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A Parsimonious Macroeconomic ABM for Labor Market Regulations

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2021/46 December 2021
ISSN(ONLINE) 2284-0400

A Parsimonious Macroeconomic ABM for Labor Market Regulations

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December 2021

Abstract

The literature on macroeconomic agent-based models (MABMs) has gained growing attention since the early 2000s. Most MABMs dealing with market regulations have been focusing on the financial market. In contrast, only a small number of MABMs investigate the effects of labor market regulations. In this paper, we provide a parsimonious yet extendable agent-based model that focuses on labor market dynamics within a macroeconomic framework, suitable to analyze labor market regulations such as minimum wages and employment protection legislations. The model is stock-flow-consistent and small-scaled, i.e., there are only workers and firms interacting in the goods and in the labor market. There are two different types of workers, namely skilled and unskilled, and firms produce according to a CES production function. This allows for substitutability between the two types of workers. A one-factor-at-a-time (OFAT) sensitivity analysis is performed to gain insights into the mechanisms and patterns produced by the model. Results show that the model is sensitive to the minimum wage parameter and that for reasonable values of the minimum wage, income inequality decreases, while aggregate consumption rises. Overall, the results suggest that the model can be used to further investigate aggregate and distributional effects of labor market regulations.

Keywords: Labor market; minimum wage; stock-flow consistent; macroeconomic agent-based model; CATS

JEL classification: E24, C63

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1 Introduction

1.1 Motivation

This paper provides a parsimonious yet extendable agent-based model (ABM) that focuses on labor market dynamics within a macroeconomic framework, suitable to analyze labor market regulations such as minimum wages and employment protection legislations.

The literature on models of the labor market has already come a long way from the simple demand and supply model to search theoretic models that include labor market frictions. The latter approach has indeed managed to address many issues, such as the simultaneous existence of unemployed workers and open vacancies, the question why homogeneous workers can earn different wages, how wages and turnover interact and much more; see Rogerson et al. (2005) for more information on search-theoretic models of the labor market.

However, search theoretic models focus on the search and match process between workers and firms in the labor market, it is difficult to integrate additional markets or production technologies. Furthermore, as those models get more complex they become hard to solve analytically. Considering additional markets is of interest, as labor market regulations can have an impact on markets such as the goods, capital or credit markets which in turn could affect the labor market. In general, mainstream approaches fall short of emergent behavior and direct and local interaction as interaction usually takes place through prices. Hence, direct interaction and emergence are ignored in the aggregation. In other words, direct interaction between heterogeneous agents, feedback loops between different markets, and adaptive behavior of agents in a complex system play an important role with respect to the impact of labor market regulations. An agent-based model is basically an algorithm-based model in which different types of heterogeneous objects (agents) interact with each other and the environment. This type of modelling allows for direct and local interaction between agents, feedback loops, aggregate behavior that emerges endogenously and bounded rationality. Most importantly it allows for channels of interaction that could lead to countervailing effects. As Neugart and Richiardi (2018) already have stated: "Flexibility in model design, which allows for richer and more complex specifications to address unexplored economic mechanisms and empirical phenomena, is the selling point of the methodology."

1.2 Literature

The literature on the agent-based approach to macroeconomics has been growing since the early 2000s, and recently, several studies have systematically analysed the state of the art. Fagiolo and Roventini (2017) argue that the Great Recession has served as a natural experiment for economic analysis, calling the adequacy of predominant theoretical frameworks into question. As a response, numerous agent-based models dealing with macroeconomic policies have emerged. Fagiolo and Roventini (2017) provide a survey and classify those ABMs in five different areas: Fiscal policy, monetary policy, macroprudential policy, labor market policy and climate change policy. Dawid et al. (2018) provide a literature survey that presents and compares numerous landmark macroeconomic agent-based models (MABMs). They find that MABMs can differ substantially in their size, but typically include agents such as households, firms, or banks; and typically they include markets for consumption goods, capital, labor, investment goods, and finances. Furthermore, the MABMs' purposes focus on different aspects, from long-term to short-term effects and stylized facts. For more details, the interested reader is referred to the aforementioned survey articles.

The work presented in this paper is primarily based on a particular family of models that goes by the name of *Complex Adaptive Trivial Systems* (CATS). Introduced by Delli Gatti, Gallegati and co-authors, CATS models are typically medium sized with only a few types of agents and markets to mimic real world phenomena on an aggregate level emerging from the interaction of simple behavioral heuristics. This facilitates replications and ceteris paribus analyses, and they are, by comparison, less difficult to calibrate.

One of the most important CATS frameworks is described by Delli Gatti et al. (2011) where households, firms and banks interact in three different markets (labor, goods and credit market). It has been the basic building block for several subsequent models. Some notable examples are Assenza, Delli Gatti, et al. (2015), who introduce a capital goods markets and investigate how it affects crisis situations, or Delli Gatti and Desiderio (2014) and Assenza, Cardaci, et al. (2018) where the framework is extended in order to conduct monetary policy experiments. A medium to large framework is introduced by Riccetti et al. (2015), which features households, banks and firms interacting in four different markets (labor, goods, credit and deposit markets). That model also includes a government stabilizing the economy with an acyclical sector and a central bank providing private banks with liquidity depending on previous period's credit mismatch. One of several applications of this framework is Riccetti et al. (2013), where the authors investigate the effects of unemployment benefits on macroeconomic dynamics.

Caiani, Godin, et al. (2016) is another remarkable medium to large scale model that accentuates the importance of stock-flow consistency. Compared to other CATS models, this one has novel and more realistic features especially with respect to decisions in the credit and capital markets (credit rationing, evaluation of firms by banks, capital-investment decision etc.). It also address challenges in the calibration of macroeconomic agent-based models by proposing a six-step strategy, which the calibration approach in this paper is based on. An application can be found in Caiani, Russo, et al. (2018), where the authors explore the relationship between inequality and growth.

According to Dawid et al. (2018), particularly after the crisis of 2008, the focus of the agent-based literature dealing with market regulations has been on the financial and credit market. A large part of the models in the CATS literature focus on the interaction between firms and financial markets and financial fragility in complex macroeconomic systems. The model presented in this paper, however, has its focus on the interaction within and between the labor and the goods market. In order to reduce complexity and limit the enormous degrees of freedom, it is intentionally kept parsimonious, i.e., there are only households and firms and therefore only two different markets (labor and goods market). The reduced complexity also helps with understanding the connection between cause and effect more clearly.

There are, of course, already different types of agent-based models focusing on the labor market. Neugart (2008), for example, evaluates the aggregate impact of training measures. Boudreau (2010) looks into the matching of heterogeneous firms and workers and find that two-sided matching leads to stratified groups in the population. Goudet et al. (2016) apply an agent-based model to the case of France in 2011 and are able to replicate the high proportion of fixed duration contracts in the hiring flows. Fagiolo, Dosi, et al. (2005) are able to reproduce three aggregate regularities of the labor market that emerge endogenously, namely Beveridge, Wage and Okun curves. Dosi, Pereira, et al. (2017) show how structural reforms that reduce workers' bargaining power and compress wages tend to increase unemployment and income inequality by extending the Schumpeter meeting Keynes" model (Dosi, Fagiolo, et al. 2010). In the model presented by Seppecher (2012), aggregate activity decreases and unemployment increases when the flexibility of wages is increased. Seppecher (2012) then shows, that the introduction of a minimum wage could have boosted the demand and avoid the crisis.

1.3 Contribution

With respect to its scale, the model provided in this paper is similar to the earlier MABMs as it includes only firms and households. The financial market was left out in order to keep the model as parsimonious as possible and thus it can be seen as a downsized version of CATS models. There are two types of workers in the model, namely skilled and unskilled. In the MABM literature, firms usually produce according to a Leontief production function. Thus, there is no substitutability between production inputs. In this paper, however, firms produce consumption goods according to a CES production function and have to solve a constraint optimization problem based on their adaptive expectations on the employment costs. Hence, there is substitutability between production inputs. This feature is essential, because in the case where the wage ratio between different types of labor is affected by regulations, the elasticity of substitution might change the hiring decisions of firms and therefore the outcome of the regulation that is analyzed.

