) = b_g^{HH} C_h^d(t)\,, \tag{C.4}$$

where b_g^{HH} is the consumption coefficient for the g^{th} product of households.[12]

Once they have determined their consumption budget, consumers visit firms in order to purchase goods according to the search and matching mechanism, see section I A 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:

$$C_h(t) \begin{cases} = \sum_g C_{hg}^d(t) & \text{if the consumer successfully realized the consumption plan, and} \\ < \sum_g C_{hg}^d(t) & \text{if all visited firms could not satisfy the consumer's demand.} \end{cases} \tag{C.5}$$

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 (C.2) above, we assume household investment occurs according to a fixed rate ψ^H on expected disposable net income:

$$I_h^d(t) = \frac{\psi^H Y_h^e(t)}{1+\tau^{CF}}\,, \tag{C.6}$$

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

Investment demand by household h for product g net of taxes ($I_{hg}^d(t)$) is then determined by fixed weights b_g^{CFH}:

$$I_{hg}^d(t) = b_g^{CFH} I_h^d(t)\,. \tag{C.7}$$

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

$$I_h(t) \begin{cases} = \sum_g I_{hg}^d(t) & \text{if the household successfully realized the investment plan, and} \\ < \sum_g I_{hg}^d(t) & \text{if all visited firms could not satisfy its demand.} \end{cases} \tag{C.8}$$

The capital stock of household h then follows:

$$K_h(t) = K_h(t-1) + I_h(t)\,. \tag{C.9}$$

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[12] 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.

4. Income

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:

$$Y_h(t) = \begin{cases} \left(w_h(t)\left(1-\tau^{SIW}-\tau^{INC}(1-\tau^{SIW})\right)+sb^{other}\right)\bar{P}^{HH}(t) & \text{if employed} \\ \left(w_h(t)+sb^{other}\right)\bar{P}^{HH}(t) & \text{if unemployed} \\ \left(sb^{inact}+sb^{other}\right)\bar{P}^{HH}(t) & \text{if not economically active} \\ \theta^{DIV}(1-\tau^{INC})(1-\tau^{FIRM})\max(0,\Pi_i(t))+sb^{other}\bar{P}^{HH}(t) & \text{if an investor} \\ \theta^{DIV}(1-\tau^{INC})(1-\tau^{FIRM})\max(0,\Pi_k(t))+sb^{other}\bar{P}^{HH}(t) & \text{if a bank investor} \end{cases} . \tag{C.10}$$

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:[13]

$$D_h(t) = D_h(t-1) + \overbrace{Y_h(t) - ((1+\tau^{VAT})C_h(t) + (1+\tau^{CF})I_h(t))}^{\text{Savings}} + \overbrace{r\min(0, D_h(t-1))}^{\text{Interest payments}} + \overbrace{\bar{r}\max(0, D_h(t-1))}^{\text{Interest received}} . \tag{C.11}$$

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 ($D_h(t-1) > 0$). 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.

D. 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 at the aggregate level, i.e. for the general government.

1. Government Consumption

Individual government entities j ($j = 1, 2, \ldots, J$) participate in the goods market as consumers. These entities represent

1. the central governments;
2. state governments;
3. local governments;
4. and social security funds.

Final consumption demand by the general government is assumed to stay constant in real terms, but is adjusted to the price index of good g. 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

$$C^d_{jg}(t) = \frac{\bar{P}_g(t-1)c^G_g}{J} , \tag{D.1}$$

[13] 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.

where c_g^G is the real amount 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:

$$C_j(t) \begin{cases} = \sum_g C_{jg}^d(t) & \text{if the government successfully realized the consumption plan, and} \\ < \sum_g C_{jg}^d(t) & \text{if all visited firms could not satisfy its demand.} \end{cases} \tag{D.2}$$

2. Government Revenues

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

1. Taxes
   (a) an income tax including capital taxes with a tax rate τ^{INC} on both capital and labor income,
   (b) corporate tax with a rate τ^{FIRM} on firm profits,
   (c) value-added tax with a rate τ^{VAT} on household consumption,
   (d) other net taxes on products with a industry-specific rate τ_i^Y on firms' output and other net taxes on production with a industry-specific rate τ_i^K on firms' fixed assets,
   (e) net export taxes with a rate τ^{EXPORT} on total exports by firms,
   (f) net taxes on capital formation with a rate τ^{CF} on household investment,
2. Social contributions, comprising both,
   (a) social insurance contributions by employers, rate τ^{SIF} on gross wages,
   (b) social insurance contributions by employees, rate τ^{SIW} on gross wages,
3. Other transfers received, such as (a) property income, (b) other current transfers receivable, (c) investment grants and other capital transfers receivable, (d) operating surplus net, as well as (e) proceeds from sales of goods and services.

Other transfers are netted with other current expenditures by the government, and treated as a net transfer to the household sector.

The revenues of the general government are

$$\begin{aligned} Y^G(t) = {} & \overbrace{(\tau^{SIF} + \tau^{SIW})\bar{P}^{HH}(t) \sum_{h \in H^E(t)} w_h(t)}^{\text{Social security contributions}} + \overbrace{\tau^{INC}(1-\tau^{SIW})\bar{P}^{HH}(t) \sum_{h \in H^E(t)} w_h(t)}^{\text{Labour income taxes}} \\ & + \overbrace{\tau^{VAT} \sum_h C_h(t)}^{\text{Value added taxes}} + \overbrace{\tau^{INC}(1-\tau^{FIRM})\theta^{DIV} \left(\sum_i \max(0, \Pi_i(t)) + \max(0, \Pi_k(t)) \right)}^{\text{Capital income taxes}} \\ & + \overbrace{\tau^{FIRM} \left(\sum_i \max(0, \Pi_i(t)) + \max(0, \Pi_k(t)) \right)}^{\text{Corporate income taxes}} + \underbrace{\tau^{CF} \sum_h I_h(t)}_{\text{Taxes on capital formation}} \\ & + \underbrace{\sum_i \tau_i^Y P_i(t) Y_i(t)}_{\text{Net taxes/subsidies on products}} + \underbrace{\sum_i \tau_i^K P_i(t) Y_i(t)}_{\text{Net taxes/subsidies on production}} + \underbrace{\tau^{EXPORT} \sum_l C_l(t)}_{\text{Export taxes}} . \end{aligned} \tag{D.3}$$

3. *Government Expenditures*

Expenditures of the general government include

1. final consumption of government entities
2. interest payments
3. social benefits other than social transfers in kind
4. subsidies
5. other current expenditures, such as (a) other current transfers, (b) adjustment for changes in pension entitlements, (c) capital transfers payable, (d) net government investment expenditures)

Interest payments of the general government are made with a fixed average interest rate r^G on loans taken out by the government $L^G(t-1)$. Social transfers by the government consist of social benefits for inactive households ($\sum_{h \in H^{inact}} sb^{inact}$) such as pension payments or social exclusion benefits, social benefits for any household h ($\sum_h sb^{other}$) such as relating to family, sickness or housing, as well as unemployment benefits for unemployed households ($\sum_{h \in H^U(t)} w_h(t)$). 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_i^Y) and production (τ_i^K), respectively.[14]

4. *Government Deficit*

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

$$\begin{aligned}\Pi^G(t) = \; & \overbrace{Y^G(t)}^{\text{Government revenues}} - \overbrace{\sum_j C_j(t)}^{\text{Government consumption}} - \overbrace{r^G L^G(t-1)}^{\text{Interest payments}} \\ & \underbrace{- \sum_{h \in H^{inact}} \bar{P}^{HH}(t) sb^{inact} + \sum_{h \in H^U(t)} \bar{P}^{HH}(t) w_h(t) + \sum_h \bar{P}^{HH}(t) sb^{other}}_{\text{Social benefits and transfers}} .\end{aligned} \tag{D.4}$$

5. *Government Debt*

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

$$L^G(t) = L^G(t-1) + \Pi^G(t) . \tag{D.5}$$

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. One major reason to account for the stock of government debt in this stylized way is to calculate the yearly interest payments, since they are an important part of government expenditures.

E. The bank

For reasons of simplicity we assume the existence of one representative bank.[15] The bank takes deposits from firms and households, extends loans to firms and receives advances from, or deposits reserves, at the central bank.

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

[15] This assumption of one representative bank is most of all due to conventions in national accounting. 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 III 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.

