Wage formation, unemployment and business cycle in Latvia*

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May 23, 2017

Abstract

This paper integrates the alternating-offer wage bargaining (AOB) mechanism in a fully fledged New Keynesian open economy model, and estimates it to the Latvian data. Further on, the paper studies the model's properties and compares them to alternative specifications for labor market modeling, i.e. the Nash wage bargaining with both Taylor-type wage rigidity and without exogenously imposed wage inertia, a reduced-form sharing rule, and a reduced-form wage rule. The goal of the paper is to choose a labor market modeling specification that suits best the needs of the central bank of Latvia in terms of macroeconomic modeling and forecasting. The results indicate that the AOB model suits the Latvian labor market well. The paper concludes with a simulation of economic effects from a permanent increase in the minimum to average wage ratio as observed in Latvia, and finds potentially large losses of employment and output.

Keywords: alternating-offer bargaining, DSGE model, forecasting, minimum wage
JEL code: E0, E2, E3, F4

*I thank an anonymous referee, Mathias Trabandt, Viktors Ajevskis, Olegs Krasnopjorovs, Martins Bitans and seminar participants at Latvijas Banka for feedback. All remaining errors are my own.

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1 Introduction

When it comes to modeling labor market in a dynamic stochastic general equilibrium (DSGE) model, the search-and-matching framework (Diamond, 1982; Mortensen, 1982; Mortensen and Pissarides, 1994; Merz, 1995; Andolfatto, 1996) has become the dominant theory in the literature. Wages are often determined by the Nash bargaining between employer and employee (Shimer, 2005; Ljungqvist and Sargent, 2015). On top of that, modelers usually impose some sort of exogenous wage stickiness, typically either of Calvo (Gertler, Sala and Trigari, 2008) or Taylor (Christiano, Trabandt and Walentin, 2011; henceforth CTW) type.

Such an approach (the Nash wage bargaining and Taylor-type wage rigidity; henceforth Nash-Taylor) has been pursued in an estimated DSGE model of Latvijas Banka (Buss, 2015). However, the results can be considered less than perfect. Particularly, Figure 1 shows the frequency of base wage change in Latvia as reported by Fadejeva and Krasnopjorovs (2015) based on firm survey data. Figure 1 shows that the distribution of frequency of wage change is not unimodal, as there are peaks at both 'once a year' and 'less frequently than every two years' with a valley in between. Also, the distribution tends to shift across time, as there are more firms changing wages less frequently after the crisis than in the pre-crisis period. Therefore, Taylor-type wage frictions that set a fixed wage updating frequency is not suitable for Latvia. Neither is Calvo-type wage rigidity with a fixed, unimodal wage setting frequency distribution. Rather, a wage formation that allows firms to freely choose the frequency and size of wage change seems more suitable

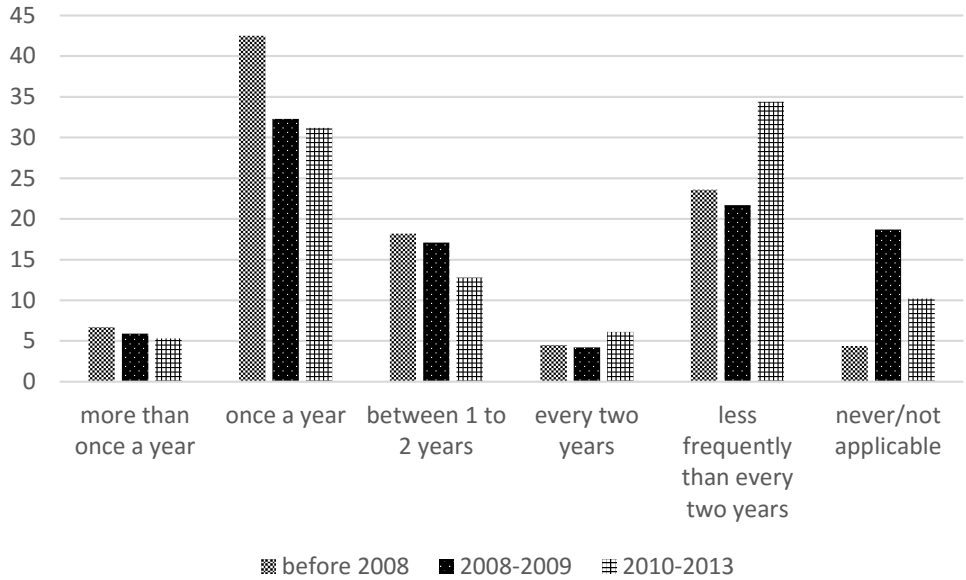

Figure 1: Frequency of base wage change (%)

Note: Weighted to represent employees in the population. Source: Fadejeva and Krasnopjorovs (2015).

Second, the coding of Taylor-type rigidity is relatively heavy, thus imposing limitations on further expansion of the model. Third, the impulse response functions (IRFs) of wages inherit a ragged behavior.[1]

[1]In particular, wages are renegotiated every $N = 4$ quarters in a staggered way. Therefore, after

Therefore, this paper tries alternative ways of modeling wages, with the goal to both improve realism, simplify the model's code, and hopefully improve the model's performance relative to Buss (2015). The first alternative is the alternating offer wage bargaining (AOB) mechanism of Hall and Milgrom (2008) and Christiano, Eichenbaum and Trabandt (2016; henceforth CET). Particularly, a model of Buss (2015) is taken, which is similar in structure to that of Christiano, Trabandt and Walentin (2011) but is shaped to suit a member of a currency union by implementing a currency peg. The following changes to the model of Buss (2015) are made. First, the Nash wage bargaining with Taylor-type wage rigidity is replaced with AOB without exogenously imposed wage rigidity. As discussed in Hall and Milgrom (2008), the major difference between the Nash bargaining and AOB lies in their bargaining threats. In the Nash bargaining, the threat is to end the worker-employer relationship. Moreover, this threat is exerted every period (a quarter in a quarterly model, unless some kind of an exogenous wage rigidity is imposed upon the model), which might not be a realistic description of a typical, established worker-employer relationship, as both are often better-off by continuing their co-operation. By contrast, in AOB the threat is to extend bargaining rather than terminate a contract. The result is a looser connection between wages and outside options - and, hence, less volatile wages compared to the Nash bargaining.

Second, the endogenous separation mechanism is switched off. This modification leaves the model without the labor preference shock, and thus potentially degrades the model's data fitting performance[2]. However, monetary business cycle models have been criticized for over-relying on labor supply shocks to match the data at business cycle frequencies (e.g. Chari, Kehoe and McGrattan, 2009). Also, among others, Gertler, Sala and Trigari (2008) and CET prefer a model version without a household disutility of labor. Therefore, in the new model with AOB, all changes in total hours worked are attributed to the extensive part of labor supply, that is, to the number of employed. Otherwise the model's structure is similar to Buss (2015), hence it is taken as a benchmark in comparison exercises[3]. Both models are estimated using the Latvian data spanning 1995Q2-2012Q4.[4]

Also, similar to CET, this paper compares the model with AOB to models with i) Nash wage bargaining without exogenously imposed wage rigidity, ii) a reduced form sharing rule, and iii) a simple reduced form wage rule.

Note that the new model with AOB is different from and more detailed than that reported by CET. First, it is an open economy model with import content in consumption, investment and exports, and the foreign economy represented by a structural vector autoregression (VAR), whereas CET work with a closed-economy model. Second, our

a shock has occurred, some of the N employment agencies are stuck with wages that they set before the shock hits. Depending on how large wage adjustment is needed, the wage adjustment can be quite vigorous when the $N-1$-th or N-th employment agency have their turn to set wages optimally.

[2]In the Nash-Taylor wage model, the effect of suspending the labor preference shock can be seen by comparing the results of Buss (2015) to the results of the benchmark model in this paper, which is close to Buss (2015) but with a suspended labor preference shock. Briefly, among others, we see a sign of deterioration in the forecasting performance. However, the usefulness of re-introducing the labor supply shock in the new model is not discussed in this paper.

[3]The labor preference shock has been suspended also in the benchmark model for comparability purposes.

[4]The period after 2012 is skipped on purpose to avoid the discussion about the choice of the shadow rate of the monetary policy rate, as such a discussion would be tangential to the goal of this paper.

model features a financial accelerator as in Bernanke, Gertler and Gilchrist (1999, henceforth, BGG) which is absent from the CET model. Third, the model herein features many shocks that are typical in estimated medium-sized New Keynesian models, whereas CET estimate only three shocks.