Often, stock-flow inconsistency arises in the exit-entry process of firms, when new firms are assumed to replace bankrupt ones with given financial endowments. In this case, usually, additional assets are introduced to the system, which can affect the behavior of agents and macroeconomic variables; see Caiani, Godin, et al. (2016) for more information on stock-flow consistency and agent-based modelling. Therefore, it is assumed that shareholders finance bankrupt firms. When no financial resources are available anymore in the current period, bankrupt firms that could not be refinanced go inactive. This way, stock-flow consistency is achieved without adding more complexity to the model.

The model dynamics are explored by performing a One-factor-at-a-time sensitivity analysis (OFAT). The results show, that the model is sensitive to the minimum wage parameter. Higher minimum wages within a reasonable range lead to less income inequality and stimulate the aggregate consumption.

The paper is organized as follows. Section 2 describes the model. Section3 deals with model calibration and the setup of the OFAT sensitivity analysis, and presents experiments and main results. Finally, Section 4 concludes.

2 The Model

2.1 Short Description

The proposed model follows the Complex Adaptive Trivial Systems (CATS) literature as outlined in Section 1.2. It incorporates only two types of agents, firms

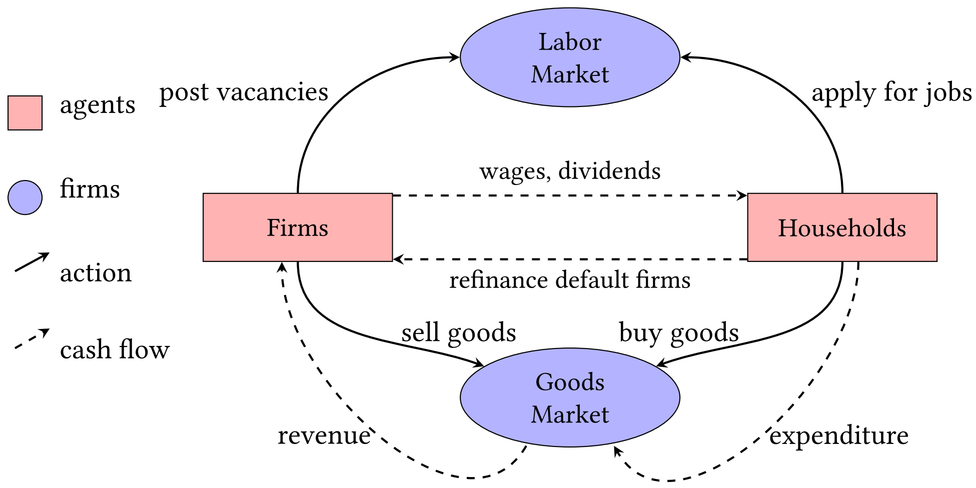

Figure 1: Overview of the model.

and households. Households are employed by firms in the labor market and buy consumption goods in the goods market. They are also shareholders of firms. Firms employ households as workers, produce consumption goods and pay dividends to households. The model is kept small scale, and the financial sector, government and central bank are left out to focus more on the interaction between the goods and the labor market, but also in order to better understand the connection between employers and employees and to investigate cause and effect of the agents' behavior. In the case of bankruptcy, firms either are refinanced by shareholders or go inactive which allows for stock-flow consistency.

The agents and their properties and behavior will be described in more in detail in the following sections. Figure 1 illustrates the model, and Table 1 provides the sequence of events.

2.2 Firms

2.2.1 Objectives and Behaviors

Firms produce one type of homogeneous consumption good which they sell on a goods market. They are rational decision makers who want to maximize their profits and plan on a period-per-period basis. The only critical production factor is workforce; materials or infrastructure are considered irrelevant in the decision processes and therefore ignored. Each period, firms decide how much they want to produce and what the price per unit should be. Based on that, they determine the required workforce and recruit or lay off workers accordingly. Their only source of income are revenues from sales. Unsold products can be stored and sold

Table 1: Sequence of events.

- Initialization
- At the beginning of each period

1. Agents make decisions based on the events of the period before. Firms decide how much output they want to produce based on their sales expectations and current inventories. Households choose their desired wages and consumption based on their current income, wealth and the expected prices.
2. Firms decide whether they want to hire or fire workers and post open vacancies.

- During each period

3. Households and firms interact in the labor market.
4. Firms produce goods.
5. Firms and households interact in the goods market.

- At the end of each period

6. Firms calculate profits pay dividends to households and update their net worth. Some firms default.
7. Households as shareholders refinance the firms in a random order.
8. Default firms that can not be refinanced pay their remaining wage bills, loose all employees and become inactive until they can be refinanced again.

in future periods. Firms are fully equity-financed, and their profits are paid as dividends to their stockholders.

2.2.2 Production Planning

Firm f expects sales in period t of

$$\hat{s}_{f,t} = \hat{s}_{f,t-1} + \lambda \left(s_{f,t-1} - \hat{s}_{f,t-1} \right) \tag{1}$$

where $s_{f,t-1}$ are the actual sales in the previous period. To buffer against unexpected demand swings (cf. Steindl 1952) and avoid disappointing customers (cf. Lavoie 1992), firms aim at holding a certain amount of inventories inv_t, proportional to $\hat{s}_{f,t}$ (see Caiani, Godin, et al. 2016). The target for the inventory is $\nu \cdot \hat{s}_{f,t}$. Their desired output is then

$$y^*_{f,t} = \hat{s}_{f,t}(1 + \nu) - inv_{f,t-1} \tag{2}$$

where $inv_{f,t-1}$ is the inventory at the beginning of the current period from previous overproductions.

2.2.3 Labor Demand

Firms produce the good with labor only. With $U_{f,t}$ unskilled and $S_{f,t}$ and skilled workers, respectively, the actual output follows a CES production function

$$y_{f,t} = Y(U_{f,t}, S_{f,t}) = \left((\mu_u U_{f,t})^\rho + (\mu_s S_{f,t})^\rho) \right)^{1/\rho} \tag{3}$$

where $\mu_u < \mu_s$ are the productivity parameters, and $\rho = \frac{\eta - 1}{\eta}$ is the substitution parameter. This causes expected costs of $C(U_{f,t}, S_{f,t}) = \hat{w}^u_{f,t} U_{f,t} + \hat{w}^s_{f,t} S_{f,t}$, where $\hat{w}^u_{f,t}$ and $\hat{w}^s_{f,t}$ is the assumed average wage for an unskilled and skilled worker, respectively. Akin to sales predictions, the wage estimates for each type of worker are updated according to

$$\hat{w}_{f,t} = \hat{w}_{f,t-1} + \lambda_F \left(w_{f,t-1} - \hat{w}_{f,t-1} \right). \tag{4}$$

The price is set by adding a mark-up to production costs; details will be presented in Section 2.2.4. Sales of the produced good at a price $p_{f,t}$ will eventually generate revenues of $y_{f,t} p_{f,t}$. The firm wants to be profitable and achieve the desired output $y^*_{f,t}$ as efficiently as possible. At the same time, it faces a budget constraint, restricting how big a workforce it can afford: costs for labor, which are its only liability, must not exceed the liquid assets available from the (just finished) previous year, $A_{f,t-1}$, together with the expected revenue for the current year, $\hat{s}_{f,t} p_{f,t}$. The firm therefore needs to solve the optimization problem

$$\begin{aligned}
&\max_{U_{f,t}, S_{f,t}} && Y(U_{f,t}, S_{f,t}) p_{f,t} - C(U_{f,t}, S_{f,t}) && \text{(5a)} \\
&\text{subject to} && \lambda_1 \, : \, y^*_{f,t} \geq Y(U_{f,t}, S_{f,t}) && \text{(5b)} \\
& && \lambda_2 \, : \, A_{f,t-1} + \hat{s}_{f,t} p_{f,t} \geq C(U_{f,t}, S_{f,t}) && \text{(5c)}
\end{aligned}$$

where λ_1 and λ_2 are the corresponding Lagrange multipliers. If the budget constraint (5c) is binding, i.e., $\lambda_2 > 0$ and $\lambda_1 = 0$, the actual production will be below the desired output. Otherwise, $\lambda_1 > 0$ and $\lambda_2 = 0$, and $y^*_{f,t}$ can be achieved, at least in principle and under assumed wages. Effectively, the firm might miss the target if it cannot find sufficient workers within its budget.