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

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

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 - as any other agent - has no knowledge of the realized value both of its equity capital or loans extended to individual firms i due to fundamental uncertainty prevailing in the model economy. Therefore, the bank has to form expectations both for its equity capital ($E_k^e(t)$) as well as the sum of all loans extended to firms in the economy ($\sum_{i=1}^{I} L_i^e(t)$):

$$\frac{E_k^e(t)}{\sum_{i=1}^{I} L_i^e(t)} = \frac{E_k(t-1)}{\sum_{i=1}^{I}(L_i(t-1) + \Delta L_i(t))} \geq \zeta \tag{E.2}$$

Here, $\Delta L_i(t)$ is the realized amount of new loans to firm i in period t as given in equation (E.6), which is either the full amount of new credit demanded by firms ($\Delta L_i^d(t)$, see equation (A.23)) in case the capital requirements for the banks have not been surpassed yet, but is equal to zero in case the bank does not have enough equity capital to provide the loan asked by firm i:

$$\Delta L_i(t) \leq \max\left(0, \frac{E_k(t-1)}{\zeta} - \sum_{i=1}^{I}(L_i(t-1) + \Delta L_i(t) - \min(0, D_i(t-1)))\right) \tag{E.3}$$

Furthermore, the bank forms a risk assessment on a potential default of firm i as a potential borrower. 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),

$$\frac{L_i(t) - \min(0, D_i(t-1))}{\bar{P}_i^{CF}(t) K_i(t)} \leq \zeta^{LTV} \tag{E.4}$$

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 ($L_i^e(t)$), as well as on the value of firm i's capital stock ($K_i^e(t)$):

$$\frac{L_i^e(t)}{\bar{P}_i^{CF}(t-1) K_i^e(t)} = \frac{L_i(t-1) + \Delta L_i(t) - \min(0, D_i(t-1))}{\bar{P}_i^{CF}(t-1) K_i(t-1) + \Delta L_i(t)} \leq \zeta^{LTV} \tag{E.5}$$

where it updates the value of firm i's capital stock from last period with the amount of new loans to be extended to firm i ($\Delta L_i(t)$), and thus assumes that the total amount of credit demanded by firm i would be spent on additional investment in capital stock.

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

$$\begin{aligned}\Delta L_i(t) = \min\Bigg(&\Delta L_i^d(t), \frac{\zeta^{LTV} \bar{P}_i^{CF}(t-1) K_i(t-1) - L_i(t-1) + \min(0, D_i(t-1))}{1 - \zeta^{LTV}}, \\ &\max\left(0, \frac{E_k(t-1)}{\zeta} - \sum_{i=1}^{I}(L_i(t-1) + \Delta L_i(t) - \min(0, D_i(t-1)))\right)\Bigg)\end{aligned} \tag{E.6}$$

Notice, that the order of arrival of firms to the bank is random. A financially robust (low leverage) firm, who 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.

The bank's profits are computed as the difference between revenues from interest payments payable on outstanding loans to firms incl. overdrafts of deposit accounts 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 ($D_{i,h}(t-1) > 0$) as well as write-offs of bad debt:

$$\begin{aligned}\Pi_k(t) = {} & \underbrace{\bar{r}\max(0, D_k(t-1)) + r\left(\sum_{i=1}^{I} L_i(t-1) - \sum_{i=1}^{I}\min(0, D_i(t-1)) - \sum_{h=1}^{H}\min(0, D_h(t-1))\right)}_{\text{Interest received}} \\ & \underbrace{+\,\bar{r}\min(0, D_k(t-1)) - \bar{r}\left(\sum_{i=1}^{I}\max(0, D_i(t-1)) + \sum_{h=1}^{H}\max(0, D_h(t-1))\right)}_{\text{Interest payments}} \\ & \underbrace{-\sum_{i\in I'}(L_i(t) - D_i(t) - \zeta^b \bar{P}_i^{CF}(t)K_i(t))}_{\text{Write-off of bad debt}}\end{aligned} \tag{E.7}$$

where I' is the set of insolvent borrowers, where we assume that outstanding overdraft of firm i's deposit account as well as a fraction $(1-\zeta_b)\bar{P}_i^{CF}(t)K_i(t)$ of loans extended to firm i have to be written off from the bank's balance sheet, thus reducing bank profits correspondingly. Deposits are remunerated with the policy rate $\bar{r}$, 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 $\bar{r}$:

$$r = \bar{r} + \mu\,. \tag{E.8}$$

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

$$E_k(t) = E_k(t-1) + \Pi_k(t) - \underbrace{\theta^{DIV}(1-\tau^{FIRM})\max(0, \Pi_k(t))}_{\text{Dividend payments}} - \underbrace{\tau^{FIRM}\max(0, \Pi_k(t))}_{\text{Corporate taxes}}\,. \tag{E.9}$$

The residual and balancing item on the bank's balance sheet ($D_k(t)$),[16] 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 ($D_k(t) < 0$).[17]

$$D_k(t) = \sum_{i=1}^{I} D_i(t) + \sum_{h=1}^{H} D_h(t) + E_k(t) - \sum_{i=1}^{I} L_i(t)\,. \tag{E.10}$$

F. The Central Bank

The central bank (CB) sets the policy rate $\bar{r}$ exogenously, 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.

The central bank's profits $\Pi^{CB}(t)$ 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 a vis the banking system:

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

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

$$E^{CB}(t) = E^{CB}(t-1) + \Pi^{CB}(t)\,. \tag{F.2}$$

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

[17] Please 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 thus is 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 took 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 the same 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 (F.4).

TABLE I. 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 non-financial assets	nama_10_nfa_bs
Non-financial transactions	nasa_10_nf_tr
Business demography by legal form (from 2004 onwards, NACE Rev. 2)	bd_9ac_l_form_r2
Current level of capacity utilization in manufacturing industry	teibs070
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

The net creditor/debtor position of the national economy to the rest of the world ($D^{RoW}(t)$)[18] evolves according to the following law of motion

$$D^{RoW}(t) = D^{RoW}(t-1) - \overbrace{(1+\tau^{EXPORT})\sum_{l} C_l(t)}^{\text{Exports}} + \overbrace{\sum_{m} P_m(t) Q_m(t)}^{\text{Imports}}, \tag{F.3}$$

where e.g. a balance of trade surplus (deficit) enters with a negative (positive) sign, since $D^{RoW}(t)$ is on the liability side of the CB's balance sheet and thus a trade surplus (deficit), i.e. 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[19] to the government deficit (surplus)[20] and to the balance of trade:[21]

$$\begin{aligned} E^{CB}(t) + D^{RoW}(t) &= L^G(t) - D_k(t) \\ &= L^G(t) - \sum_{i=1}^{I} D_i(t) - \sum_{h=1}^{H} D_h(t) - E_k(t) + \sum_{i=1}^{I} L_i(t)\,. \end{aligned} \tag{F.4}$$

II. CALIBRATION – THE ECONOMY OF AUSTRIA

Austria is a typical example for an advanced small open economy[22]: 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 %, the import quota about 48 %). Austria's well-developed service sector constitutes about 71 % of total GDP, while the industry sector takes a smaller share with about 28 % in GDP and the agricultural sector contributes much less (about 1.5 % 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 %, while the overall tax burden, i.e. the ratio of total taxes and social security contributions to GDP, reaches 43 %.

We calibrate the model to the Austrian economy at a scale of 1:1, i.e. each agent in the model represents a natural person or legal entity, such as corporations, government entities and institutions, in Austria. The time steps of the model are quarters, and the calibration period is 2012:Q4. All model parameters are collected in table II. We obtain the data for the model parameters from Eurostat and Statistik Austria. Specifically, we rely on data from census

[18] In case $D^{RoW}(t) < 0$, the national economy is net creditor to the RoW, if $D^{RoW}(t) > 0$, the national economy is a net debtor to the RoW.

[19] 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.

[20] Financial flows relating to a deficit (surplus) by 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}.

[21] 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.

[22] For facts and figures about the Austrian economy see e.g. the Austrian Statistical Agency, `http://statistik.at/web_en/statistics/index.html`. All data for the Austrian economy is provided for the year 2016.

TABLE II. Collection of all model parameters.