The main findings are as follows. First, the absence of exogenously rigid wages has improved model's realism, as firms can change wages optimally at any time. Second, the AOB model's forecasts of wages, total hours worked and gross domestic product (GDP) do not exert excess volatility, and the model's forecasting performance is among the best considered in this paper. Particularly, the AOB model tends to produce more precise wage forecasts than the Nash-flexible wage model. Meanwhile, the reduced form wage rule tends to generate excessively volatile total hours worked and GDP growth, compared to the data. Third, AOB has simplified the model's code thus easing its daily usage and facilitating its further development. Specifically, because the coding of Taylor-type wage rigidity requires specifying wage dynamics for each of the (four) employment agencies in Buss (2015), the labor market block in that model takes roughly four times as many equations as in a model without Taylor-type wage rigidity. Fourth, the model remains firmly micro-theory based.

The paper also simulates the effects of a permanent increase in minimum to average wage ratio, as seen in the Latvian data since the period of 2008-2009. The model captures three endogenous reactions of firms, all being supported by survey evidence: an increase of product prices, reduction of hiring, and substitution of labor with capital. Simulation results suggest that the economic effects of permanently increasing the minimum to average wage ratio are negative and potentially sizable in the long run. Among other factors, the external competitiveness, a channel CET are silent about in their discussion of the effects of unemployment benefits with their closed-economy model, of Latvian firms deteriorates. Another channel absent from the CET model is the financial accelerator; as shown in this paper, the net worth of firms deteriorates, and it has additional downward pressure on the economic activity via the credit channel, for it gets more costly for firms to finance investment. Therefore, caution is needed in increasing the minimum wage further in Latvia.

This paper complements two streams of the literature. One is labor market modeling in a DSGE framework, particularly the usage of AOB as an alternative to the Nash bargaining. Hall and Milgrom (2008) build on the theory of AOB developed by Binmore, Rubinstein and Wolinsky (1986) to construct a simple labor market model, and conclude that their model is more plausible than the standard Mortensen-Pissarides model. Hertweck (2013) uses the approach of Hall and Milgrom (2008) in a calibrated real business cycle model. CET implement AOB in a New Keynesian model for a closed economy, and estimate three shocks using a limited information approach. Recently, Bodenstein, Kamber and Thoenissen (2016) have used AOB to study the effect of commodity price shocks on labor market in a simple New Keynesian model estimated using a limited information approach. The model in this paper is more detailed than either of the above, and is estimated using many (22) observables with full information approach. Another stream comprises models for policy analysis and forecasting used by central banks, fiscal authorities, or international organizations. These models are relatively more detailed, and in many cases, estimated using many observables. Examples are the ECB's NAWM (Christoffel, Coenen and Warne, 2008), Riksbank's Ramses II (Adolfson et al., 2013),

and the European Commission's Quest III (Ratto, Roeger and Veld, 2009; Kollmann et al., 2015). The model in this paper is similar to Ramses II and NAWM. Meanwhile, the model herein is the first policy model that uses the theory of AOB.

The paper is structured as follows. Section 2 overviews the model. Section 3 describes the estimation procedure and the results. Section 4 simulates the effects of a permanent increase in the minimum to average wage ratio. Section 5 concludes. Appendix A contains more information about model's calibration, estimation and the results.

2 Model in brief

The model is a modification of the estimated DSGE model for Latvijas Banka, which is described by Buss (2015 and 2016) and is close to CTW but modified to suit a member of a currency union by implementing a currency peg. A brief description of the previous version of the model follows.

2.1 The previous version of the model

The model of Buss (2015) consists of the core block, the financial frictions block and the labor market block.

The **core block** builds on Christiano, Eichenbaum and Evans (2005) and Adolfson, Laseen, Linde and Villani (2008). The three final goods - consumption, investment and exports - are produced by combining the domestic homogeneous good with specific imported inputs for each type of final good. Specialized domestic importers purchase a homogeneous foreign good, which they turn into a specialized input and sell to domestic import retailers. There are three types of import retailers. One uses specialized import goods to create a homogeneous good used as an input into the production of specialized exports. Another uses specialized import goods to create an input used in the production of investment goods. The third type uses specialized imports to produce a homogeneous input used in the production of consumption goods. Exports involve a Dixit-Stiglitz (Dixit and Stiglitz, 1977) continuum of exporters, each of which is a monopolist that produces a specialized export good. Each monopolist produces its export good using a homogeneous domestically produced good and a homogeneous good derived from imports. The homogeneous domestic good is produced by a competitive, representative firm. The domestic good is allocated between government consumption (which consists entirely of the domestic good) and the production of consumption goods, investment goods, and export goods. A part of the domestic good is lost due to real friction in the model economy arising from investment adjustment and capital utilization costs.

Households maximize expected utility from a discounted stream of consumption (subject to habit) and leisure. In the core block, households own the economy's stock of physical capital. They determine the rate at which the capital stock is accumulated and the rate at which it is utilized. Households also own the stock of net foreign assets and determine the rate of the stock accumulation.

Monetary policy is conducted as a hard peg of the domestic nominal interest rate to the foreign nominal interest rate. The government spending grows exogenously. Taxes in the model economy are: the capital tax, the payroll tax, the consumption tax, the labor

income tax, and the bond tax. Any difference between the government spending and tax revenue is offset by lump-sum transfers.

Foreign economy is modeled as a structural vector autoregression (henceforth, SVAR) in foreign output, inflation, nominal interest rate and technology growth. The model economy has two sources of exogenous growth, and they are the neutral technology growth and the investment-specific technology growth.

The **financial frictions block** adds the Bernanke, Gertler and Gilchrist (1999, henceforth BGG) financial frictions to the above core model. Financial frictions show that borrowers and lenders are different people, and that they have different information. Thus the model introduces 'entrepreneurs' who are agents with a special skill in operation and management of capital. Their skill in operating the capital is such that it is optimal for them to operate more capital than their own resources can support by borrowing additional funds. There is financial friction, because managing capital is risky, i.e. entrepreneurs can go bankrupt, and only entrepreneurs observe their own idiosyncratic productivity with no costs incurred.

In this model, households deposit their money in banks. The interest rate on household deposits is nominally non state-contingent.[5] The banks then lend funds to entrepreneurs using a standard nominal debt contract, which is optimal given the asymmetric information.[6] The amount that banks are willing to lend to an entrepreneur under debt contract is a function of the entrepreneurial net worth. This is how balance sheet constraints enter the model. When a shock occurs that reduces the value of entrepreneurs' assets, this cuts into their ability to borrow. As a result, entrepreneurs acquire less capital and this translates into a reduction in investment and leads to a slowdown in the economy. Although individual entrepreneurs are risky, banks are not.

The financial frictions block brings two new endogenous variables, one related to the interest rate paid by entrepreneurs and the other - to their net worth. There are also two new shocks, one to idiosyncratic uncertainty and the other - to entrepreneurial wealth.

The **labor market block** adds the labor market search and matching framework of Mortensen and Pissarides (1994), Hall (2005a,b) and Shimer (2005, 2012), with the Taylor-type nominal wage rigidity as modeled in CTW to the financial frictions model of Buss (2016). A key feature of this model is that there are wage-setting frictions but they do not have a direct impact on the existing worker-employer relations as long as these are mutually beneficial[7]. However, wage-setting frictions have an impact on the effort of an employer in recruiting new employees[8]. Accordingly, the setup is not vulnerable to the Barro (1977) critique that wages cannot be allocational in on-going

[5]These nominal contracts give rise to wealth effects of unexpected changes in the price level, as emphasized by Fisher (1933). E.g., when a shock occurs which drives the price level down, households receive a wealth transfer. This transfer is taken from entrepreneurs whose net worth is thereby reduced. With tightening of their balance sheets, the ability of entrepreneurs to invest is reduced, and this generates an economic slowdown.

[6]Namely, the equilibrium debt contract maximizes the expected entrepreneurial welfare, subject to the zero profit condition on banks and the specified return on household bank liabilities.

[7]That is, the existence of nominal wage frictions does not imply that the employer-employee relations are enforced upon them, since they can separate if their relationship is not beneficial.

[8]The Nash wage depends on the relative bargaining power of the employer and the employee. The smaller the relative bargaining power of the employee is, the lower the Nash wage and, consequently the greater the incentive to recruit new employees are.

employer-employee relationships. Also, the intensive margin of labor supply as well as the endogenous separation of employees from their jobs are allowed.