The firm's optimization problem solves as

$$S^*_{f,t} = \begin{cases} \frac{y^*_{f,t}}{\mu_s} \left(1 + \left(\frac{\mu_u}{\mu_s} \Omega_{f,t}\right)^{\rho}\right)^{-1/\rho}, & \text{if } A_{f,t-1} + \hat{s}_{f,t} p_{f,t} \geq C(U^*_{f,t}, S^*_{f,t}) \\ A_{f,t-1} \left(\hat{w}^u_{f,t} \Omega_{f,t} + \hat{w}^s_{f,t}\right)^{-1}, & \text{if } A_{f,t-1} + \hat{s}_{f,t} p_{f,t} < C(U^*_{f,t}, S^*_{f,t}) \end{cases} \tag{6}$$

$$U^*_{f,t} = \Omega_{f,t} S^*_{f,t} \tag{7}$$

$$\Omega_{f,t} = \frac{\mu_s}{\mu_u} \left(\frac{\hat{w}^u_{f,t}}{\hat{w}^s_{f,t}} \frac{\mu_s}{\mu_u} \right)^{\frac{1}{\rho - 1}} \tag{8}$$

where the desired number of skilled workers $S^*_{f,t}$ has a lower bound $\underline{S} = 1$. Details about the job market and the adjustment of the workforce will be presented in Section 2.4.2.

2.2.4 Pricing

Following Caiani, Godin, et al. (2016), prices of goods are set as a non-negative mark-up $m_{f,t}$ over expected unit labor costs, based on desired output:

$$p_{f,t} = (1 + m_{f,t}) \cdot \frac{C(U^*_{f,t}, S^*_{f,t})}{Y(U^*_{f,t}, S^*_{f,t})} = (1 + m_{f,t}) \cdot \frac{\hat{w}^u_{f,t} U^*_{f,t} + \hat{w}^s_{f,t} S^*_{f,t}}{y^*_{f,t}}. \tag{9}$$

The mark-up is adjusted depending on how well the sales went in the previous period. If more inventory is left from the previous period than needed for this period, $inv_{f,t-1} > \nu \cdot \hat{s}_{f,t}$, then $m_{f,t}$ is assumed to be too high, and will be lowered to encourage higher demand; and increased otherwise. Either way, the actual adjustment has a random component to it:

$$m_{f,t} = \begin{cases} m_{f,t-1} \cdot (1 + |\sigma_m z_{f,t}|), & \text{if } inv_{f,t-1} \leq \nu \cdot \hat{s}_{f,t} \\ m_{f,t-1} \cdot (1 - |\sigma_m z_{f,t}|), & \text{if } inv_{f,t-1} > \nu \cdot \hat{s}_{f,t} \end{cases} \tag{10}$$

where $z_{f,t} \sim \mathcal{N}(0,\ 1)$.

2.2.5 Annual Reports and Profitability

The goods are sold to households; the details of households' consumption behavior and the matching on the goods market will be described in Section 2.4.1. Once the firm's sales for the current period $s_{f,t}$ are known (see equation (24)), it can update its inventory according to

$$inv_{f,t} = inv_{f,t-1} + y_{f,t} - s_{f,t} \tag{11}$$

and the profits can be determined as

$$\pi_{f,t} = s_{f,t}p_{f,t} - \left(w^u_{f,t}U_{f,t} + w^s_{f,t}S_{f,t}\right) \tag{12}$$

where $w^\ell_{f,t}$ is the firm's current average wage to a worker of group ℓ with $\ell \in \{u, s\}$.

A firm defaults when its loss exceeds its liquid assets from the beginning of this period, $A_{f,t-1} + \pi_{f,t} < 0$. In that case, wages cannot be covered with existing liquid assets plus revenues, $A_{f,t-1} + s_{f,t}p_{f,t} < w^u_{f,t}U_{f,t} + w^s_{f,t}S_{f,t}$. Due to this, it pays only a fraction

$$\theta_{f,t} = \frac{A_{f,t-1} + s_{f,t}p_{f,t}}{w^u_{f,t}U_{f,t} + w^s_{f,t}S_{f,t}} \tag{13}$$

of its wage bill. If such a firm can be refinanced immediately, then the remainder of the wage bill will also be covered and $\theta_{f,t} = 1$ (as for any non-distressed firm), and the firm continues its activities. Otherwise, it dismisses its employees with immediate effect. It will then be incapable of producing new goods, but will try to sell of its inventory and seeking refinancing until there are enough means to start operations again; see Section 2.4.3.

2.2.6 Dividends

As in Riccetti et al. (2015), all firms are fully equity funded and owned by the households; firms therefore pay a share of their profits as dividends to the households. How much of their profits they actually want to distribute depends on their production plans for the next period: Based on how much of their production they have sold and what their current inventory is, their desired output will be higher or lower than this period's, leading to higher or lower requirements for liquid assets to cover the expected costs. Similar to the price mark-up, the adjustment is not fully deterministic but has a random component:

$$\delta_{f,t} = \begin{cases} \delta_{f,t-1}(1 + |\sigma_\delta z|), & \text{if } y^*_{f,t+1} < y^*_{f,t} \\ \delta_{f,t-1}(1 - |\sigma_\delta z|), & \text{otherwise} \end{cases} \tag{14}$$

with an anticipated desired output of $y^*_{f,t+1} = \hat{s}_{f,t+1}(1+\nu) - inv_{f,t}$, again, $z \sim \mathcal{N}(0,\ 1)$. Since no dividends are paid if the firms generated a loss, the firm's actual payment is

$$div_{f,t} = \max\left\{\delta_{f,t}\pi_{f,t}, 0\right\}, \tag{15}$$

leaving the firm with end-of-period liquid assets of

$$A_{f,t} = \max\left\{A_{f,t-1} + \pi_{f,t} - div_{f,t}, 0\right\}. \tag{16}$$

The dividends will be distributed amongst the firm's shareholders proportionally to their contribution to the firm's equity; see equation (18).

2.3 Households (Workers)

2.3.1 Objectives and behavior

Households are linked to firms in different capacities. They provide the workforce and are thus suppliers to the labor market; the terms "household" and "worker" are therefore used interchangeably. They are also consumers in the goods market. And finally, as shareholders, they finance and refinance firms and receive dividends, their second source of income apart from wages.

2.3.2 Applications and Employment

Jobs are the main source of income. Households want to be in a good job situation and are constantly participating in the job market, either to get out of unemployment or to find themselves a better-paid position. Therefore, in each period, every household h sends out N_{app} applications, regardless of their employment status. An application contains the worker's desired wage which is adjusted regularly, depending on the current job situation and the success of previous applications:

$$w^D_{h,t} = \begin{cases} w^D_{h,t-1}(1 - |\sigma_w z|) & \text{if currently unemployed or no job offer in } t-1 \\ w^D_{h,t-1}(1 + |\sigma_w z|) & \text{otherwise} \end{cases} \tag{17}$$

with a parameter σ_w and a stochastic component $z \sim \mathcal{N}(0, 1)$. The lowest wage for which households are willing to work, i.e., the reservation wage w^R_h is the lower bound for $w^D_{h,t}$. This mechanism introduces implicit bounds to a worker's demanded wages: once too high to generate offers, the worker will lower their demanded wage; once low enough to attract offers, it will be increased. How firms make offers to applicants, and how households accept or reject offers, will be described in Section 2.4.2.

2.3.3 Income and Wealth

Besides wages, households generate additional income by (re-)financing firms and, subsequently, receiving dividends. Right from the start each household has a share in any firm's equity. Households do not withdraw equity, but they can provide additional equity of $R_{hf,t}$ to insolvent firms and make them operational again; details are provided in Section 2.4.3. In return, at the end of the year, household h receives dividends of

$$div_{h,t} = \frac{e_{hf,t}}{\sum_{\hbar} e_{\hbar f,t}} \sum_f div_{f,t} \tag{18}$$

where $e_{hf,t}$ is the amount household h has contributed to firm f's equity by the end of period t. The household's current income is therefore $w_{h,t} + div_{h,t}$ which it receives at the end of period t.