Parameter	Description	Value
G/S	Number of products/industries	64
I_s	Number of firms/investors in the s^{th} industry	see table III
H^{act}	Number of economically active persons	4901221
H^{inact}	Number of economically inactive persons	4130385
J	Number of government entities	317010
L	Number of foreign consumers	158505
ν	Memory parameter (investment)	0.5
ρ	Quantity adjustment parameter	0.9
η^a	Support price adjustment parameter (random variable)	0
η^b	Support price adjustment parameter (random variable)	0.05
υ	Population growth rate	0.0025
$\bar{\alpha}_i$	Average productivity of labor of the i^{th} firm	see section II A 2
κ_i	Productivity of capital of the i^{th} firm	see section II A 2
β_i	Productivity of intermediate consumption of the i^{th} firm	see section II A 2
δ_i	Depreciation rate for capital of the i^{th} firm	see section II A 2
ω	Desired capacity utilization rate	0.8458
$\bar{w}_i$	Average wage rate of firm i	see section II A 2
sb^{inact}	Pension/social benefits in mln. Euro	0.0024
sb^{other}	Social benefits received by all households in mln. Euro	0.0006
a_{sg}	Technology coefficient of the g^{th} product in the s^{th} industry	see section II A 2
b_g^{CF}	Capital formation coefficient of the g^{th} product (firm investment)	see table III
b_g^{CFH}	Household investment coefficient of the g^{th} product	see table III
b_g^{HH}	Consumption coefficient of the g^{th} product of households	see table III
c_g^G	Consumption of the g^{th} product of the government in mln. Euro	see table III
c_g^E	Exports of the g^{th} product in mln. Euro	see table III
c_g^I	Imports of the g^{th} product in mln. Euro	see table III
τ^{INC}	Income tax rate	0.2189
τ^{FIRM}	Corporate tax rate	0.0879
τ^{VAT}	Value-added tax rate	0.1531
τ_i^Y	Net tax rate on products of the i^{th} firm	see section II C 2
τ_i^K	Net tax rate on production of the i^{th} firm	see section II C 2
τ^{SIF}	Social insurance rate (employers' contributions)	0.2121
τ^{SIW}	Social insurance rate (employees' contributions)	0.1693
τ^{EXPORT}	Export tax rate	0.0024
τ^{CF}	Tax rate on capital formation	0.262
θ^{UB}	Unemployment benefit replacement rate	0.3569
ψ	Fraction of income devoted to consumption	0.9247
ψ^H	Fraction of income devoted to investment in housing	0.0855
θ^{DIV}	Dividend payout ratio	0.8318
θ	Rate of installment on debt	0.05
$\bar{r}$	Policy rate (bank refinancing rate)	0.0014
μ	Risk premium on policy rate	0.0109
r^G	Interest rate on government bonds	0.0083
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

and demographic surveys, input-output tables, government statistics, national annual sector accounts and business surveys. Macroeconomic data are obtained from the Eurostat bulk download facility where they are freely available.[23] 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. Eurostat data tables are collected in table I.

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[23] see `http://ec.europa.eu/eurostat/estat-navtree-portlet-prod/BulkDownloadListing?sort=1&dir=data` (Last accessed December 15^{th}, 2017)

TABLE III. Sectoral/Product parameters.

	I_s	N_s	$\bar{\alpha}_s$	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	0.013	1.6884	0.0517	0.0121	0.0004	0.01	-0.2272	0.0023	0.0017	0.011	0	236.8827	646.8664
A02	1867	18107	0.0345	1.9611	0.2225	0.0132	0.0025	0.0082	-0.0384	0	0	0.0024	0	18.5508	164.4364
A03	234	283	0.0554	1.5201	0.0443	0.0078	0.0025	0.0199	0.0032	0	0	0.0004	0	0.7063	15.7531
B	448	6273	0.0882	2.0612	0.2229	0.0301	0.0086	0.0149	-0.007	0.0006	0.0046	0.0003	0	261.2803	2718.2566
C10-12	4757	82473	0.0579	1.3643	0.5403	0.0243	0.0058	0.0038	-0.009	0	0	0.0661	0.1383	2241.6105	1985.6214
C13-15	2302	21779	0.0336	1.4745	0.3603	0.0193	0.0059	0.0047	-0.0032	0.0027	0.0001	0.0309	0	810.785	1733.3023
C16	3860	35741	0.0514	1.2712	0.443	0.0157	0.006	0.0043	0.0034	0.003	0.0697	0.0004	0	838.6087	391.7621
C17	1024	19411	0.0789	1.3816	0.4208	0.0236	0.0095	0.003	-0.0006	0	0	0.002	0	1083.3919	645.3532
C18	410	11355	0.0541	1.5942	0.3017	0.0265	0.0098	0.0032	0.0054	0	0	0	0.7114	146.5366	17.9048
C19	8	1294	1.0855	1.0435	1.1841	0.0327	0.015	0.0086	-0.0023	0	0	0.0229	0	611.0467	1740.8156
C2	465	17644	0.1964	1.0798	0.7877	0.0189	0.0079	0.0022	0.0008	0	0.0018	0.0075	0	3074.6665	3439.261
C21	100	12488	0.0594	1.8165	0.1987	0.0233	0.0083	0.0028	0.0067	0	0	0.0053	362.6765	677.4728	992.2112
C22	684	29409	0.0452	1.5493	0.4131	0.0255	0.0081	0.0036	0.009	0.0028	0.0106	0.0031	0	974.0927	1128.7509
C23	1673	33312	0.0416	1.5627	0.2567	0.0214	0.0082	0.0095	0.0091	0.002	0.0248	0.0011	0	537.3611	512.1566
C24	2593	38264	0.1034	1.2631	0.6197	0.0254	0.0088	0.0058	0.0044	0.0057	0.0002	0	0	2700.8871	2358.3828
C25	2107	69927	0.046	1.5131	0.4595	0.024	0.0089	0.0036	0.0065	0.014	0.0138	0.0021	0	1614.5241	1329.6179
C26	482	22254	0.0549	1.7995	0.2088	0.035	0.0081	0.0017	0.003	0.0448	0.0013	0.0102	8.3906	1432.9269	2165.1725
C27	852	42643	0.0506	1.7231	0.349	0.0331	0.0079	0.0011	0.0033	0.0352	0.0011	0.0063	0	1901.293	1701.8589
C28	1530	76751	0.0617	1.4445	0.619	0.0272	0.0089	0.0017	0.0074	0.1116	0.0057	0.0008	0	4111.0151	3225.8986
C29	385	29445	0.1057	1.3422	0.4287	0.0294	0.0098	0.0017	0.0037	0.0692	0.0021	0.0173	0	3160.2191	3042.8159
C3	105	10133	0.0841	1.297	0.8693	0.0501	0.0096	0.002	0.0068	0.0149	0.0004	0.0018	2.5061	802.1304	540.184
C31˙32	6042	48253	0.0316	1.5358	0.438	0.0182	0.0056	0.0067	0.0107	0.0298	0.0009	0.0207	52.792	1017.2674	1217.8629
C33	2314	25105	0.0758	1.7862	1.6048	0.0007	0.0182	0.0026	0.0138	0.0379	0.0011	0	0	326.8518	267.1497
D	3464	30136	0.1788	1.2795	0.2154	0.0196	0.0104	0.005	0.0089	0	0	0.0265	0	535.1516	330.3382
E36	323	1609	0.1205	2.4664	0.0385	0.0086	0.0135	0.0086	0.0262	0	0	0	0	0.739	0.0729
E37-39	2802	14670	0.1147	1.7808	0.0738	0.0126	0.0131	0.0142	0.0081	0	0	0.0005	0	229.852	435.3843
F	41270	298483	0.0398	1.617	0.4166	0.013	0.0076	0.0046	0.0119	0.2843	0.7134	0.0097	0	143.1482	163.4686
G45	13457	84091	0.0234	2.058	0.4489	0.0125	0.0061	0.0051	0.018	0.0162	0.0005	0.0255	0	163.0212	9.4187
G46	34691	216153	0.0379	2.4177	0.4471	0.022	0.0091	0.0065	0.0143	0.037	0.0142	0.0393	153.0269	2521.8589	171.6682
G47	54313	379213	0.0136	2.7554	0.3463	0.0156	0.0043	0.0089	0.02	0.0069	0.0321	0.119	148.1679	0	0
H49	15377	132344	0.0278	2.0744	0.1581	0.0173	0.0059	0.0283	0.019	0.0013	0.0014	0.0258	460.2394	1389.1238	1109.5918
H5	237	708	0.0271	1.4156	0.1718	0.0474	0.0033	0.003	0.0077	0	0	0.0003	0	105.2748	314.932
H51	302	7585	0.1202	1.1583	0.5588	0.0511	0.0106	0.004	0.0062	0	0	0.0095	0.0603	223.2084	235.2614
H52	1669	50907	0.0443	2.6821	0.0472	0.0116	0.0097	0.0057	0.0198	0.0008	0.0005	0.0049	399.1448	552.6995	496.9917
H53	765	26495	0.0235	2.1402	0.9526	0.0246	0.008	0.0117	0.024	0	0	0.0019	0	97.0928	61.3058
I	57370	313570	0.0184	2.6971	0.2693	0.0102	0.0044	0.0155	0.0056	0	0	0.1229	3.8962	555.3137	434.3863
J58	1631	14294	0.0597	1.606	1.5878	0.0554	0.0112	0.002	0.0037	0.006	0.0002	0.0076	13.9559	233.7607	385.7143
J59˙6	3970	14639	0.0422	1.6539	0.5918	0.0521	0.0076	0.0049	-0.0167	0.0025	0.0001	0.0061	0.2237	74.5477	183.3492
J61	428	11262	0.1369	1.6506	0.1367	0.0304	0.0176	0.0033	0.01	0	0	0.0157	0	180.2524	160.2939
J62˙63	20936	69201	0.045	2.0346	1.0735	0.079	0.0121	0.0035	0.0184	0.0895	0.0027	0	0	761.3236	481.1782
K64	2315	80883	0.0427	2.3776	0.2407	0.0194	0.0125	0.0442	0.0608	0	0	0.0116	5.8317	548.7606	281.5103
K65	432	28965	0.0549	1.8021	0.3554	0.0104	0.0132	0.0442	0.0199	0	0	0.025	0.0377	305.453	156.174
K66	10925	24005	0.0314	1.6969	2.1615	0.0431	0.0049	0.0242	0.0116	0	0	0.0017	1.3674	28.6206	13.3978
L68A	12703	28596	0.3778	3.1243	0.0797	0.0246	0.0126	0.0138	0.0105	0.0065	0.0094	0.1756	8.1468	35.0229	24.1186
M69˙7	43686	131051	0.0329	2.0539	0.8827	0.0162	0.0085	0.0045	0.0173	0.0008	0.0014	0.0025	0	531.0091	420.1841
M71	22134	66633	0.0317	2.1331	0.4176	0.0245	0.0073	0.0031	0.0162	0.0247	0.0756	0	28.1556	420.8905	160.9575
M72	2293	16051	0.1483	3.8832	1.251	0.1881	0.0536	0.0131	0.0021	0.1436	0.0043	0	45.4848	438.1191	192.2224
M73	14414	38333	0.0357	1.4641	1.4795	0.0336	0.0044	0.0102	0.0084	0	0	0	1.928	245.0094	288.5762
M74˙75	14224	23056	0.0233	2.0357	0.7738	0.0334	0.0035	0.0075	0.0057	0	0	0.0021	2.667	36.0686	17.2111
N77	3617	12665	0.1539	3.1441	0.0871	0.0623	0.0075	0.0067	0.0038	0	0	0.0079	21.5119	260.3277	272.6119
N78	1498	91425	0.0133	9.0439	5.8056	0.0385	0.0087	0.001	0.0464	0	0	0	0	23.4148	30.4304
N79	2725	15003	0.0417	1.2959	1.0959	0.0208	0.0048	0.01	0.0065	0	0	0.0137	28.06	16.4318	14.4284
N80-82	16122	123369	0.0144	2.7125	0.5922	0.0173	0.0044	0.0067	0.0224	0.0016	0.0044	0.006	132.2162	56.7962	77.6044
O	10000	251139	0.0213	3.4019	0.0995	0.0114	0.0094	0.0428	0.0186	0	0	0.0004	5091.0778	34.0627	14.3932
P	12652	122290	0.0338	7.4233	0.1433	0.0166	0.0194	0.0271	0.0275	0	0	0.0142	3438.6954	8.8079	16.3112
Q86	42618	175068	0.0299	3.494	0.1874	0.0126	0.0114	0.0455	0.0127	0	0	0.0348	3734.6819	33.4694	17.7666
Q87˙88	34706	159810	0.0103	3.3566	0.1748	0.0093	0.0053	0.0322	-0.0335	0	0	0.0239	811.7351	0	90.8112
R90-92	15872	35081	0.0248	3.4789	0.236	0.0228	0.0086	0.0232	-0.0049	0.002	0.0001	0.0133	200.3667	54.0488	75.4527
R93	6721	25111	0.0183	2.734	0.0665	0.0087	0.0043	0.0172	0.0044	0	0	0.0097	74.2059	6.8246	4.7961
S94	7328	58500	0.0143	2.722	0.14	0.0081	0.0058	0.0662	0.032	0	0	0.0109	341.4687	0	0
S95	1893	4762	0.0555	2.5901	2.2338	0.1992	0.0141	0.0052	0.0175	0	0	0.002	0	0.5907	2.0889
S96	19993	62487	0.0124	3.4651	0.1704	0.0124	0.0028	0.0109	0.014	0	0	0.017	30.7723	0	8.9059