The search and matching framework dispenses with the specialized labor services abstraction and the accompanying monopoly power in the financial frictions model. Labor services are instead supplied by 'employment agencies', i.e. a modeling construct best viewed as a goods producing firm's human resource division, to the homogeneous labor market where they are bought by the intermediate goods producers. Each employment agency retains a large number of workers, and each is permanently allocated to one of $N = 4$ different equal-sized cohorts. Cohorts are differentiated by the period (quarter) in which they renegotiate their wage. The nominal wage paid to an individual worker is determined by the Nash bargaining, which occurs once every N periods.[9] Since there is an equal number of agencies in each cohort, $1/N$ of the agencies bargain in each period.

The events during the period in an employment agency take place in the following order. At the beginning of the period an exogenously determined fraction of workers is randomly selected to separate from the agency and go into unemployment. Also, a number of new workers arrive from unemployment in proportion to the number of vacancies posted by the agency in the previous period. Then, the economy's aggregate shocks are realized. After that, each agency's nominal wage rate is set. When a new wage is set, it evolves over the subsequent $N - 1$ periods. The wage negotiated in a period covers all workers employed at the agency for each of the subsequent $N - 1$ periods, even those that will arrive later. Next, each worker draws an idiosyncratic productivity shock. A cutoff level of productivity is determined, and workers with lower productivity are laid off.[10] After the endogenous layoff decision, the employment agency posts vacancies and the intensive margin of labor supply is chosen efficiently by equating the marginal value of labor services to the employment agency with the marginal cost of providing it by the household. At this point the employment agency supplies labor to the labor market.

2.2 The new version

This paper modifies the previous version of the model in the following manner. First, the Nash wage bargaining with Taylor-type wage rigidity is replaced with AOB without exogenously imposed wage rigidity, as in CET. The introduction of AOB changes the setup of production of the intermediate good which is now split into wholesaler and retailer blocks, as discussed below. Second, there is no endogenous separation mechanism. Therefore, in the new model with AOB, all changes in total hours worked are attributed to the extensive part of labor supply. Third, I introduce technology diffusion as in Schmitt-Grohe and Uribe (2012), and Christiano, Trabandt and Walentin (2010), and which is also present in CET.

A minor modification from CET setup in terms of the labor market block is that I allow for separation rate to vary exogenously and in a predetermined way[11] as an AR(1) process to be able to fit the model to the data of both hiring and separation rates. The

[9] The bargaining arrangement is atomistic, so that each worker bargains separately with a representative of the employment agency.

[10] From a technical point of view the modeling of endogenous separation is symmetric to the modeling of entrepreneurial idiosyncratic risk and bankruptcy.

[11] It is reasonable to assume that both firms and employees anticipate what they will be doing in terms of separation in the next quarter, compared to the case when separation comes unexpectedly to both of

hiring and separation rates vary in time and show co-movement in the Latvian data, so allowing for the hiring rate to vary but fixing the separation rate, as CET do, might be a slight departure from the Latvian data.[12]

Also, similar to CET, this paper compares the model with AOB to those with i) the Nash wage bargaining without exogenously imposed wage rigidity, ii) a reduced form sharing rule, and iii) a simple reduced form wage rule.

A more formal description of modifications relative to Buss (2015) follows.

2.3 Household utility function

In the new model, the representative household has a unit measure of workers which it supplies inelastically to the labor market. The fraction of employed workers in the representative household in period t is denoted by L_t. It is assumed that each worker has the same concave preferences over consumption and that households provide perfect consumption insurance, so that each worker receives the same level of consumption, C_t. The preferences of the representative household are the equally-weighted average of the preferences of its workers:

$$E_0 \sum_{t=0}^{\infty} \beta^t \zeta_t^c \log\left(C_t - bC_{t-1}\right), \ 0 \leq b < 1, \tag{2.1}$$

where β is the discount factor, b controls the degree of habit formation in preferences, and ζ_t^c is a shock to consumption preferences.

2.4 Final domestic good and retailers

As in Buss (2015), the homogeneous domestic good Y_t is produced by competitive, identical firms using

$$Y_t = \left[\int_0^1 Y_{i,t}^{\frac{1}{\lambda_d}} di\right]^{\lambda_d}, \ 1 \leq \lambda_d < \infty, \tag{2.2}$$

and taking the price of output, P_t, and the price of inputs, $P_{i,t}$, as given. Here, $Y_{i,t}$ denotes the specialized inputs and $1/\lambda_d$ their degree of substitutability. The representative firm chooses specialized inputs, $Y_{i,t}$, to maximize profits

$$P_t Y_t - \int_0^1 P_{i,t} Y_{i,t} di$$

subject to the production function (2.2). The firm's first order condition for i^{th} input is

$$Y_{i,t} = \left(P_t / P_{i,t}\right)^{\frac{\lambda_d}{\lambda_d - 1}} Y_t. \tag{2.3}$$

them. Therefore, in the model, the separation process is modeled as predetermined one quarter before the separation actually takes place.

[12] In the future work, it might be beneficial to re-introduce endogenously determined separation.

The specialized input good i in (2.2) is produced by a retailer using the production function

$$Y_{i,t} = (z_t H_{i,t})^{1-\alpha} \epsilon_t K_{i,t}^{\alpha} - z_t^{+} \phi, \tag{2.4}$$

where $K_{i,t}$ denotes capital services rented by i^{th} retailer, $\log(z_t)$ is a technology shock whose first difference has a positive mean, $\log(\epsilon_t)$ is a stationary neutral technology shock, and ϕ denotes fixed production cost. The economy has two sources of growth: the positive drift in $\log(z_t)$ and a potentially positive drift in $\log(\Psi_t)$, where Ψ_t is an investment-specific technology shock. The object z_t^{+} in (2.4) is defined as

$$z_t^{+} = \Psi_t^{\frac{\alpha}{1-\alpha}} z_t.$$

The departure from Buss (2015) is that $H_{i,t}$ is the quantity of intermediate good, not labor, purchased by the ith retailer. This good is purchased in competitive markets at price P_t^H from a wholesaler. Similar to Buss (2015), I assume that the retailer must borrow $P_t^H H_{i,t}$ at the gross nominal interest rate, R_t. The retailer repays the loan at the end of period t after receiving sales revenues. The retailer is a monopolist in the product market and is competitive in factor markets. The ith retailer sets its price, $P_{i,t}$, subject to the demand curve (2.3) and Calvo-type price frictions. With probability ξ_d the ith retailer cannot reoptimize the price, in which case

$$P_{i,t} = \tilde{\pi}_{d,t} P_{i,t-1}, \ \tilde{\pi}_{d,t} := (\pi_{t-1})^{\kappa_d} (\bar{\pi})^{1-\kappa_d},$$

where $\kappa_d \in (0,1)$, π_{t-1} is the lagged inflation rate, and $\bar{\pi}$ is the steady state of the inflation rate.

2.5 Wholesalers and the labor market

The law of motion for aggregate employment, L_t, is given by:

$$L_t = (\rho_{t-1} + \chi_t) L_{t-1} \tag{2.5}$$

Here, ρ_{t-1} is the probability that a given firm/worker match continues from one period to the next, and its law of motion is given by $\log \rho_t = (1-\rho_\rho) \log \rho + \rho_\rho \log \rho_{t-1} + \epsilon_{\rho,t}$. Note that ρ_{t-1} is predetermined in (2.5).[13] So, $\rho_{t-1} L_{t-1}$ denotes the number of workers that were attached to firms in period $t-1$ and remain attached at the start of period t. Also, $\chi_t L_{t-1}$ denotes the number of new firm/worker meetings at the start of period t. χ_t is defined as the hiring rate, because in equilibrium meetings always result in employment. According to (2.5) workers are engaged in production as soon as they are hired.[14]

[13] Contrary to CET assumption of a fixed separation rate, here this is a simple way of modeling the time-varying separation rate that allows to match this variable to the data. It is reasonable to assume that the decision on separation takes some time and thus it is made before the current period's shocks are realized.

[14] This timing differs from that in CTW and Buss (2015) but is in line with CET.