During the same period, households spend on consumption, mainly depending on their financial situation and the supply; details are provided in Section 2.4.1. Let $c_{hf,t}$ be the quantity household h buys from firm f for their price $p_{f,t}$, then this household effectively pays a price of

$$p_{h,t} = \frac{\sum_f c_{hf,t} p_{f,t}}{c_{h,t}} \quad \text{where} \quad c_{h,t} = \sum_f c_{hf,t} \tag{19}$$

per unit. After receiving the wages from employer f dividends from all firms, and with all consumption bills paid, the household generates additional savings (or uses up existing ones) of

$$\pi_{h,t} = \theta_{f,t} w_{h,t} + div_{h,t} - p_{h,t} c_{h,t}. \tag{20}$$

This is typically the net change in the liquid assets. Occasionally, there might be refinancing costs of $R_{h,t} > 0$, otherwise $R_{h,t} = 0$. All things considered, this household closes period t with liquid assets of

$$A_{h,t} = A_{h,t-1} + \pi_{h,t} - R_{h,t}. \tag{21}$$

2.4 Allocations

2.4.1 Consumption and Goods Market

As shown in Table 1, the consumption decision is made at the beginning of the period before the interaction on the job market takes place. The income and the end of period savings from the previous period form the basis on which household h determines its consumption for the current period. Assuming that the effective price will be

$$\hat{p}_{h,t} = \hat{p}_{h,t-1} + \lambda_H \cdot (p_{h,t-1} - \hat{p}_{h,t-1}) \tag{22}$$

the desired level of consumption for the current period is

$$c^D_{h,t} = \alpha_1 \frac{w_{h,t-1} + div_{h,t-1} - R_{h,t-1}}{\hat{p}_{h,t}} + \alpha_2 \frac{A_{h,t-1}}{\hat{p}_{h,t}}. \tag{23}$$

The actual consumption depends on the prices and supply as determined by the firms. The allocation follows a stochastic process where, repeatedly, households, in random order, pick a random supplier f and buy small quantities $c_{hf,t}$ for a price of $p_{f,t}$, until all demand is satisfied or supply is exhausted. Consequently, firm f will generate sales of

$$s_{f,t} = \sum_h c_{hf,t} \leq inv_{f,t-1} + y_{f,t} \tag{24}$$

where $inv_{f,t-1}$ and $y_{f,t}$ are firm f's opening inventory and production in that period, respectively.

2.4.2 Job Market

Activities on the job market driven, on the one hand, by firms trying to adjust their workforce; on the other, by households who want to find higher paying jobs, or are currently unemployed.

As described in Section 2.3.2, every household reconsiders its wage demands and, in each period, sends out applications to several firms, not knowing whether they have vacancies or not. Simultaneously, firms determine their optimal number of employees $S^*_{f,t}$ and $U^*_{f,t}$, respectively; see Section 2.2.3. These are compared to the existing workforce, i.e., employees in the previous period, minus those who have been laid off in the previous period. If there is excess workforce, the corresponding number of the employees with the highest wages will be laid off. While workers can resign with immediate effect, a contract termination by a liquid company at the beginning of period t does not reduce the workforce immediately, but takes effect at the beginning of the subsequent period, at $t + 1$.

If a firm wants to hire, it makes an offer to the applicant with the lowest demanded wage. An unemployed applicant accepts the offer for certain. An already employed applicant, might refuse the offer: If their current job earned $w_{h,t-1}$ in the last period, they accept the offer only with a probability of

$$p_{LM} = \begin{cases} 1 - \exp\left(\lambda_{LM} \frac{w^D_{h,t} - w_{h,t-1}}{w_{h,t-1}}\right) & \text{if } w^D_{h,t} > w_{h,t-1} \\ 0 & \text{otherwise} \end{cases} \tag{25}$$

where λ_{LM} indicates loyalty; see Delli Gatti, Gallegati, et al. (2010).

Applications can have a demanded wage below the current salary: Even though they decline the resulting offer, having received the offer or not will result in adjusting the demanded wage up or down. This keeps their demands in line with the wage level in the market, which might be helpful in future periods if they need a job quickly due to unemployment.

If there are several firms with vacancies, they make their offers subsequently in random order, one offer at a time; a household therefore only receives one offer at a time. Once recipients of offers have made their decisions and, if relevant, resigned from their current position, the new and the former employers have one vacancy less and more to fill, respectively. Once an applicant has accepted, they no longer consider offers from other firms in this period. If an applicant declines an offer, the firm offers the position to another applicant. Likewise if a new vacancy has emerged because a current employee is leaving for another firm. This is repeated until there are no more vacancies or no open applicants.

A firm with excess workforce waits until the end of the job market in case any of its workers leave for another offer. If the workforce is still too high, it informs some of its employees that they will have to leave at the end of the period, starting with its highest earners.

2.4.3 Financing and Refinancing

Households are shareholders and, in the absence of banks or other liquidity providers, the only financiers of firms. Initially, any household h contributes $e_{hf,0}$ to firm f's equity. Households do not withdraw equity, but can increase it to provide additional liquidity to firms in distress, in a fashion similar to Riccetti et al. (2015). This implies $e_{hf,t} = e_{hf,t-1}$ unless there is need for refinancing.

If a firm's losses exceed its liquid assets, it can not pay out the full wages in the current period, and it would not be in a position to keep its workforce and produce in the next period. Such a firm seeks refinancing by increasing its equity. The target is to regain liquid assets that would typically found in a small producer,

$$A^D_{f,t} = perc(\{A_{f,t}\}_{f\in\mathcal{S}}, q) \tag{26}$$

where $\mathcal{S}$ is the set of currently active (surviving) firms, $perc(., q)$ is the q percentile, and $q \sim U(0.3, 0.5)$.

If the firm demands less than the households have available in liquid assets at that stage, $A^D_{f,t} < \sum_h A_{h,t-1} - c_{h,t}p_{h,t}$, then each household h contributes proportional and increases its equity in that firm f by

$$R_{hf,t} = \frac{A_{h,t-1} - c_{h,t}p_{h,t}}{\sum_{\hbar}(A_{\hbar,t-1} - c_{\hbar,t}p_{\hbar,t})}(A^D_{f,t} + (A_{f,t-1} + \pi_{f,t})) \quad \text{and} \quad e_{hf,t} = e_{hf,t-1} + R_{fh,t}. \tag{27}$$

The firm then immediately pays out the remaining wages of $|A_{f,t-1} + \pi_{f,t}|$, sets $\theta_{f,t} = 1$, making its end-of-period assets $A_{h,t} = A^D_{f,t}$. If more than one firm is seeking refinancing, they are put in random order and treated one after the next, as longs as there is liquidity available. The household then faces total contributions of $R_{h,t} = \sum_{f\in\mathcal{R}} R_{hf,t}$ where $\mathcal{R}$ is the set of firms receiving refinancing.

2.5 Minimum Wage

In order to get a small foretaste of an application of the model, a minimum wage parameter is introduced

$$\phi_{mw} = \frac{w^*_{min}}{median(w)}. \tag{28}$$

The parameter ϕ_{mw} describes the targeted Kaitz index, which is the ratio between the nominal minimum wage and the current nominal median wage. The minimum wage parameter ϕ_{mw} is set exogenously and stays constant throughout the simulation. At the beginning of each period a hypothetical law maker will assess the nominal median wage and compute the desired minimum wage w^*_{min} that he needs to set in order to comply with the target ratio between the minimum and median wage. There are three reasons for introducing the Kaitz index as the minimum wage parameter. Firstly, it gives a good intuition about how binding an increase of the minimum wage is going to be. Secondly, comparing the minimum to the median wage allows for a natural benchmark for judging the level of the minimum wage across time periods. Thirdly, the median wage is a good reference point to assess whether the level of a minimum wage is reasonable or not.[1]

3 Experiments

3.1 Calibration

Caiani, Godin, et al. (2016) emphasize how calibration is an issue in agent-based modelling. Technical difficulties, time, and computational limits are mentioned as problems that prevent modellers to explore the parameter space and the space of initial endowments of agents. They also point out that most articles do not provide an explanation of the logic used to calibrate initial values.