A. Firms

1. *Number of Firms*

Parameters that specify the number of firms are taken directly (or derived from) business demography data. Annual business demography data shows the characteristics and demography of the business population. The data is drawn from business registers and depicts (1) the population of active enterprises, (2) the number of enterprise births and deaths, and (3) related variables on employment. Specifically we are using 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) and the public administration and defence, compulsory social security sector (O64). The number of firms in industries A01-A03 is set according to the Grüner Bericht,[24] and the number of firms in industry O64 (i.e. generic administrative government units) is set to $10,000$.

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 % of domestically producing firms, which approximately corresponds to the share of exports in total value added.

2. *Sectoral Classification of Firms and Input-output Parameters*

For the classification of industries (s) we use the statistical classification of economic activities in the European Community (NACE), which is used for the classification of economic activities in the European Union. 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 Euro area 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) to 64 ($S = 64, G = 64$).

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 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 [30]. 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)[25] of 64 (CPA*64) products for the technology coefficient of the g^{th} product in the s^{th} industry a_{sg}. In order to get 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) of 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 ($\bar{\alpha}_i = \bar{\alpha}_s \quad \forall i \in I_s$).

[24] 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, please see `http://www.awi.bmlfuw.gv.at/index.php?id=gruenerbericht` (Last accessed December 15^{th}, 2017).

[25] 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).

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.[26] The average wage employees receive from firm i ($\bar{w}_i = \frac{w_s}{N_s} \quad \forall i \in I_s$) (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 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)[27] in the industry multiplied by the desired capacity utilization rate (ω, see the next section II A 3). 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 as 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 III B. 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.

3. *Income/Expenditure and Other Behavioral Parameters*

To depict adaptive behavior, a weighted average of past values of a certain variable provides a good information set for firm agents to form expectations about the future development of this variable.[28] Given the arguments put forth on this matter, it seems reasonable to assume that the weight of the most recent developments of the variable in question, i.e. the memory parameter, is rather high. Consequently, we set the weight firm i places on last period's excess supply for its formation of expected demand to $\rho = 0.9$, which relates to consumption as a rather stable economic aggregate according to empirical observed regularities. However, given the larger volatility of investment we can see in the data, we set the memory parameter lower for the computation of average capital with $\nu = 0.5$, since firms will tend to place less weight on the last observation due to their knowledge of prospectively larger changes in investment as compared to consumption. We assume the volatility of individual prices to be rather low and to be uniform across all different goods of type g. Specifically, we set the rate of change of the individual price to range between 0 and 5 % for each individual firm i. Therefore, support for the uniform distribution for the price adjustment $\eta_i(t)$ is $\eta^a = 0, \eta^b = 0.05$.

Firms' dividend payout ratio θ^{DIV} is set to match interest and dividend receipts (D.4 received) plus mixed income (B.2A3N)[29] by the household sector in national accounting data (NASA, 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 to the ownership of property rights in non-financial and financial firms by the household sector - and is set accordingly for each individual firm.

Business surveys provide information on areas not covered by quantitative statistics. The long run desired rate of capital utilization (ω) is set according to the current level capacity utilization (BS-ICU-PC) obtained from business surveys in Austria, which is given in the Eurostat data set current level of capacity utilization in manufacturing industry (teibs070).

B. Households

1. *Number of Households*

Parameters that specify the number of households (persons) are taken directly (or derived from) census data. A population census provides a numerical picture of the structure of the population, households and families in a

[26] 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) who during the reference week performed work - even if just for one hour a week - for pay, profit or family gain. (`http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Employed_person_-_LFS`)

[27] 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.

[28] This notion ultimately, among many others, goes back to Keynes, see e.g. [31, p.2].

[29] In the logic of IOTs, 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.

country. 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 labour reserve) is taken from the European Labour Force Survey (LFS).[30] The population growth parameter υ is set to 0.025 to match a yearly average growth of the Austrian population of 1 %, which is roughly equal to average population growth in Austria for the years 2012-2016 according to demographic statistics by Statistik Austria.[31]

2. *Income/Expenditure and Other Behavioral Parameters*

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, S.15).

Transfers other than consumption, savings, taxes and subsidies[32] 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 concerning social benefits (D.62) are attributed to the different household (consumer) types according to their status of employment. The data is taken from national accounting statistics on general government expenditures by function (COFOG classification, Eurostat table gov_10a_exp), which is used to allocate the total flow of the different social benefits (sb^{inact}, sb^{other}) from the government to persons for which this transfer applies. To break 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. The replacement rate for unemployment benefits θ^{UB} is chosen according to the statutory replacement rate of 55 % of net income, which amounts to a replacement rate on gross income of $\theta^{UB} = 0.55(1 - \tau^{INC})(1 - \tau^{SIW})$.

The parameter ψ^H capturing the fraction of household expected disposable income $Y_h(0)$ that 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[33] and gross fixed capital by sector from IOTs are mutually consistent.