The number of workers searching for work at the start of period t is the sum of the number of unemployed workers in period $t-1$, $1-L_{t-1}$, and the number of workers that separate from firms at the end of $t-1$, $(1-\rho_{t-1})L_{t-1}$. The probability, f_t, that a searching worker meets a firm is given by:

$$f_t = \frac{\chi_t L_{t-1}}{1-\rho_{t-1}L_{t-1}}. \tag{2.6}$$

Wholesaler firms produce the intermediate good using labor which has a fixed marginal productivity of unity. A wholesaler firm that wishes to meet a worker in period t must post a vacancy at cost s_t, expressed in units of the homogeneous domestic good. The vacancy is filled with probability Q_t. In case the vacancy is filled, the firm must pay a fixed real cost, κ_t, before bargaining with the newly-matched worker. Let J_t denote the value to firm of a worker expressed in units of the homogeneous domestic good:

$$J_t = \vartheta_t^p - w_t^p.$$

Here, ϑ_t^p denotes the expected present value, over the duration of the worker/firm match, of the real intermediate good price, $\vartheta_t = P_t^H/P_t$. Also, w_t^p denotes the expected present value of the real wage paid by the firm, w_t. The real wage is determined by worker-firm bargaining and is discussed below. The recursive form is as follows:

$$\vartheta_t^p = \vartheta_t + \rho_t E_t m_{t+1}\vartheta_{t+1}^p, \quad w_t^p = w_t + \rho_t E_t m_{t+1} w_{t+1}^p. \tag{2.7}$$

Here, m_{t+1} is the time t household discount factor which firms and workers view as an exogenous stochastic process. Free entry by wholesalers implies that, in equilibrium, the expected benefit of a vacancy equals the cost:

$$Q_t\left(J_t - \kappa_t\right) = s_t \tag{2.8}$$

Let V_t denote the value to a worker of being matched with a firm. Then V_t is expressed as the sum of the expected present value of wages earned while the match endures and the continuation value, A_t, when the match terminates:

$$V_t = w_t^{p,w} + A_t, \tag{2.9}$$

where

$$w_t^{p,w} = w_t(1-\tau_t^y)/(1+\tau^w) + \rho_t E_t m_{t+1} w_{t+1}^{p,w}, \tag{2.10}$$

where $w_t^{p,w}$ takes into account the assumption from Buss (2015) that the firm pays the payroll tax and the worker pays the labor income tax, thus $w_t^{p,w}$ is the present value of the wage received by the worker after taxes. Also,

$$A_t = (1-\rho_t)\, E_t m_{t+1} \left[f_{t+1} V_{t+1} + (1-f_{t+1})\, U_{t+1} \right] + \rho_t E_t m_{t+1} A_{t+1}. \tag{2.11}$$

Here, U_t denotes the value of being unemployed,

$$U_t = b_t^u + \tilde{U}_t, \tag{2.12}$$

and $\tilde{U}_t$ denotes the continuation value of unemployment:

$$\tilde{U}_t := E_t m_{t+1} \left[f_{t+1} V_{t+1} + (1-f_{t+1})\, U_{t+1} \right]. \tag{2.13}$$

The vacancy filling rate, Q_t, and the job finding rate for workers, f_t, are assumed to be related to labor market tightness, Γ_t, as follows:

$$f_t = \sigma_m \Gamma_t^{1-\sigma},\ Q_t = \sigma_m \Gamma_t^{-\sigma},\ \sigma_m > 0,\ 0 < \sigma < 1,$$

where

$$\Gamma_t = \frac{v_t L_{t-1}}{1 - \rho_{t-1} L_{t-1}}. \tag{2.14}$$

Here, $v_t L_{t-1}$ denotes the number of vacancies posted by firms at the start of period t.

Market clearing of intermediate goods requires

$$\int_0^1 H_{i,t} di = L_t.$$

2.6 The alternating-offer wage bargaining mechanism

This section summarizes the bargaining arrangement between firms and workers, which follows CET. At the start of period t, L_t matches are determined. At this point, each worker in L_t engages in bilateral bargaining over the current wage rate, w_t, with a wholesaler firm. Each worker/firm bargaining pair takes the outcome of all other period t bargains as given. In addition, agents have beliefs about the outcome of future wage bargains, conditional on remaining matches. Under their beliefs those future wages are not a function of current actions. Since bargaining in period t applies only to the current wage rate, this is called the period-by-period bargaining.

Periods, $t = 1, 2, \ldots$ in the model represent quarters. It is supposed that bargaining proceeds across M subperiods within the period, where M is even. The firm makes a wage offer at the start of the first subperiod. It also makes an offer at the start of a subsequent odd subperiod in the event that all previous offers have been rejected. On the other hand, the worker makes a wage offer at the start of an even subperiod in case all previous offers have been rejected. The worker makes the last offer. In subperiods

$j = 1, \ldots, M-1$, the recipient may declare an end to the negotiations or she may plan to make a counteroffer at the start of the next subperiod. In the latter case, there is probability, δ_b, that bargaining breaks down. To make a counteroffer, the firm pays a real cost, $\gamma_{b,t}$.

CET derive a simple closed-form expression for the solution of such a bargaining mechanism:

$$w_t^p = \frac{1}{\alpha_1 + \alpha_2} \left[\alpha_1 \vartheta_t^p + \alpha_2 (U_t - A_t) + \alpha_3 \gamma_{b,t} - \alpha_4 (\vartheta_t - b_t^u) \right], \tag{2.15}$$

where

$$\alpha_1 = 1 - \delta_b + (1 - \delta_b)^M, \ \alpha_2 = 1 - (1 - \delta_b)^M,$$
$$\alpha_3 = \alpha_2 \frac{1 - \delta_b}{\delta_b} - \alpha_1, \ \alpha_4 = \frac{1 - \delta_b}{2 - \delta_b} \frac{\alpha_2}{M} + 1 - \alpha_2,$$

and α_1, α_2, α_3 and α_4 are strictly positive.

After rearranging the terms in (2.15) and making use of (2.7) and (2.9), (2.15) can be written as follows:

$$J_t = \beta_1 (V_t - U_t) - \beta_2 \gamma_{b,t} + \beta_3 (\vartheta_t - b_t^u), \tag{2.16}$$

with $\beta_i = \alpha_{i+1}/\alpha_1$, for $i = 1, \ 2, \ 3$. The expression (2.16) is referred as the alternating offer bargaining sharing rule.

For the details on AOB, see CET or Hall and Milgrom (2008).

2.7 Alternative models

2.7.1 The Nash bargaining mechanism

The paper considers an alternative model with the Nash wage bargaining without exogenous wage rigidity. Therefore, the Nash sharing rule is defined as follows:

$$J_t = \frac{1 - \eta}{\eta} (V_t - U_t). \tag{2.17}$$

Here, η is the share of total surplus, $J_t + V_t - U_t$, received by the worker.

Comparing the AOB sharing rule with the Nash sharing rule, an important parameter that enters the AOB sharing rule is γ_b, the firm's cost of delay in bargaining (together with δ_b, the probability that the bargaining breaks down, that enters the multiplier of γ_b). As discussed by Hall and Milgrom (2008), the employer never encounters this cost on the equilibrium path. In equilibrium, the parties do not actually spend any time bargaining. They think through the consequences of a sequence of offers and counter-offers and move immediately to an agreement, without wasting time and resources haggling over the wage. The first wage offer is accepted, which is assumed to be made by the employer. Nevertheless, the firm's cost of counter-offer has an important role in determining the equilibrium path. The importance of this parameter is also emphasized by Ljungqvist and Sargent (2015).

2.7.2 The reduced form sharing rule

The paper also considers a model with the reduced form sharing rule, defined as:

$$J_t = \epsilon_1(V_t - U_t) - \epsilon_2 + \epsilon_3(\vartheta_t - b_t^u), \tag{2.18}$$

where ϵ's are unrestricted. This sharing rule nests, as special cases, both AOB and Nash sharing rule. In the AOB model, $\epsilon_1 = \beta_1$, $\epsilon_2 = \beta_2\gamma_b$, $\epsilon_3 = \beta_3$. In the Nash model, $\epsilon_1 = (1-\eta)/\eta$, $\epsilon_2 = \epsilon_3 = 0$.

2.7.3 The simple reduced form wage rule

The simple wage rule used in this paper is similar to that of CET and is in the following form:

$$\ln(\bar{w}_t/\bar{w}) = \iota_1 \ln(\bar{w}_{t-1}/\bar{w}) + \iota_2 \ln(L_{t-1}/L) + \iota_3 \ln(\mu_{z,t}/\mu_z) + \iota_4 \ln \epsilon_t. \tag{2.19}$$

Here, $\bar{w}_t$ denotes real wage scaled by unit-root technology trend, $\bar{w}_t := w_t/z_t^+$, $\mu_{z,t}$ is unit-root neutral technology growth, ϵ_t is stationary neutral technology growth, and $\iota_1, \iota_2, \iota_3, \iota_4$ are free parameters to be estimated.