Therefore, they propose a calibration procedure where initial values are set based on steady-state stock flow norms. By doing so, the aim is to limit the arbitrariness in defining agents' initial endowments, to restrict the number of free behavioral parameters, and to find a criterion for setting the values of other parameters. The procedure has to define the initial values of different types of stocks held by each sector and then the aggregate stocks are distributed across agents within each sector. Motivated by Caiani, Godin, et al. (2016), the following three-step strategy was adopted:

1. Derive an aggregate version of the model; details are provided in Appendix A. As there is no nominal growth in the model, a steady growth has not not to be assumed, and the model is already in a stationary state.

2. Solve the model by setting exogenously reasonable values for parameters for which some empirical information is available or that we want to con-

[1] see https://www.hamiltonproject.org/assets/legacy/files/downloads_and_links/state_local_minimum_wage_policy_dube.pdf

trol. Then obtain the initial values for each stock and flow variable of the aggregate steady state, as well as the values of some behavioral parameters, which are compatible with the steady state (e.g. the propensity to consume out of income).

3. Distribute each sector's aggregate values uniformly across agents' in that sector. In this way the total value of each type of stock held by agents (e.g. cash and inventories) and agents' past values to be used for expectations are derived. (e.g. past sales, wages, and profits).

3.2 One-Factor-at-a-Time Sensitivity Analysis

In their paper, Broeke et al. (2016) argue that a One-factor-at-a-time sensitivity analysis (OFAT) can be used effectively to address issues related to the analysis of ABMs (existence of multiple levels, nonlinear interactions and feedbacks, emergent properties). OFAT is a local sensitivity analysis, in which a default parameter setting is selected and then one parameter at a time is varied while keeping all other parameters fixed. This helps understand the model mechanisms by showing the relationship between the parameter that is varied and the resulting model output. Hence, a OFAT sensitivity analysis is performed.

Table 2 describes the default parameter setting. At this point, the aim is not to reproduce empirical regularities; instead, the parameters reported in Table 2 have been chosen such that unrealistic patterns are ruled out and outcomes are plausible. The parameter σ_δ was deliberately set very low (see Table 2). By doing so, households are better able to refinance bankrupt firms which simplifies the model dynamics by lowering the firm exit rate. Table 3 shows the initial conditions and parameter α_1 derived from the calibration method described in Section 3.1.

For the OFAT sensitivity analysis, five parameters are changed and for each parameter there are five values as listed in Table 4, adding up to a total of 25 settings. 50 simulations per parameter setting are performed in order to estimate the spread of the output. Thus, 1250 simulations are executed in total. Each simulation is run for a time span of 1000 periods, for each output per simulation the average of the last 300 periods is computed, i.e., from period $t = 701$ to $t = 1000$. All implementations were made in Python 3.8. Code is available upon request.

Table 2: Default parameter-setting.

Symbol	Description	Value
H	Number of households	1000
F	Number of firms	160
w^u_{init}	Initial wage for unskilled workers	1
$A_{h,init}$	Initial wealth of households	1
N_{app}	Number of applications per household	4
N_{shop}	Number of firms observed in the goods market by households	4
γ_s	Share of skilled workers in the economy	0.4
λ_{LM}	Sensitivity parameter for loyalty in the labor market	10
λ_H	Households' adjustment parameter for adaptive expectations	1.0
λ_F	Firms' adjustment parameter for adaptive expectations	0.5
σ_m	Adjustment parameters for mark-ups	0.35
σ_w	Adjustment parameters for wage	0.4
σ_δ	Adjustment parameters for dividends	0.0001
α_2	Propensity to consume wealth	0.25
μ_u	Productivity parameter of unskilled workers	0.4
μ_s	Productivity parameter of skilled workers	0.6
m_{init}	Initial mark-up	0.1
ν	Firms' inventory target share	0.1
ϕ_{mw}	Minimum wage parameter (Kaitz index)	10^{-14}
u_{init}	Initial unemployment rate	0.08
η	Elasticity of substitution	1.5

Table 3: Values derived from aggregate steady-state version.

Symbol	Description	Steady-state value
Ω_{init}	Initial ratio of unskilled to skilled workers employed by firms	1.5
α_1	Propensity to consume income	0.79
S^{tot}_{init}	Initial number of skilled workers that are employed in total	184
U^{tot}_{init}	Initial number of unskilled workers that are employed in total	276
ws_{init}	Initial wage of skilled workers	1.5
$y_{f,init}$	Initial number of consumption goods produced per firm	11.04
uc_{init}	Initial unit costs	0.625
$p_{f,init}$	Initial price	0.6875
$\pi_{f,init}$	Initial profits	0.69
δ_{init}	Initial dividend rate	1.0
$div_{h,init}$	Initial dividend received by households	0.1104
$div_{f,init}$	Initial dividends paid by firms	0.69
$A_{f,init}$	Initial firm net-worth	6.9

Table 4: Ranges for sensitivity analysis

Symbol	Range for OFAT	Parameter values
N_{app}	2 – 12	$[2, 3, 5, 8, 12]$
N_{shop}	2 – 12	$[2, 3, 5, 8, 12]$
λ_{LM}	1 – 15	$[1, 3, 5, 10, 15]$
σ_w	0.1 – 0.5	$[0.1, 0.2, 0.3, 0.4, 0.5]$
ϕ_{mw}	10^{-14} – 0.8	$[10^{-14}, 0.2, 0.4, 0.6, 0.8]$

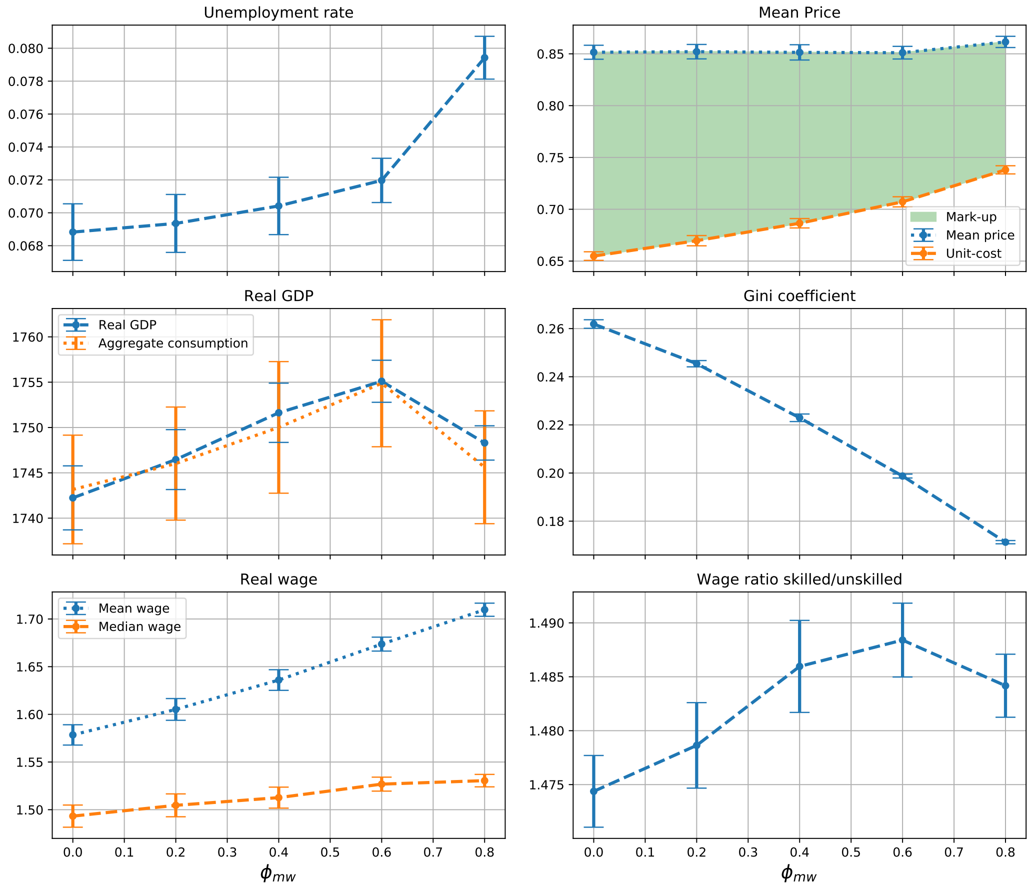

Figure 2: Results of the OFAT analysis for ϕ_{mw}. The error bars represent standard deviations.