C. Government

1. *Number of Government Agents*

The number of government entities (J) is set to 25 % 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, districts, among others, in Austria according to their participation in the Austrian economy.

2. *Income/Expenditure and Other Behavioral Parameters*

Tax, subsidy and investment rates for the government are set such that these rates approximate the actual financial flows observed in national accounting data (Eurostat, National Annual Sector Accounts - NASA), i.e. non-financial transactions (nasa_10_nf_tr), as well as government revenue, expenditure and main aggregates (gov_10a_main). In the

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[30] 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 informs on persons who do not meet the ILO criteria for unemployment but who are willing and available to work within short notice (labour reserve).

[31] Please see `http://www.statistik.at/web_en/statistics/PeopleSociety/population/population_stock_and_population_change/index.html` for further reference.

[32] 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)

[33] See `https://www.statistik.at/web_en/statistics/Economy/national_accounts/input_output_statistics/index.html` 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.

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 which 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.

Especially, the income tax rate τ^{INC} on income from both labor and capital is 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).[34] 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 NASA non-financial transaction data, 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 subtract 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 ($\tau_i^Y = \tau_s^Y \quad \forall i \in I_s$) as well as on production ($\tau_i^K = \tau_s^K \quad \forall i \in I_s$) 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 33).

D. The Bank

Banks' capital requirement coefficient (ζ) is set to 3%. A capital requirement of 3% corresponds to the maximum leverage ratio (tier 1 capital in relation to total exposure) as recommended in the Basel III framework. The rate of debt installment (θ) is set such that firms repay 1.25% of their total outstanding debt every quarter, which means that the implicit maturity is 20 years.

The interest rate r paid on firms' outstanding loans is the ratio of total interest payments (D.41) received by financial corporations (S.12) that we obtain from NASA data to total loans extended to firms (L_t), and is adjusted to match empirically observed interest rates to our model financial market where firm debt constitutes the only financial asset held by the banking sector. The policy rate $\bar{r}$ is set according to the 3-months EURIBOR interest rate obtained from money market interest rates (irt_st_a) scaled to quarters. The risk premium by the banking sector μ is then calculated by the difference between the policy rate $\bar{r}$ set by the central bank and the interest rate.

The bank's maximum loan-to-value (LTV) ratio (ζ^{LTV}) is set to 60%. LTV is one of the most common ratios considered for secured loans, and loans with an LTV ratio below 60% are typically considered as low or medium risk loans. We choose the loan-to-value ratio for a new firm replacing a bankrupt firm ζ^b to be equal to 0.5 (see equation A.33), which is roughly in line with average values obtained from the SABINA database.[35]

III. INITIAL CONDITIONS – THE ECONOMY OF AUSTRIA

We set initial conditions representing the Austrian economy according to 2012:Q4. All initial conditions in the model are collected in table IV.

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34 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.

35 The SABINA Database covers all financial statements of all Austrian firms obliged to provide this statement by law. See http://www.bvdinfo.com/en-gb/our-products/company-information/national-products/sabina (Last accessed December 14^{th}, 2017) for further information.

TABLE IV. Collection of all initial conditions in the model.

Parameter	Description
$P_i(0)$	Initial price of the i^{th} firm
$Y_i(0)/\bar{Y}_i(0)/Q_i^d(0)$	Initial production/demand of the i^{th} firm (in mln. Euro)
$K_i(0)$	Initial capital of the i^{th} firm (in mln. Euro)
$M_i(0)$	Initial stocks of raw materials, consumables, supplies, spare parts of the i^{th} firm (in mln. Euro)
$S_i(0)$	Initial stocks of finished goods of the i^{th} firm (in mln. Euro)
$N_i(0)$	Initial number of employees of the i^{th} firm
$D_i(0)$	Initial liquidity (deposits) of the i^{th} firm (in mln. Euro)
$L_i(0)$	Initial debt of the i^{th} firm (in mln. Euro)
$D_h(0)$	Initial personal assets (deposits) of the h^{th} household (in mln. Euro)
$w_h(0)$	Initial wage of the h^{th} household (in mln. Euro)
$K_h(0)$	Initial household capital (in mln. Euro)
$L^G(0)$	Initial government debt (in mln. Euro)
$E_k(0)$	Initial banks' equity (in mln. Euro)
$E^{CB}(0)$	Initial central banks' equity (in mln. Euro)
$D^{RoW}(0)$	Initial net creditor/debtor position of the national economy to RoW (in mln. Euro)

TABLE V. Initial conditions for the institutional sectors of the Austrian economy.

Parameter	Description	Value
D^I	Initial liquidity (deposits) of the firm sector (in mln. Euro)	58356.6
L^I	Initial debt of the firm sector (in mln. Euro)	474437.9
w^{UB}	Initial unemployment benefits (in mln. Euro)	0.0037
D^H	Initial personal assets (deposits) of the household sector (in mln. Euro)	232685.8
K^H	Initial capital (dwellings) of the household sector (in mln. Euro)	434603.9
$L^G(0)$	Initial government debt (in mln. Euro)	260111
$E_k(0)$	Initial banks' equity (in mln. Euro)	67370.1818

A. 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 [32, 33]. Therefore initial employment of firm i ($N_i(0) \quad \forall i \in I_s$) is 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 the firm size distribution in Austria.[36] To determine initial sectoral production $Y_s(0)$, 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 $\bar{\alpha}_i$:

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

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 $^{\text{th}}$ firm in sector s as measured by production, accounting for 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 buffers stock of material inputs $1/\omega$ - firms hold enough intermediate inputs so as to provide for expected use of these inputs as well as accounting for their desired buffer stock:

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

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

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 sectoral capital stock $K_s(0)$.

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

where the total amount of firm debt L^I is obtained from national accounting (NASA) data as the total non-consolidated asset position of the financial corporations sector (S.12) regarding loans (F.4) as well as other accounts receivable/payable (F.8), which is mostly composed of trade credit. Total initial liquidity (deposits) of all firms as an aggregate, D^I, is set according to NASA data (F.2, i.e. deposits, held by non-financial corporations sector, S.11, the non-consolidated asset position). 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:

$$D_i(0) = D^I \frac{\max(0, \Pi_i(0) + r(L_i(0) - \min(0, D_i(0))) - \bar{r}\max(0, D_i(0)))}{\sum_i \max(0, \Pi_i(0) + r(L_i(0) - \min(0, D_i(0))) - \bar{r}\max(0, D_i(0)))} \,.$$

The initial sectoral 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 drawn from a normal distribution with mean 1 and standard deviation 0.02.

B. Households

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 employer of household h, or equal to 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:

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

Initial personal assets (deposits) of the h^{th} household ($D_h(0)$) are obtained from national accounting (NASA) data (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:

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

where D^H are the initial personal assets (deposits) of the household sector and $Y_h(0)$ is determined according to equation (C.10). Initial capital (dwellings) of the h^{th} household ($K_h(0)$) is set to match dwellings (N111N) owned by the household and NPISH sectors (S14_S15) as obtained from balance sheets for non-financial assets (nama_10_nfa_bs) 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:

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

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

C. Government

Initial government debt ($L^G(0)$) 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).

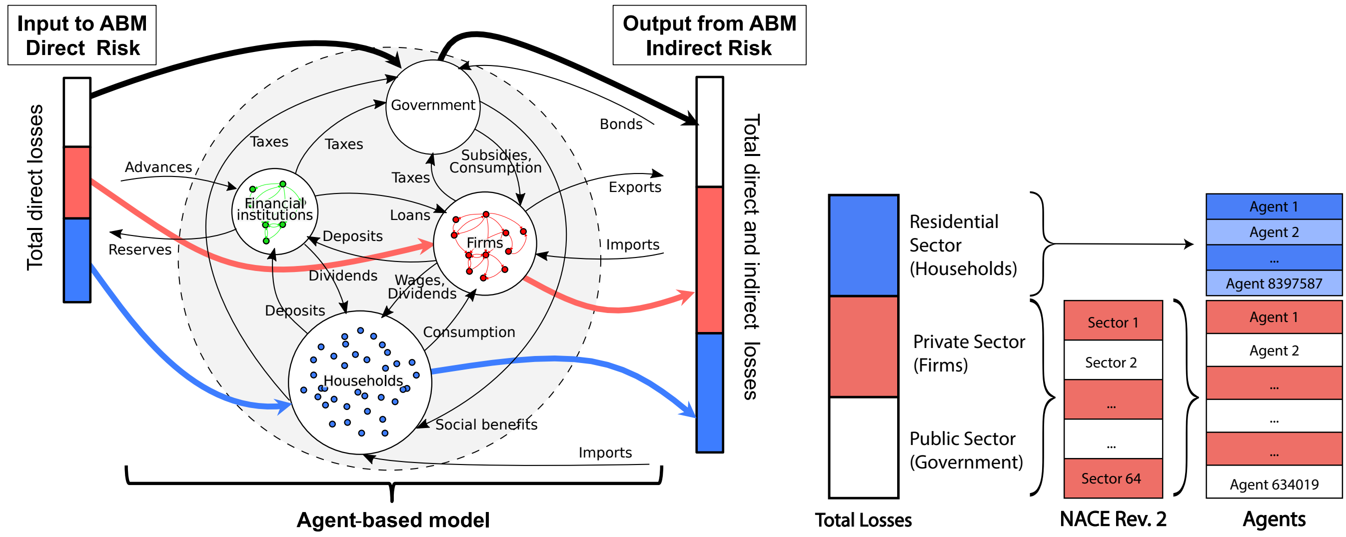

FIG. 2. (a) Schematic overview of the ABM structure showing the institutional sectors (households, non-financial and financial firms and a general government), and their interactions. (b) Distribution of total losses to institutional sectors, industry sectors, and to individual agents.