2.8 Technology diffusion

To guarantee balanced growth in the nonstochastic steady state, it is required that each element in $[\phi_t, G_t, b_t^u, W_{e,t}, s_t, \kappa_t, \gamma_{b,t}]$ - where ϕ_t is fixed cost of production, G_t is government spending, b_t^u is unemployment benefit, $W_{e,t}$ is wealth transfer to entrepreneurs in BGG block, s_t is vacancy posting cost, κ_t is hiring fixed cost, $\gamma_{b,t}$ is firm's cost of counter-offer in AOB block - grows at the same rate as technology trend, z_t^+, in the steady state.

Following Christiano, Trabandt and Walentin (2010), Schmitt-Grohe and Uribe (2012) and CET, the new model in this paper utilises the concept of technology diffusion, so that a shock to unit-root technology does not necessarily transfer to the above elements fully in the same period the shock occurs.

Particularly, I adopt the following specification:

$$[\phi_t, G_t, b_t^u, W_{e,t}, s_t, \kappa_t, \gamma_{b,t}]' = [\phi, G, b^u, W_e, s, \kappa, \gamma_b]'\Omega_t. \tag{2.20}$$

Here, Ω_t is defined as

$$\Omega_t = {z_{t-1}^+}^{\theta} (\Omega_{t-1})^{1-\theta}, \tag{2.21}$$

where $0 < \theta \leq 1$ is a parameter to be estimated. With this specification, Ω_t/z_{t-1}^+ converges to a constant in the nonstochastic steady state. When θ is close to zero, Ω_t is virtually unresponsive in the short-run to an innovation in the unit-root technology shock, a feature that is found to be attractive on a priori grounds. Given the specification of exogenous processes, the trending model variables scaled by z_t^+ converge to constants in the nonstochastic steady state.

3 Estimation and results

The time unit is a quarter. A subset of model's parameters is calibrated and the rest are estimated using the data for Latvia (domestic part) and the euro area (foreign part). The foreign block is estimated separately in line with the assumption that shocks in Latvia do not affect the foreign economy.

The model is estimated with the Bayesian techniques in Matlab/Dynare environment (Adjemian et al, 2011) using 22 observables including unemployment rate, quarterly growth rate of total number of vacancies, and hiring and separation rates.[15] Other observables are standard in estimated medium-sized New Keynesian models: nominal interest rate, real private consumption, real investment, real government spending, real imports, real exports, real GDP, real wage, total hours worked, consumer price index (CPI) inflation, investment deflator inflation, GDP deflator inflation, real exchange rate, stock price index as a proxy for firm net worth, spread between bank lending rates to non-financial corporations and the monetary policy rate, foreign nominal interest rate, foreign CPI inflation, foreign GDP. The real variables are in terms of demeaned per capita quarterly growth rates. The data cover 1995Q2-2012Q4.

Appendix A lists shock processes and measurement equations.

3.1 Calibration and prior-posterior analysis

The model's calibration and estimation strategy is similar to that of Buss (2015) except for the labor block, on which details follow. The rest of the calibration details are relegated to Appendix A.

CET calibrate a few parameters relating to the labor block. Particularly, they set quarterly job survival rate to 0.9, maximum bargaining rounds per quarter to 60, and vacancy quarterly filling rate to 0.7. The second parameter above appears to be set somewhat arbitrary. Given that the data on labor market behavior in Latvia is more scarce than for the US, I let the model estimate these three parameters along with those estimated also by CET. In addition, in contrast to CET, I allow for non-zero price indexation to inflation and, as is standard in the literature, fix price markups. I calibrate vacancy posting costs to zero and estimate recruiting costs. The prior-posterior results regarding the domestic economy are summarized in Table 1.

[15] Data on hiring and separation rates come from a micro data study of Fadejeva and Opmane (2016).