The results with regard to ϕ_{mw} (the Kaitz index representing the nominal minimum wage in relation to the median wage) are the most interesting, which is why here we focus on the OFAT analysis for ϕ_{mw}. Results for other parameters will be summarized in Appendix A.3.

Figure 2 shows how changes in ϕ_{mw} affect the unemployment rate, mean price, real GDP, Gini coefficient showing the wage inequality, real wages and the wage ratio between skilled and unskilled workers.

The results show that the unemployment rate is increasing in ϕ_{mw}. However, the increase is rather small for reasonable values of ϕ_{mw} of 0.6 or less. Increasing ϕ_{mw} further would increase unemployment noticeably. The effect on nominal prices, on the other hand, is negligible, in particular for reasonable values of ϕ_{mw}: The unit production costs do go up, but firms settle for a lower mark-up. A the same time, the real GDP, which is measured as the number of goods produced per period, is increasing for $\phi_{mw} \leq 0.6$; an unusually high value of ϕ_{mw} would undo some of that effect. Moreover, the aggregate consumption and real GDP are matching very well. Regarding the real wages, both the median and mean wage are increasing in ϕ_{mw}. The mean wage, however, has a steeper increase compared to the median wage. The wage ratio between skilled unskilled workers is only slightly affected by the minimum wage. The Gini coefficient is decreasing almost linearly in ϕ_{mw}.

3.3 Discussion

The OFAT results show that the unemployment rate is only minimally affected for reasonable values of the minimum wage parameter ϕ_{mw}. This can be attributed to feedback effects between the goods and the labor market. The mean and median wages are both increasing in ϕ_{mw}, which indicates that there is a shift of the wage distribution to the right. Furthermore, the declining Gini coefficient suggests that outliers occur less often for higher values of ϕ_{mw}. The aggregate consumption increases because a large part of the population becomes wealthier, while the distribution of wages becomes more equal. Although prices stay stable for reasonable values of ϕ_{mw}, the composition of the prices changes. That is, firms ask for lower mark-ups as the unit-costs rise. It is worth noting, that the aggregate consumption increases even though households receive less dividends by firms.

4 Conclusion and Outlook

In this paper, a parsimonious macroeconomic agent-based model was developed that is suitable to analyze labor market regulations, and its behavior was explored by performing a OFAT sensitivity analysis and sanity checks for plausible parameterizations. One of the challenges was to develop a stock-flow consistent model with defaulting firms without banks granting loans or a government bailing out firms that cannot be refinanced anymore. This problem was solved by allowing firms to go inactive when the shareholders do not have any resources left to refinance them. The model features two different types of workers, which is why substitutability among inputs plays an important role, as it affects the hiring decisions of firms. Therefore substitutability among the two types of workers was introduced as this is a relevant feature when analyzing labor market regulations affecting wages. The elasticity of substitution is introduced to the model by assuming a CES production function and letting firms solve a constrained optimization problem based on their adaptive expectations on wage costs. The focus is on the results with respect to the minimum wage parameter ϕ_{mw}, as it is contextually the most interesting parameter. The results show that for reasonable values of the minimum wage parameter, higher minimum wages lead to less income inequality and have a positive effect on the aggregate consumption. There is a shift of the income distribution to the right increasing the aggregate consumption and real GDP. The unemployment rate increases only gradually, which could be explained by the increased aggregate consumption dampening the expected negative effects of higher production costs on employment.

Overall, the results are plausible and in line with typical macroeconomic findings, which suggest that the model can be indeed used to investigate aggregate and distributional effects of labor market regulations. Future research will be done using the model to conduct more detailed investigations on distributional effects of the minimum wage on income and firm profits.

Acknowledgements

The authors would like to thank Marius Faber for valuable discussions on modelling production and labor markets; and David Gallusser on minimum wages. We are also grateful for suggestions and comments from Sarah M. Lein, and from anonymous participants at several conferences and seminars.

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A Appendix

A.1 Deriving an Aggregate Version

A.1.1 Model and Parameters

Following parameters will be chosen exogenously:

A_H^{ss} aggregate wealth of households in the steady state
u_{ss} steady state unemployment rate
γ^S proportion of skilled workers in the economy
m_{ss} steady state mark-up
η elasticity of substitution
w_{ss}^u steady state wage earned by an unskilled worker
H number of households
F number of firms
μ_u productivity parameter for unskilled workers
α_2 propensity to consume wealth

In order to simplify the system we adopt the following assumption:

Assumption 1 *In the steady the ratio between unskilled and skilled workers employed by firms is equal to the ratio within the economy. Thus*

$$\Omega_{ss} = \frac{1 - \gamma_{ss}^S}{\gamma_{ss}^S} = \frac{U_{ss}^{tot}}{S_{ss}^{tot}}$$

Following parameters will be derived given the exogenous parameters and assumptions mentioned above:

α_1 propensity to consume income
μ_s productivity parameter for skilled workers
Ω_{ss} steady state ratio between employed unskilled and skilled workers
S_{ss}^{tot} number of employed skilled in the steady state
U_{ss}^{tot} number of employed unskilled in the steady state
Y_{ss} total amount of produced goods by firms in the steady state
w_{ss}^s steady state wage earned by an skilled worker
uc_{ss} unit cost of producing the consumption good in the steady state
p_{ss} steady state price
Π_{ss} total amount of profits earned by firms
δ_{ss} steady state dividend rate
A_F^{ss} aggregate net-worth of firms in the steady state

The steady state system is derived in two sub-systems: the first block contains the equations which refer to firms and the second one refers to households. Once the first block is solved, its solutions are used to solve the second one.

A.1.2 Firms' Steady State Equations

1. Compute w_{ss}^{s} and μ_s using (8) and assumption 1:

$$\mu_s = \Omega_{ss}\mu_u \tag{29}$$

$$ws_{ss} = \left(\frac{\mu_s}{\mu_u}\right)^{\rho} w_{ss}^{u}\Omega^{1-\rho} \tag{30}$$

2. Get S_{ss}^{tot} and U_{ss}^{tot} using H and u_{ss}

$$S_{ss}^{tot} + U_{ss}^{tot} = H \cdot (1 - u_{ss}) \tag{31}$$

$$S_{ss}^{tot} = \frac{H \cdot (1 - u_{ss})}{1 + \Omega_{ss}} \tag{32}$$

$$U_{ss}^{tot} = \Omega_{ss}S_{ss}^{tot} \tag{33}$$

3. Get Y_{ss} using (3)

$$Y_{ss} = \left[(\mu_u U_{ss}^{tot})^{\rho} + (\mu_s S_{ss}^{tot})^{\rho}\right]^{\frac{1}{\rho}} \tag{34}$$

4. Get uc_{ss} and p_{ss} using m_{ss} and (9):

$$uc_{ss} = \frac{U_{ss}^{tot}w_{ss}^{u} + S_{ss}^{tot}w_{ss}^{s}}{Y_{ss}} \tag{35}$$

$$p_{ss} = (1 + m_{ss}) \cdot uc_{ss} \tag{36}$$

5. Get Π_{ss} using (12):

$$\Pi_{ss} = Y_{ss}p_{ss} - U_{ss}^{tot}w_{ss}^{u} - S_{ss}^{tot}w_{ss}^{s} \tag{37}$$

A.1.3 Households' Steady State Relations

1. Get total dividends and income that households receive:

$$DIV_{ss} = \delta_{ss} \cdot \Pi_{ss} \tag{38}$$

$$I_{ss} = U_{ss}^{tot}w_{ss}^{u} + S_{ss}^{tot}w_{ss}^{s} + DIV_{ss} \tag{39}$$

2. Assuming that there is market clearing, the aggregate steady state consumption can be computed:

$$C_H^{ss} = Y_{ss} \tag{40}$$

$$\Delta A_H^{ss} = I_{ss} - C_H^{ss} p_{ss} \tag{41}$$

Where ΔA_H^{ss} is the aggregate change of the households' wealth. As the model is a closed system there is no growth in the steady state therefore $\Delta A_H^{ss} = 0$:

$$I_{ss} = Y_{ss} \cdot (1 + m_{ss}) \cdot uc_{ss} \tag{42}$$

$$\delta_{ss} \Pi_{ss} = m_{ss} \cdot (U_{ss}^{tot} w_{ss}^{u} + S_{ss}^{tot} w_{ss}^{s}) \tag{43}$$

$$\delta_{ss} = 1 \tag{44}$$

3. Get α_1 by using the consumption decision (23) and market clearing (40)

$$\alpha_1 = \frac{C_H^{ss} p_{ss} - \alpha_2 A_H^{ss}}{I_{ss}} \tag{45}$$

A.2 Initial Setup

Table 5 shows the aggregate balance sheet, and Table 6 shows the aggregate transaction flow matrix.