D. The Bank

Initial banks' equity ($E_k(0)$) is set to match the solvency ratio of Austrian banks as obtained from publicly available data from the Austrian National Bank.[37]

E. The Central Bank

Initial central bank's equity ($E^{CB}(0)$) is the residual on the central banks' passive side, 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 banks' equity ($E^{CB}(0)$) is set according to equation (F.4) where the initial balance of trade with the rest of the world ($D^{RoW}(0)$) is assumed to be zero and initial bank reserves held ($D_k(0)$) are set according to equation (E.10).

IV. FLOOD RISK ESTIMATION AND DAMAGE SCENARIO GENERATOR: A COPULA APPROACH

Generally speaking, estimating losses due to natural disaster events is done via so-called catastrophe modelling approaches [34, 35]. There, losses are a function of the natural hazard, the exposure and the physical vulnerability of the exposed elements. As the hazard is represented in probabilistic terms (e.g. the probability of daily rainfall), also the losses are probabilistic and usually represented via a loss distribution which gives the relationship between losses and their corresponding probabilities. Most modelling approaches calculate such loss distributions on the very local scale, taking the average and summing up these averages over given regions to obtain average losses on larger scales. Unfortunately, averages do not capture the specific characteristics of extreme events, which are by definition low probability events. Thus, the application of averages over the whole risk curve (in form of loss distributions) on larger levels is needed. The main problem here is that in order to upscale the loss distributions to larger levels, the dependency of the risk between regions has to be taken into account. A simple example can illustrate this: while small scale flooding occurs usually only in local areas, large scale flooding happens in larger areas and across regions. Hence, losses for extreme events will be much larger than losses for small scale events, and such dependencies need to be taken explicitly into account to avoid underestimation of risks [36]. Given the importance of extreme events in

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[37] Please see `https://www.oenb.at/en/Publications/Financial-Market/Facts-on-Austria-and-Its-Banks.html` (Last accessed January 15th, 2018) for the corresponding data set.

our analysis, we therefore also need to model this behavior explicitly and use a copula-approach which can explicitly model increasing tail dependencies.

The details of the copula methodology, which is now seen as appropriate to avoid underestimation of extreme risk [36], and a general algorithm to perform such coupling can be found in [37]. In the classic sense, copulas are used for modeling multivariate distributions of continuous random variables. The copula model separates the marginal distributions (e.g. individual risk in the form of a probability distribution) and the structure of dependencies. The method goes back to Sklars theorem [38], which states that the joint distribution function H of any continuous random variables X, Y can be written as

$$H(x, y) = C[F_x(x), F_y(y)] \quad x, y \in \mathbb{R} \quad ,$$

with marginal probability distributions $F_x(x)$ and $F_y(y)$ and $C = [0,1]^2 \rightarrow [0,1]$ as the (two-dimensional) copula. If $F_x(x)$ and $F_y(y)$ are continuous, C is uniquely defined. There are many different copula types available (Gaussian, Clayton, Gumbel, Frank, Joe – to mention a few), each describing different types of dependence structures including independence (McNeil et al. 2015). The flood loss distribution data on the local and basin scale is based on analysis done in Jongman et al. (2014) and used as the input (e.g. the $F_x(x)$, $F_y(y)$, $\ldots$) for upscaling distributions to the country level. The different river basin dependencies in Austria are estimated using different copula types C (e.g. Clayton, Frank or Gumbel) and are built on maximum river discharges for the period 1990-2011 for each basin. The loss distributions from each basin are coupled using the given copulas and a minimax ordering approach to finally derive a loss distribution on the country level. To the authors best knowledge, there are only two other models currently available for Austria using a copula approach [39, 40]. The analysis presents an extension of the analysis of [39] in the sense that focus and estimation were performed for very extreme events. For example, the 1500 loss return period used in our study provides a method to distribute losses for a given event over the whole Austrian scale on a very fine scale. In more detail, the loss distributions for Austria, derived by the application of the copula approach, form the basic input for the agent-based modelling approach via a damage scenario generator discussed next.

Lets assume we have the loss distribution calculated based on the method explained above. The task is to distribute the losses of an event to the exposed agents, including households, firms, banks, and the like. This is achieved via an overlaying approach of land cover data and explicit spatial information of exposure in the different sectors. For example, Figure 3(a) shows the exposure for the region Salzburg. In the case of a hazard event, not all exposed elements will be affected. Figure 3(b) shows the flood area for a 100-year event based on Hora, which we overlay with the exposure map to finally derive the information of affected risk bearers according to the realized risk (e.g. 100 year flood loss event), see Figure 3(c). This was done on all regions in Austria as well as the selected return periods from the loss distribution (see fig. 2).

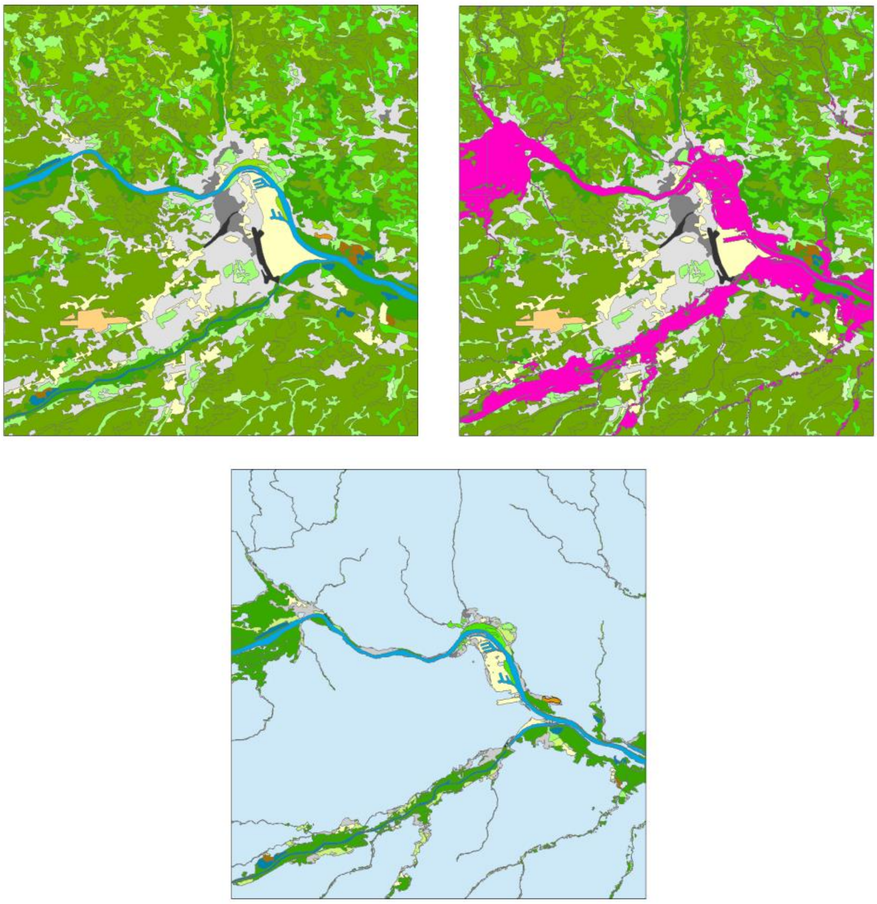

FIG. 3. Overlaying of exposed elements, with flood hazard maps, to derive agents affected for a given flood loss return period (here a 100-year event for the region of Salzburg in Austria).