Table 1: Estimated parameters

	Parameter description	Prior $\mathcal{D}$,**Mean**,std	Posterior **Mean** [2.5-97.5%] Nash, Taylor wage	AOB	Nash, flex wage
ξ_d	Calvo, domestic	β,**0.75**,0.075	**0.834** [0.791 0.876]	**0.766** [0.701 0.833]	**0.739** [0.675 0.798]
ξ_x	Calvo, exports	β,**0.75**,0.075	**0.860** [0.803 0.906]	**0.831** [0.779 0.885]	**0.853** [0.800 0.917]
ξ_{mc}	Calvo, imports for consumpt.	β,**0.75**,0.075	**0.861** [0.797 0.933]	**0.812** [0.725 0.907]	**0.819** [0.750 0.882]
ξ_{mi}	Calvo, imports for investment	β,**0.75**,0.075	**0.415** [0.309 0.524]	**0.542** [0.454 0.637]	**0.536** [0.437 0.626]
ξ_{mx}	Calvo, imports for exports	β,**0.66**,0.10	**0.273** [0.171 0.384]	**0.736** [0.635 0.848]	**0.739** [0.647 0.820]
κ_d	Indexation, domestic	β,**0.40**,0.15	**0.361** [0.155 0.563]	**0.383** [0.191 0.586]	**0.366** [0.151 0.581]
κ_x	Indexation, exports	β,**0.40**,0.15	**0.367** [0.159 0.582]	**0.045** [0.015 0.077]	**0.046** [0.015 0.078]
κ_{mc}	Indexation, imports for cons.	β,**0.40**,0.15	**0.666** [0.430 0.892]	**0.636** [0.408 0.854]	**0.683** [0.493 0.896]
κ_{mi}	Indexation, imports for inv.	β,**0.40**,0.15	**0.367** [0.142 0.609]	**0.537** [0.334 0.734]	**0.446** [0.270 0.628]
κ_{mx}	Indexation, imports for exp.	β,**0.40**,0.15	**0.259** [0.078 0.462]	**0.042** [0.013 0.073]	**0.048** [0.015 0.087]
κ_w	Indexation, wages	β,**0.40**,0.15	**0.361** [0.122 0.627]		
ν^j	Working capital share	β,**0.50**,0.1	**0.470** [0.031 0.908]	**0.520** [0.329 0.713]	**0.490** [0.291 0.673]
$0.1\sigma_L$	Inverse Frisch elasticity	Γ,**0.30**,0.15	**1.059** [0.816 1.307]		
b	Habit in consumption	β,**0.65**,0.15	**0.896** [0.832 0.963]	**0.854** [0.783 0.935]	**0.838** [0.748 0.928]
$0.1S''$	Investment adjustm. costs	Γ,**0.50**,0.15	**0.226** [0.122 0.348]	**0.253** [0.164 0.357]	**0.233** [0.152 0.323]
σ_a	Variable capital utilization	Γ,**0.20**,0.075	**0.472** [0.227 0.733]	**0.557** [0.305 0.811]	**0.513** [0.265 0.799]
η_x	Elasticity of subst., exports	$\underline{\Gamma}$,**1.50**,0.25	**1.586** [1.144 2.058]	**1.456** [1.045 1.864]	**1.373** [1.031 1.701]
η_c	Elasticity of subst., cons.	$\underline{\Gamma}$,**1.50**,0.25	**1.319** [1.010 1.670]	**1.276** [1.010 1.596]	**1.281** [1.010 1.628]
η_i	Elasticity of subst., invest.	$\underline{\Gamma}$,**1.50**,0.25	**1.409** [1.025 1.783]	**1.102** [1.010 1.289]	**1.094** [1.010 1.244]
η_f	Elasticity of subst., foreign	$\underline{\Gamma}$,**1.50**,0.25	**1.678** [1.211 2.162]	**1.536** [1.136 2.032]	**1.609** [1.155 2.075]
μ	Monitoring cost	β,**0.30**,0.075	**0.248** [0.176 0.318]	**0.488** [0.377 0.602]	**0.498** [0.378 0.620]
$F(\bar{\omega})$	SS bankruptcy rate	β,**0.005**,0.002	**0.020** *	**0.008** [0.005 0.011]	**0.008** [0.004 0.011]
$hshare, \%$	Hiring fixed costs	Γ,**0.20**,0.075	**0.089** [0.067 0.111]	**0.179** [0.064 0.319]	**0.164** [0.057 0.283]
$bshare$	Utility flow, unemployed	β,**0.75**,0.075	**0.566** [0.426 0.697]	**0.381** [0.274 0.490]	**0.484** [0.370 0.593]
ρ	SS exog match surviv rate	β,**0.90**,0.05	**0.970** *	**0.821** [0.784 0.858]	**0.779** [0.733 0.825]
σ	Unemp share, matching f-n	β,**0.60**,0.10	**0.500** *	**0.678** [0.628 0.727]	**0.715** [0.671 0.760]
M_{sc}**	Scaled # of negot rounds	β,**0.1**,0.02		**0.189** [0.144 0.238]	
$\Delta\%$	Prob(barg session termin)	β,**0.50**,0.10		**0.765** [0.650 0.868]	
Q	Vacancy filling rate	β,**0.70**,0.10	**0.700** *	**0.712** [0.547 0.889]	**0.732** [0.557 0.895]
θ	Technology diffusion	β,**0.50**,0.075		**0.482** [0.349 0.626]	**0.474** [0.342 0.606]
ρ_ϵ	Persistence, stationary tech.	β,**0.85**,0.075	**0.876** [0.799 0.952]	**0.887** [0.806 0.956]	**0.912** [0.850 0.969]
ρ_Υ	Persistence, MEI	β,**0.85**,0.075	**0.478** [0.267 0.690]	**0.391** [0.258 0.541]	**0.381** [0.242 0.533]
ρ_{ζ^c}	Persist., consumption prefs	β,**0.85**,0.075	**0.872** [0.790 0.940]	**0.893** [0.808 0.959]	**0.878** [0.795 0.960]
$\rho_{\tilde{\phi}}$	Persist., country risk prem.	β,**0.85**,0.075	**0.908** [0.869 0.947]	**0.953** [0.917 0.988]	**0.957** [0.918 0.992]
ρ_g	Persist., gov. spending	β,**0.85**,0.075	**0.784** [0.620 0.938]	**0.763** [0.610 0.924]	**0.790** [0.657 0.926]
ρ_γ	Persistence, entrep. wealth	β,**0.85**,0.075	**0.787** [0.617 0.926]	**0.644** [0.442 0.827]	**0.652** [0.497 0.810]
ρ_ρ	Persist., survival rate	β,**0.85**,0.075		**0.890** [0.806 0.967]	**0.872** [0.779 0.970]
		Shock standard deviations			
$10\sigma_\epsilon$	Stationary technology	Γ^{-1},**0.15**,inf	**0.160** [0.126 0.195]	**0.126** [0.099 0.151]	**0.128** [0.101 0.158]
σ_Υ	Marginal efficiency of invest.	Γ^{-1},**0.15**,inf	**0.228** [0.114 0.356]	**0.292** [0.193 0.409]	**0.278** [0.177 0.382]
σ_{ζ^c}	Consumption prefs	Γ^{-1},**0.15**,inf	**0.258** [0.120 0.466]	**0.215** [0.114 0.351]	**0.200** [0.104 0.321]
$100\sigma_{\tilde{\phi}}$	Country risk premium	Γ^{-1},**0.50**,inf	**0.559** [0.471 0.654]	**0.538** [0.454 0.628]	**0.530** [0.445 0.620]
$10\sigma_g$	Government spending	Γ^{-1},**0.50**,inf	**0.478** [0.387 0.573]	**0.482** [0.402 0.572]	**0.487** [0.405 0.576]
σ_{τ^d}	Markup, domestic	Γ^{-1},**0.50**,inf	**0.571** [0.302 0.890]	**0.295** [0.138 0.501]	**0.222** [0.120 0.341]
σ_{τ^x}	Markup, exports	Γ^{-1},**0.50**,inf	**0.924** [0.399 1.564]	**0.619** [0.306 1.012]	**0.838** [0.307 1.854]
$\sigma_{\tau^{m,c}}$	Markup, imports for cons.	Γ^{-1},**0.50**,inf	**1.285** [0.372 2.890]	**0.843** [0.224 1.850]	**0.828** [0.335 1.438]
$\sigma_{\tau^{m,i}}$	Markup, imports for invest.	Γ^{-1},**0.50**,inf	**0.521** [0.315 0.761]	**0.933** [0.583 1.360]	**0.875** [0.532 1.283]
$\sigma_{\tau^{m,x}}$	Markup, imports for exports	Γ^{-1},**0.50**,inf	**0.758** [0.432 1.108]	**4.646** [1.607 9.095]	**4.861** [2.230 8.306]
$10\sigma_\gamma$	Entrepreneurial wealth	Γ^{-1},**0.40**,inf	**0.293** [0.213 0.387]	**0.348** [0.243 0.470]	**0.348** [0.236 0.464]
$10\sigma_\rho$	Exog survival rate	Γ^{-1},**0.10**,inf		**0.168** [0.124 0.212]	**0.167** [0.121 0.215]
		Model fit items			
	Log marginal likelihood***		-3399.4	-3388.8	-3411.5

Note: Based on two Metropolis-Hastings chains each with 50'000 draws after a burn-in period of 200'000 draws. * - calibrated. ** - the (unscaled) number of wage negotiation rounds is calculated as $M = 2ceil(200M_{sc})$ where *ceil* is a function of rounding towards positive infinity. *** - calculated using the same set of observables and the same set of estimated parameters across all three models, for comparison purposes. The rest of parameters that vary between models are set to their posterior mode. Note that truncated priors, denoted by $\underline{\Gamma}$, with no mass below 1.01 have been used for elasticity parameters η_j, $j = \{x, c, i, f\}$.

In Table 1, the results for the three models are not completely comparable, as the Nash-Taylor wage model's coding is similar to Buss (2015) but without the labor supply shock, whereas the results for AOB and Nash-flexible wage models are based on the new code and are comparable to each other. Table 1 shows that the posterior means for indexation of exports, and imports for exports have approached zero with the new coding of wage. However, the posterior means for the rest of indexation parameters (for the domestic goods and imports for consumption and investment) are non-zero and similar to the benchmark's. Also, the new coding of wages has affected the size of some shocks; particularly, the size of the domestic markup shock has decreased, whereas the size of the markup shock to imports for exports has increased.

Second, in the steady state the total cost associated with hiring a new worker is roughly 1.67% of the wage rate.[16] This is lower than the CET estimate of 6.8% for the US. However, it is not straightforward to interpret the differences in the results of this paper and CET as the differences between Latvia and the US, as the two models and their estimation approaches are different. This paper uses a full information approach in the estimation of the model, whereas CET use a limited information approach by fitting selected IRFs to the IRFs of a VAR model.

Third, the posterior mean of the replacement ratio is 0.38, thus, AOB does not need a high replacement ratio to fit the data, but so does the Nash wage bargaining model without exogenous wage frictions (last column) and with Taylor-type frictions. My unreported results show that the estimate of the replacement rate is sensitive to calibration, e.g. the exclusion of the labor preference shock and the calibration of vacancy posting costs.

Fourth, the posterior means of parameters governing technology diffusion tend to be similar across each other; therefore, they have been reduced to a single common parameter whose posterior mean is close to 0.5. Thus, fixed cost and/or benefit parameters are less responsive to short-run technology shocks than the typically modeled unit-elasticity but more responsive than in CET.[17]

3.2 Impulse response analysis

One of the reasons to search for an alternative to the Nash bargaining with Taylor-type wage inertia was the ragged behavior of wage impulse responses. In the benchmark model's IRFs, there is usually a sharp change in wages after around 4 quarters, and this is the artifact of the Taylor-type modeling of nominal wage rigidity. Such dynamics of the modeled real wage can be considered as implausible and suggest that Taylor-type frictions may be too strict for the particular sample of Latvian data.

Figure 2 shows IRFs to the country risk premium shock for the Nash-Taylor wage, AOB, and Nash-flexible wage models. It shows that the AOB model generates smooth dynamics of wages. Depending on the type of a shock, the reaction of wages might be considered as quick and sizable. On the other hand, wages in Latvia have been rather

[16] Calculated as $\frac{\eta_s+\eta_h}{1-\rho}\frac{Y}{wL} = 0.0167$, where η_s and η_h are vacancy posting and hiring costs per aggregate output, respectively.

[17] The posterior mean of this parameter is close to its prior mean but this is because the prior is selected to be close to the posterior and thus should not be an indication of weak identification. Particularly, if the prior mean is set to 0.1, the posterior still goes to about 0.4.

flexible over the considered sample span (see data in the forecasting section). Therefore, next we will study the model's forecasting performance to see whether there is excess volatility in wage forecasts.