Table 5: Aggregate balance sheet (initial situation).

	Households	Firms	Total
Cash	1000	1104	2104
Consumption goods	0	1335.84	1335.84
Net worth	1000	2439.84	3439.84

Table 6: Aggregate transaction flow matrix (initial situation). Stock-flow consistency implies that the rows and columns of the transaction flow matrix sum to zero; cf. Caiani, Godin, et al. (2016).

	Households	Firms	Σ
Consumption	−1214.4	+1214.4	0
Wages	+1104	−1104	0
Δ inventories	0	0	0
Profits	0	0	0
Dividends	+110.4	−110.4	0
Δ Total	0	0	0

A.3 OFAT results

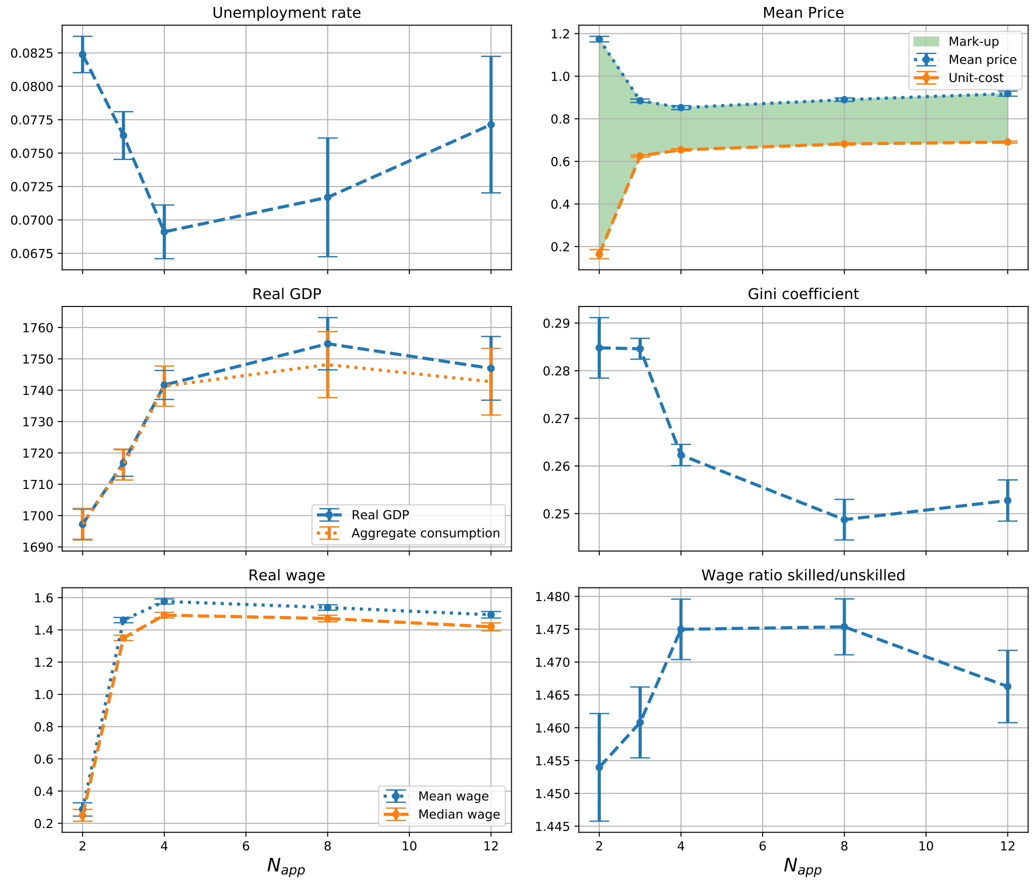

Figure 3: Results of the OFAT analysis for N_{app}. The error bars represent standard deviations.

Figure 3 shows the OFAT results for N_{app}, which is the number of firms that a worker applies to. The unemployment rate is decreasing in N_{app} for $N_{app} \leq 4$ and increasing afterwards. Real GDP increases steeply until $N_{app} = 4$ and it flattens out for higher values of N_{app}. The aggregate consumption is matching the real GDP as seen in the OFAT results for ϕ_{mw}. The Gini coefficient is decreasing until $N_{app} = 8$ and increases slightly for $N_{app} = 12$. Both mean and median of the real wages experience a steep increase for $N_{app} \leq 4$ and decrease slightly afterwards. The wage ratio between skilled and unskilled workers is not much affected by this parameter.

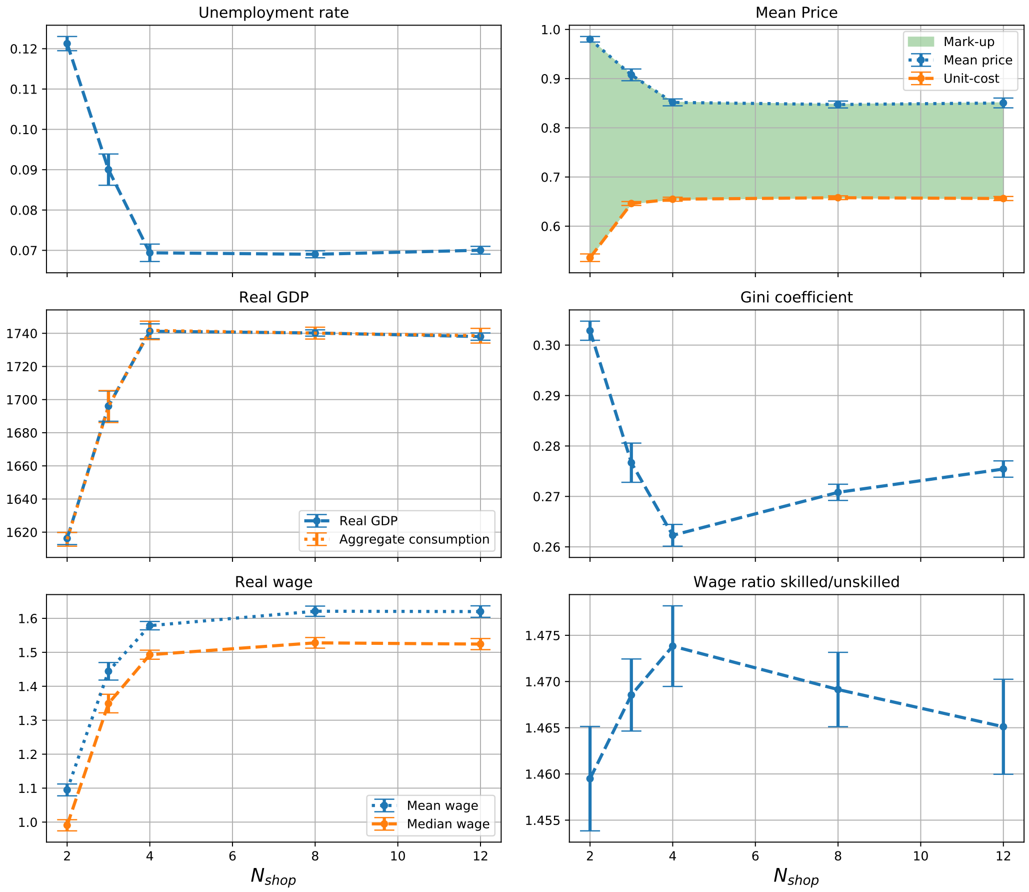

Figure 4: Results of the OFAT analysis for N_{shop}. The error bars represent standard deviations.