We developed a damage scenario generator using an importance sampling algorithm to generate scenarios over given time horizons. Importance sampling is especially useful for the simulation of very extreme events. It ensures that extreme events (i. e. events with high losses) have a higher chance of being selected during the sampling process than frequent events. Consequently, the sampling size can be greatly reduced and one can focus on the events of main interest (see Borgomeo et al. 2016). For illustration purposes, a snapshot of one output of the generator is shown in Table VI below with a total number of 3000 events sampled over a 10-year period. The first scenario is the no-event scenario, afterwards we selected scenarios, which show the basic structure and advantage of importance sampling, namely the emphasis on extreme events rather than frequent ones.

TABLE VI. Output example of the scenario generator.

Scenario/Years	1	2	3	4	5	6	7	8	9	10
1	0	0	0	0	0	0	0	0	0	0
32	0	932	0	0	0	0	0	0	0	0
69	7748	0	0	9301	0	0	0	0	0	0
850	0	140	0	0	0	0	0	12000	0	0
2102	0	14443	0	0	0	932	0	11500	0	0

Note, not only single scenarios can be looked at (Scenario 1), but also multiple events over the selected time period, e.g. Scenario 69 has two events, in year 1 and year 4, respectively. Furthermore, events that occur shortly or very late after a disaster can be looked at, too, e.g. scenario 2102 has loss events in year 2, year 6 and year 8. The loss event information in the cells is only the first step within the damage scenario generator, in the next step the losses are distributed to the agents as discussed above. Summarizing, using a copula approach, losses for large scale events on the country level were estimated and a damage scenario generator was built, which is used to provide the input in form of losses to individual agents across 65 different sectors based on real world spatial explicit banks, firms and household asset data.

TABLE VII. Cumulative growth effects on sectoral GDP after a 250-year flood event for all industry sectors in pp relative to the baseline scenario.

Sector		Cumulative Growth Effect (pp), Simulation Years									
		2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
CPA_A01	Products of agriculture, hunting and related services	-0.21	-0.58	-0.06	0.35	0.24	-0.05	-0.58	-0.75	-1.15	-1.03
CPA_A02	Products of forestry, logging and related services	0.37	4.88	4.21	1.32	1.00	1.40	1.16	0.77	0.54	0.49
CPA_A03	Fish and other fishing products;	-0.16	0.10	1.51	1.78	1.68	1.02	0.44	0.00	-0.56	-0.29
CPA_B	Mining and quarrying	0.04	0.04	-0.29	0.21	0.00	-0.63	-2.15	-4.05	-4.96	-5.01
CPA_C10T12	Food products, beverages and tobacco products	-0.54	-0.26	0.22	0.20	0.07	-0.18	-0.52	-0.75	-1.00	-0.73
CPA_C13T15	Textiles, wearing apparel and leather products	-0.06	1.95	4.26	4.06	3.02	1.79	0.80	0.05	-0.87	-0.68
CPA_C16	Wood and of products of wood and cork,	4.63	5.85	1.88	0.60	0.75	0.56	0.18	-0.02	-0.05	0.02
CPA_C17	Paper and paper products	-0.65	-0.22	0.09	0.11	0.03	-0.17	-0.43	-0.62	-0.68	-0.67
CPA_C18	Printing and recording services	-0.13	-0.13	0.73	0.80	0.30	-0.20	-0.59	-0.68	-0.75	-0.66
CPA_C19	Coke and refined petroleum products	0.01	0.26	0.92	1.14	0.90	0.23	-0.34	-0.81	-1.27	-1.02
CPA_C20	Chemicals and chemical products	0.02	0.23	0.33	0.50	0.59	0.32	-0.31	-0.74	-1.03	-1.09
CPA_C21	Basic pharmaceutical prod., pharmaceutical preparations	-0.10	0.31	0.75	0.69	0.56	0.41	0.29	-0.07	-0.26	-0.14
CPA_C22	Rubber and plastics products	0.50	0.82	0.50	0.54	0.50	-0.11	-0.83	-1.06	-1.06	-0.67
CPA_C23	Other non-metallic mineral products	3.29	7.28	3.13	1.39	1.15	0.65	0.15	-0.13	0.00	-0.03
CPA_C24	Basic metals	0.03	-0.36	-0.54	-0.31	-0.13	-0.54	-1.22	-1.71	-1.87	-1.81
CPA_C25	Fabricated metal products, except machinery and equipment	0.56	2.12	1.63	0.91	0.39	-0.23	-0.67	-0.84	-0.90	-0.87
CPA_C26	Computer, electronic and optical products	-0.10	0.13	0.69	1.11	0.10	-1.67	-2.75	-2.80	-2.61	-2.07
CPA_C27	Electrical equipment	-0.09	0.39	0.85	1.10	0.77	0.37	-0.12	-0.17	0.00	-0.10
CPA_C28	Machinery and equipment n.e.c.	-0.07	0.74	1.22	0.71	-0.03	-1.00	-1.64	-1.78	-1.67	-1.54
CPA_C29	Motor vehicles, trailers and semi-trailers	-0.22	0.33	0.91	0.89	0.65	-0.02	-0.43	-0.56	-0.70	-0.71
CPA_C30	Other transport equipment	0.09	0.69	1.29	1.04	0.12	-0.73	-1.13	-1.14	-1.04	-0.81
CPA_C31_32	Furniture; other manufactured goods	-0.13	0.35	0.54	0.61	0.41	-0.33	-0.70	-0.46	-0.76	-0.67
CPA_C33	Repair and installation services of machinery and equipment	0.28	2.44	2.42	0.95	-0.15	-1.18	-1.77	-1.45	-1.49	-1.02
CPA_D35	Electricity, gas, steam and air-conditioning	-4.15	-2.25	-1.44	-1.33	-1.39	-1.50	-1.73	-2.00	-2.21	-2.23
CPA_E36	Natural water; water treatment and supply services	-1.45	-2.76	-1.96	-1.44	-1.17	-1.03	-1.09	-1.07	-1.33	-1.39
CPA_E37T39	Sewerage; waste collection, treatment and disposal activities;	-0.96	-2.16	-1.44	-0.72	-0.57	-0.75	-1.20	-1.48	-1.73	-1.77
CPA_F	Constructions and construction works	5.74	6.40	2.89	1.92	1.02	0.01	-0.64	-0.35	-0.31	-0.41
CPA_G45	Wholesale, retail trade, repair serv. of motor veh., motorcycles	-0.62	-0.28	0.45	0.47	0.21	-0.30	-0.59	-0.86	-0.98	-0.75
CPA_G46	Wholesale trade serv., exc. of motor veh. and motorcycles	-0.01	0.80	0.88	0.58	0.33	-0.02	-0.30	-0.42	-0.45	-0.40
CPA_G47	Retail trade services, except of motor vehicles and motorcycles	-0.63	-0.76	-0.41	-0.24	-0.22	-0.52	-0.64	-0.91	-0.97	-1.01
CPA_H49	Land transport services and transport services via pipelines	-0.23	0.39	0.61	0.48	0.32	0.12	-0.05	-0.30	-0.44	-0.37
CPA_H50	Water transport services	0.00	0.01	0.35	0.65	1.26	1.03	0.04	-0.01	-0.40	-1.48
CPA_H51	Air transport services	-0.24	0.09	0.56	0.46	0.23	-0.01	-0.27	-0.64	-0.79	-0.69
CPA_H52	Warehousing and support services for transportation	-0.21	0.02	0.39	0.38	0.25	0.05	-0.23	-0.39	-0.54	-0.50
CPA_H53	Postal and courier services	-0.25	-0.11	0.56	0.46	0.19	-0.14	-0.43	-0.57	-0.66	-0.58
CPA_I	Accommodation and food services	-1.31	-1.32	-0.80	-0.39	-0.22	-0.41	-0.48	-0.54	-0.70	-0.53
CPA_J58	Publishing services	-0.14	0.28	1.13	0.91	0.16	-0.46	-0.88	-0.94	-1.06	-0.86
CPA_J59_60	Motion picture, video and television programme prod. serv.	-0.56	-0.39	0.68	0.81	0.37	-0.20	-0.65	-0.78	-0.97	-0.90
CPA_J61	Telecommunications services	-0.54	-0.56	0.23	0.13	-0.01	-0.28	-0.47	-0.76	-0.97	-0.83
CPA_J62_63	Computer programming,	0.47	4.10	4.67	1.85	-0.28	-1.93	-2.78	-2.09	-1.43	-1.12
CPA_K64	Financial services, except insurance and pension funding	-0.99	0.00	0.35	0.27	0.03	-0.31	-0.61	-0.76	-0.86	-0.74
CPA_K65	Insurance, reinsurance and pension funding services,	-0.78	-0.42	0.16	0.15	-0.04	-0.33	-0.33	-0.75	-1.04	-0.83
CPA_K66	Services auxiliary to financial services and insurance services	-0.36	-1.57	-0.59	-0.10	-0.15	-0.27	-0.53	-0.62	-0.88	-0.91
CPA_L68	Real estate services excluding imputed rents	-3.27	-2.09	-1.50	-1.14	-1.21	-1.28	-1.39	-1.49	-1.59	-1.62
CPA_M69_70	Legal and accounting services;	-0.12	0.92	1.04	0.62	0.25	-0.15	-0.59	-0.75	-0.82	-0.76
CPA_M71	Architectural, engineering serv.; techn. testing, analysis serv.	4.87	6.40	2.15	0.84	0.68	0.07	-0.47	-0.46	-0.49	-0.48
CPA_M72	Scientific research and development services	1.01	5.58	5.42	1.57	-0.82	-2.92	-3.83	-2.36	-2.32	-1.27
CPA_M73	Advertising and market research services	-0.24	-0.02	0.66	0.57	0.23	-0.16	-0.61	-0.81	-0.94	-0.88
CPA_M74_75	Other prof., scientific and techn. serv.; veterinary serv.	-0.38	-0.59	-0.03	0.24	0.22	-0.06	-0.37	-0.55	-0.72	-0.74
CPA_N77	Rental and leasing services	-0.35	0.55	0.83	0.61	0.31	-0.09	-0.43	-0.62	-0.70	-0.58
CPA_N78	Employment services	0.20	2.96	2.03	0.97	0.31	-0.38	-0.95	-1.10	-0.76	-0.88
CPA_N79	Travel agency, tour operator and other reservation services	-1.02	-0.90	-0.11	-0.03	-0.05	-0.32	-0.21	-0.53	-0.66	-0.53
CPA_N80T82	Security and investigation services;	-0.55	-0.26	0.02	0.05	-0.06	-0.44	-0.70	-0.77	-0.87	-0.78
CPA_O84	Public administration and defence services;	-1.02	-0.48	-0.26	-0.12	0.01	0.08	0.08	0.01	0.01	0.03
CPA_P85	Education services	-0.14	-0.09	0.07	0.03	0.02	-0.02	-0.05	-0.10	-0.13	-0.08
CPA_Q86	Human health services	-0.29	-0.23	-0.04	-0.03	0.01	-0.02	-0.09	-0.10	-0.19	-0.19
CPA_Q87_88	Social work services	-0.55	-0.57	-0.13	-0.03	-0.13	-0.17	-0.32	-0.52	-0.68	-0.52
CPA_R90T92	Creative, arts and entertainment services	-0.70	-0.37	0.21	0.27	0.10	-0.19	-0.27	-0.31	-0.53	-0.47
CPA_R93	Sporting services and amusement and recreation services	-0.87	-0.82	-0.31	-0.19	-0.14	-0.30	-0.14	-0.25	-0.47	-0.41
CPA_S94	Services furnished by membership organisations	-0.54	-0.32	0.08	0.07	-0.05	-0.28	-0.26	-0.45	-0.67	-0.61
CPA_S95	Repair services	-0.48	-0.24	0.61	0.48	0.05	-0.33	-0.59	-0.80	-0.82	-0.68
CPA_S96	Other personal services	-1.16	-1.41	-0.83	-0.67	-0.59	-0.67	-0.85	-1.08	-1.28	-1.06