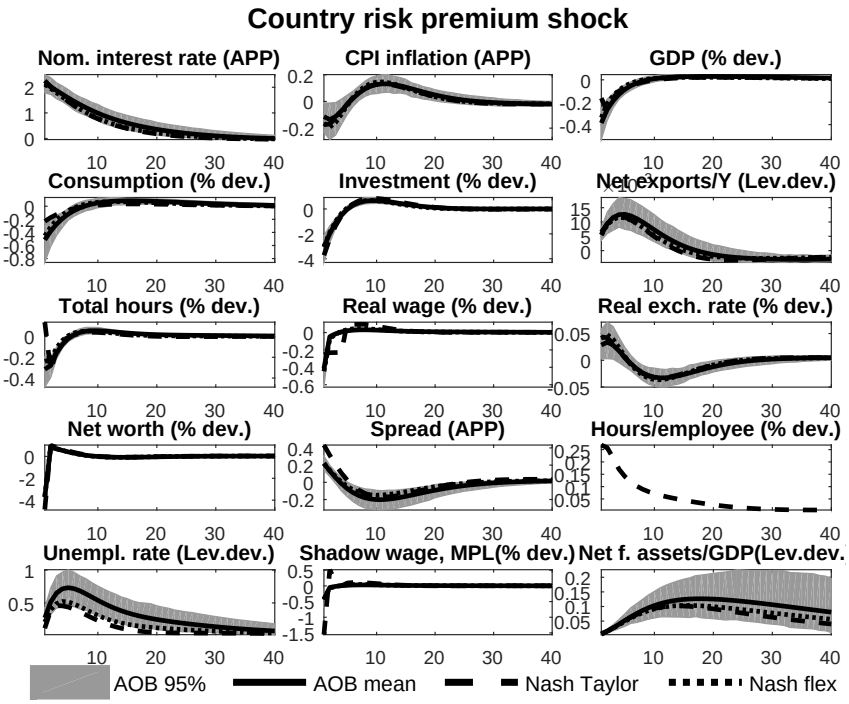

Figure 2: Impulse responses to the country risk premium shock

Note: Units on y-axis are either in terms of percentage deviation (% dev.) from the steady state, annual percentage points (APP) or level deviation (Lev.dev.).

3.3 Forecasting performance

Figure 3 shows one-quarter ahead forecasts of the AOB and benchmark models for selected observables.[18] The results for all observables are reported in Appendix A.

It turns out that the AOB model generates forecasting behavior similar to the benchmark model of the Nash bargaining with Taylor-type wage rigidity. Particularly, one-step ahead forecasts of GDP and total hours worked behave similarly across the two models. Second, the AOB model generates real wage forecasts that exhibit no excess volatility and whose behavior is also similar to the benchmark. Although the model still fails to forecast the massive wage increase during the boom years and the wage dynamics during the recovery period of 2010-2012, the AOB model's performance can be regarded as decent given that in contrast to the benchmark model there is no exogenously imposed wage inertia. Third, both the AOB and benchmark models can replicate volatile dynamics of unemployment data. Fourth, both models generate excessive short-term volatility of vacancies but the AOB model's forecasts of the level of the total number of vacancies[19]

[18]These are not true out-of-sample forecasts because the models are calibrated/estimated for the whole sample period 1995Q2-2012Q4. Nevertheless, these figures indicate an approximate relative forecasting performance of the models.

[19]The observed data are the quarterly growth rate of total registered number of vacancies. The

in the business-cycle frequency are decent.[20] Fifth, the forecasted dynamics of hiring and separation rates match well with the observed data.[21]

registered data might depart from the reality, thus the quality of the vacancy data fit can be considered as less important compared to other observables.

[20]This specification of the Nash-Taylor wage model fails to replicate vacancy data. If the labor preference shock is activated, the model fits the vacancy data better. Note that the labor preference shock is inactive in all models considered in this paper.

[21]Note that the model-implied steady state of hiring and separation rates is about 0.18 and thus above that of the data (about 0.1). Therefore, data on hiring and separation rates are demeaned for estimation purposes.

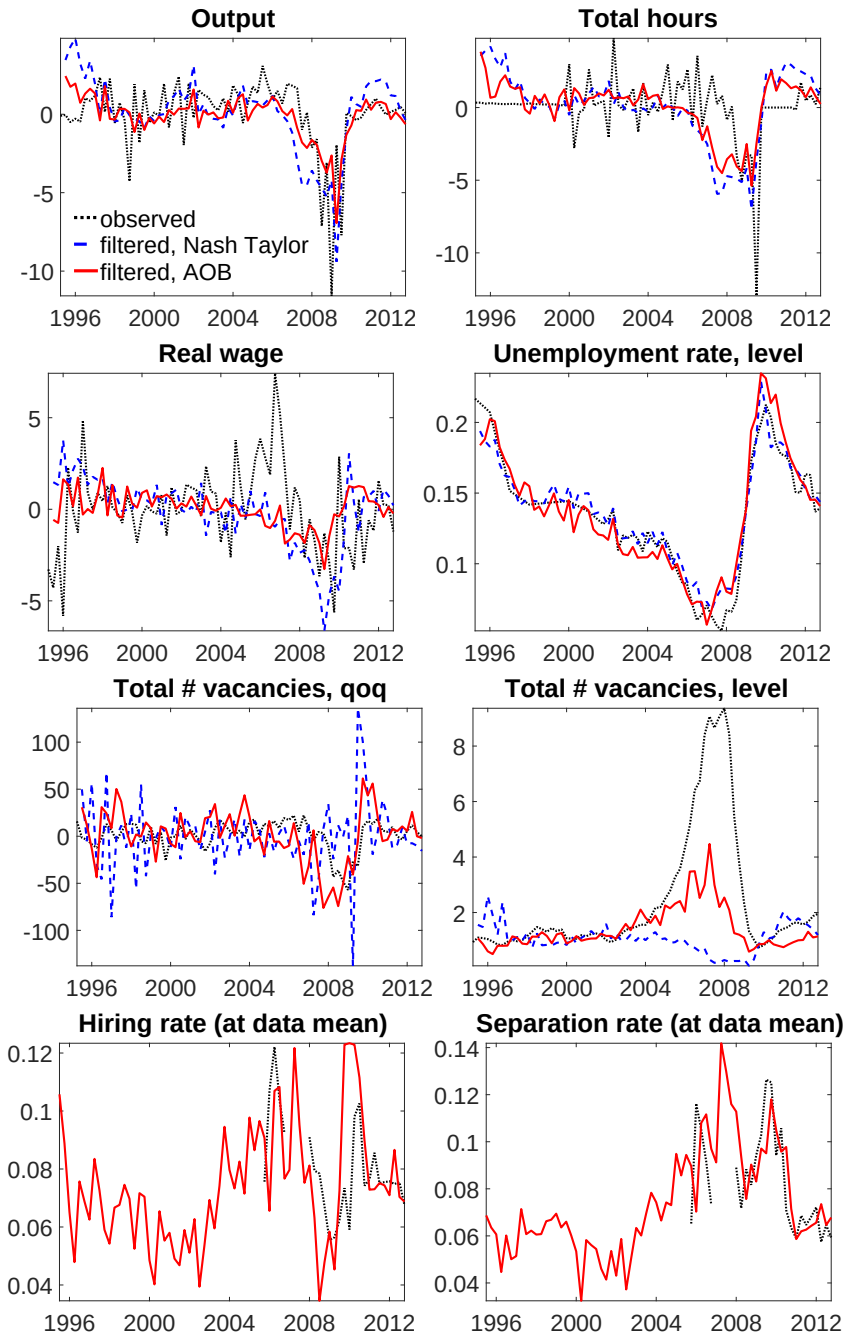

Figure 3: One-step ahead forecasts (selected)

I also estimate models with alternative specifications similar to those considered by CET, with: i) the Nash wage bargaining but with no exogenously imposed wage rigidity, ii) a reduced form sharing rule, and iii) a simple wage rule.[22] Briefly, the forecasts generated by the reduced form sharing rule lie in between those generated by other models and thus are not shown.[23] The rest of the models are compared to AOB in forecasting

[22]Note that these three specifications are more comparable to the AOB model than that of Nash bargaining with Taylor type rigidity because the latter model has a few other differences discussed in the previous section.

[23]Also, the reduced-form sharing rule generated non-convergent posteriors from Metropolis-Hastings

one quarter ahead GDP, hours worked and wages (Figure 4).