Figure 4 shows the OFAT results for N_{shop}, which is the number firms observed by households in the goods market. The unemployment rate decreases strongly from 12% to 7% for $N_{shop} \leq 4$ and stays constant thereafter. The prices and mark-ups are decreasing while unit-cost are increasing for $N_{shop} \leq 4$, those three outputs stay constant for $N_{shop} > 4$. The real GDP increases steeply for $N_{shop} \leq 4$ and flattens out afterwards, which also applies to the real median and mean wages. The Gini coefficient decreases sharply for $N_{app} \leq 4$ and increases slightly thereafter. The wage ratio is not strongly affected by this parameter.

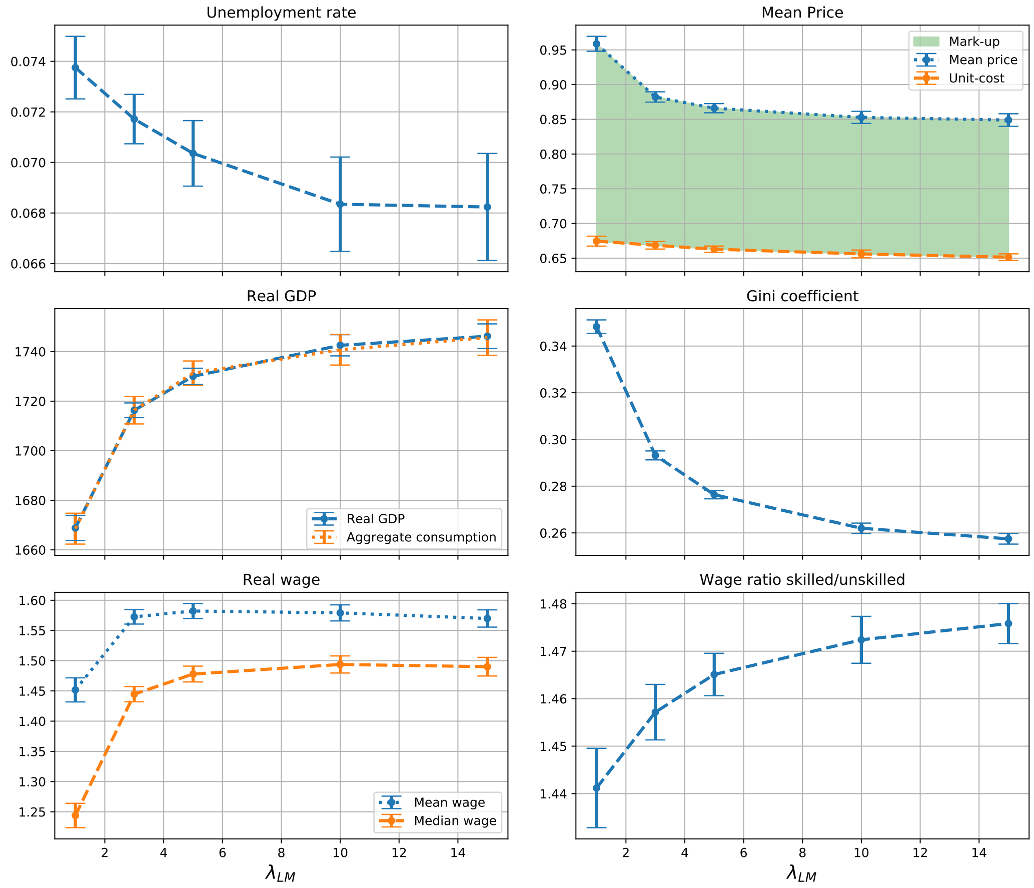

Figure 5: Results of the OFAT analysis for λ_{LM}. The error bars represent standard deviations.

Figure 5 shows the OFAT results for λ_{LM}, which is the parameter for employer loyalty. The lower λ_{LM}, the lower the likelihood that employed workers accept an employment offer by another employer. The prices, unemployment rate and Gini coefficient are all decreasing in λ_{LM}. The real GDP is increasing in λ_{LM}. The mean and median of real wages are both increasing for $\lambda_{LM} \leq 4$ and flatten out afterwards. The wage ratio between both types of workers is not strongly affected.

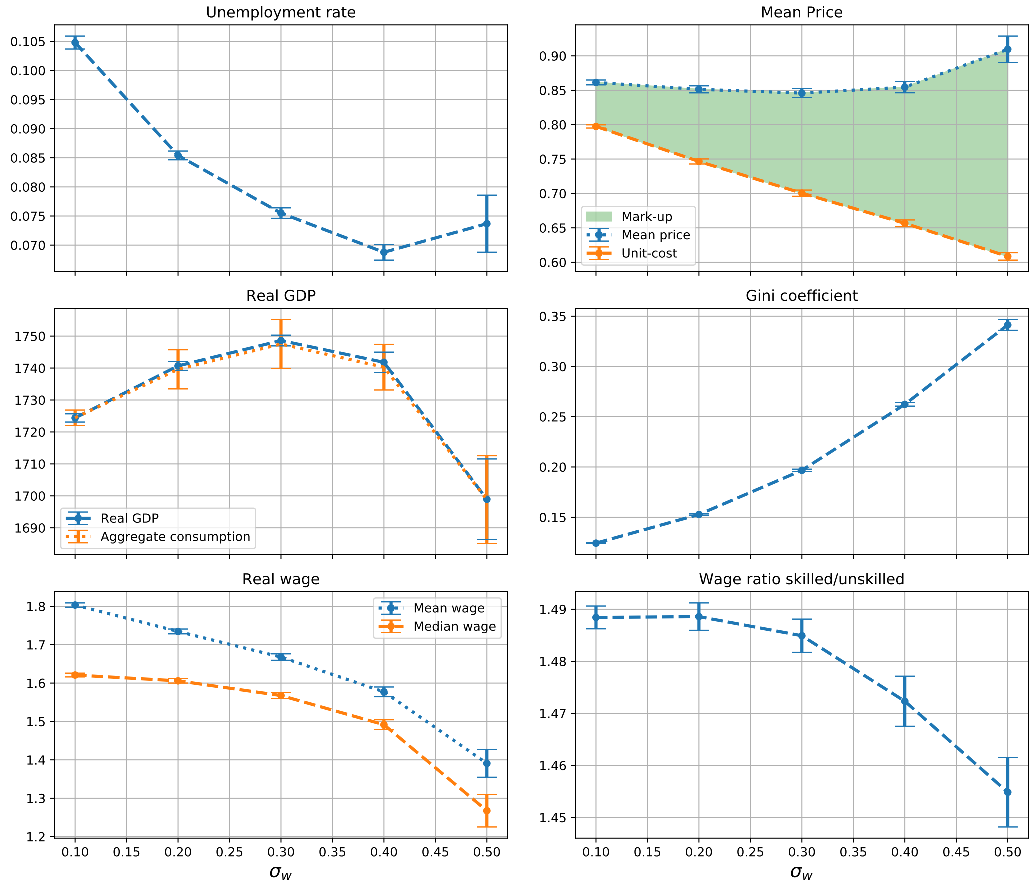

Figure 6: Results of the OFAT analysis for σ_w. The error bars represent standard deviations.

Figure 6 shows the OFAT results for σ_w, which is the adjustment parameter for wages. Workers adjust their demanded wages faster for higher values of σ_w. The unemployment rate is decreasing in σ_w for $\sigma_w \leq 0.40$ and increases slightly thereafter. The prices are more or less stable up to $\sigma_w = 0.40$ and rise slightly afterwards, while unit-costs are steadily decreasing and mark-ups are increasing for higher values of σ_w. The real GDP is increasing in σ_w for $\sigma_w \leq 0.30$ and decreases thereafter. The Gini coefficient is increasing in σ_w, while the mean and median of the real wages are decreasing in σ_w.