REFERENCES

[1] J. von Neumann, IEEE Transactions on Neural Networks **Vol. 5, No. 1**, 3 (1966).
[2] S. M. Sanchez and T. W. Lucas, Proceedings of the 34th conference on Winter simulation: exploring new frontiers , 116 (2002).
[3] H. Brooks, T. DeKeyser, D. Jaskot, D. Sibert, R. Sledd, W. Stilwell, and W. Scherer, Proceedings of the 2004 Systems and Information Engineering Design Symposium (2004).
[4] S. Brush, H. Sahlin, and E. Teller, The Journal of Chemical Physics **Vol. 45, No. 6**, 2102 (1966).
[5] A. E. Turrell, M. Sherlock, and S. J. Rose, Nature Communications **6**, 8905 (2015).
[6] M. Batty, J. Desyllas, and E. Duxbury, Urban Studies **Vol. 40, No. 8**, 1573 (2003).
[7] B. Chen and H. H. Cheng, Intelligent Transportation Systems **IEEE Transactions on 112**, 485 (2010).
[8] D. J. Fagnant and K. M. Kockelmann, Transportation Research Part C: Emerging Technologies **40**, 1 (2014).
[9] M. Tomita, K. Hashimoto, K. Takahashi, T. Shimizu, Y. Matsuzaki, F. Miyoshi, K. Saito, S. Tanida, K. Yugi, J. Venter, and C. Hutchison, Bioinformatics **15(1)**, 72 (1999).
[10] B. C. Thorne, A. M. Bailey, and S. M. Peirce, Briefings in Bioinformatics **Vol. 8, No. 4**, 245 (2007).
[11] J. R. Karr, J. C. Sanghvi, D. N. Macklin, M. V. Gutschow, J. M. Jacobs, B. Bolival Jr., N. Assad-Garcia, J. I. Glass, and M. W. Covert, Cell **Vol. 150, No. 2**, 389 (2012).
[12] d. A. Ciofi, S. Merler, C. Rizzo, M. Ajelli, M. Massari, P. Manfredi, C. Furlanello, G. Scalia Tomba, and M. Iannelli, PLoS One **33**, e1790 (2008).
[13] V. Grimm, Ecological Modelling **Vol. 115, No. 2**, 129 (1999).
[14] F. E. Werner, J. A. Quinlan, G. R. Lough, and D. R. Lynch, Sarsia **Vol. 86, No. 6**, 411 (2001).
[15] J. Liu and P. Ashton, Forest Ecology and Management **731**, 157 (1995).
[16] M. Richiardi, Eastern Economic Journal **Vol. 43, No. 2**, 271 (2017).
[17] R. Leombruni and M. Ricchiardi, Physica A **355**, 103 (2005).
[18] A. Haldane, Bank of England-GLS Shackle Biennial Memorial Lecture (2016).
[19] S. Poledna, M. Miess, and S. Thurner, "Economic forecasting with an agent-based model," (2017), in preparation.
[20] T. Assenza, D. Delli Gatti, and J. Grazzini, Journal of Economic Dynamics and Control **50**, 5 (2015).
[21] Eurostat and S. O. of the European Communities, *European System of Accounts: ESA 2010*, EDC collection (Publications Office of the European Union, 2013).
[22] S. Hallegatte and V. Przyluski, *The economics of natural disasters: concepts and methods*, Tech. Rep. 5507 (The World Bank Policy Research Working Paper, 2010).
[23] J. M. Albala-Bertrand, *The Political Economy of Large Natural Disasters with Special Reference to Developing Countries* (Oxford: Clarendon Press, 1993).
[24] M. Skidmore and H. Toya, Economic Inquiry **Volume 40, Issue 4**, 664 (2002).
[25] I. Noy and A. Nualsri, University of Harvard Working Paper **07-28** (2007).
[26] I. Noy, Journal of Development Economics **88**, 221 (2009).
[27] S. Hochrainer, World Bank Policy Research Working Paper **4968** (2009).
[28] C. R. H. Jaramillo, Universidad de los Andes, mimeo (2009).
[29] C. Raddatz, *The Wrath of God: Macroeconomic Costs of Natural Disasters* (World Bank Washington DC, 2009).
[30] Eurostat, Publications by the European Union (2013).
[31] J. M. Keynes, The Quarterly Journal of Economics **Vol. 51, No. 2**, 209 (1937).
[32] Y. Ijiri and H. A. Simon, *Skew distributions and the sizes of business firms* (North-Holland, 1977).
[33] R. L. Axtell, science **293**, 1818 (2001).
[34] P. Grossi and H. Kunreuther, eds., *Catastrophe Modeling: A New Approach to Managing Risk* (Springer, 2005).
[35] G. Woo, *Calculating catastrophe* (World Scientific, 2011).
[36] B. Jongman, S. Hochrainer-Stigler, L. Feyen, J. C. Aerts, R. Mechler, W. W. Botzen, L. M. Bouwer, G. Pflug, R. Rojas, and P. J. Ward, Nature Climate Change **4**, 264 (2014).
[37] A. Timonina, S. Hochrainer-Stigler, G. Pflug, B. Jongman, and R. Rojas, Risk Analysis **35**, 2102 (2015).
[38] M. Sklar, Universite Paris 8 (1959).
[39] T. Schinko, R. Mechler, and S. Hochrainer-Stigler, Mitigation and Adaptation Strategies for Global Change , 1 (2016).
[40] F. Prettenthaler, D. Kortschak, S. Hochrainer-Stigler, R. Mechler, H. Urban, and K. Steininger, in *Economic Evaluation of Climate Change Impacts: Development of a Cross-Sectoral Framework and Results for Austria.*, edited by S. et al. (Springer, New York, 2015) pp. 349–366.