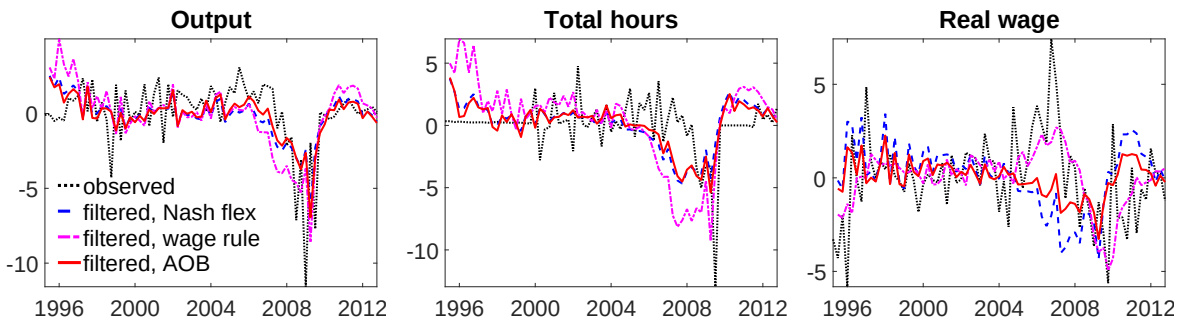

Figure 4: One-step ahead forecasts of alternative specifications (selected)

Figure 4 shows that the Nash-flexible wage model generates GDP and total hours worked forecasts that behave like those of the AOB model, but its wage forecasts tend to be more volatile and counter-cyclical relative to those of the AOB model. On the contrary, a reduced-form wage rule generates wage forecasts that mimic the behavior of wage data closely. However, the wage rule generates excessive volatility of total hours worked and GDP.

Table 2 reports the forecasting performance of AOB and Nash-Taylor wage models relative to a random walk model (in terms of quarterly growth rates) with respect to predicting CPI inflation and GDP growth for horizons of one, four, eight and 12 quarters. The table also reports the forecasting performance of alternative labor market specifications with i) the Nash bargaining with flexible wages, and ii) a simple wage rule, as well as a Bayesian SVAR (with the same structure as the foreign SVAR, and with similar priors), since it is often taken as a benchmark in the literature[24].

Table 2 shows that the AOB model's forecasting performance is similar to the benchmark performance, though slightly inferior with respect to inflation forecasts. Also, the AOB model tends to produce more precise short-term GDP forecasts than the alternative models. The forecasting performance of the Nash-flexible wage model is comparable to that of AOB in terms of inflation and GDP forecasts but tends to be inferior in terms of short term wage forecasts, supporting the graphical information shown in Figure 4. Therefore, in terms if forecasting performance AOB is among the best performing models of the labor market considered in this paper.

Markov chain Monte Carlo (MCMC) samplings and thus its analysis was discontinued.

[24]The particular SVAR has some economically implausible estimated parameters, since Latvian GDP, CPI inflation and nominal interest rate data do not possess a stable and economically plausible relationship over the particular sample span.

Table 2: Forecasting performance

Model	Distance measure	1Q CPI	1Q GDP	4Q CPI	4Q GDP	8Q CPI	8Q GDP	12Q CPI	12Q GDP
AOB	RMSE	1.28	0.77	0.75	0.79	0.56	0.67	0.60	0.64
	DM p-val	0.946	0.020	0.120	0.115	0.081	0.080	0.071	0.093
	MAE	1.45	0.85	0.84	0.77	0.61	0.61	0.61	0.61
	DM p-val	0.997	0.074	0.209	0.078	0.090	0.072	0.067	0.111
Nash-Taylor	RMSE	1.13	0.90	0.69	0.76	0.54	0.66	0.58	0.64
	MAE	1.24	1.07	0.72	0.75	0.55	0.60	0.58	0.59
Nash flex wage	RMSE	1.26	0.80	0.76	0.77	0.56	0.66	0.60	0.64
	MAE	1.43	0.91	0.85	0.75	0.61	0.60	0.61	0.60
Wage rule	RMSE	1.31	0.93	0.78	0.82	0.60	0.71	0.63	0.66
	MAE	1.49	1.14	0.89	0.83	0.67	0.67	0.66	0.63
SVAR	RMSE	0.95	0.72	0.68	0.80	0.59	0.68	0.55	0.66
	MAE	1.03	0.72	0.67	0.76	0.59	0.62	0.47	0.61
		real wage forecasts							
AOB vs Nash flex wage	RMSE	0.82		0.99		1.00		1.00	
	MAE	0.82		0.99		1.00		1.00	

Notes. 1) For RMSE (root mean squared error) and MAE (mean absolute error), a number less than unity indicates that the model makes more precise forecasts compared to the random walk model, unless stated otherwise. 2) DM p-val is a one-sided p-value of the Diebold-Mariano (Diebold and Mariano, 1995) test for equal forecast accuracy between the AOB and random walk models. Its value below 0.1 implies that the precision of a model's forecasts is better than that of the alternative models at a 10% significance level. 3) SVAR is estimated on three domestic variables - GDP, CPI and the nominal interest rate, and is of the same structure and with similar priors as the foreign SVAR. 4) However, this is not a true out-of-sample forecasting performance since the models have been estimated for the whole sample period 1995Q2-2012Q4.

4 Simulation of effects of minimum wage increase

Recently, there have been discussions in Latvia about minimum wage increases and their effects on the economy. These discussions were brought forth by repeated increases in the minimum wage in Latvia over the past years (Figure 5), and by calls[25] for continuation of minimum wage increases in the near future[26]. Proponents of raising the minimum wage mention such arguments as welfare improvement for low-wage earners, reduction of grey economy, and less reliance on social welfare, while the opponents stress that raising the minimum wage is not the most effective way towards well-being, for it harms firm competitiveness and hampers growth and welfare.

[25]E.g. by the Ministry of Welfare.

[26]The minimum wage was increased by 10 euros in 2017.

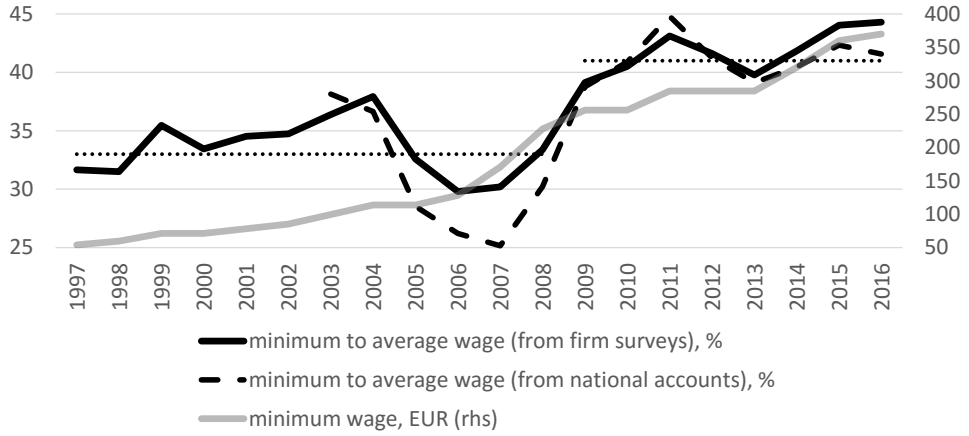

Figure 5: Minimum wage in Latvia

Source: Central statistical bureau of Latvia, likumi.lv and author's calculations.

Figure 5 shows that the minimum to average wage in Latvia[27] has increased from around 33% in 1997-2008 to about 41% in 2009-2016, i.e. it shows a pronounced and apparently permanent level shift in about 2008-2009 due to a decrease in the average wage which is not offset but, on the contrary, secured by a further increase in minimum wage in the subsequent years. Such a permanent increase in the minimum to average wage ratio might pose risks to competitiveness of firms and a further recovery of the labor market.[28]

Before simulating the effects of a minimum wage increase, it is instructive to know what firms report as the most likely potential reaction to minimum wage increases. Table 3 reports such interim findings of the European System of Central Banks (ESCB) Wage Dynamics Network for Bulgaria, Estonia, Hungary, Lithuania, Latvia, Romania and Slovenia. According to the table, firms faced with a minimum wage increase would likely take one or several of the following steps: increase product prices, decrease other costs, increase productivity, reduce hiring, and increase wages also for other than minimum wage receivers.

[27] I use two measures of average monthly wage for a full-time job. One comes from firm surveys and constitutes the official numbers. The other comes from national accounts where the shadow economy is taken into account. The two measures are similar.

[28] The unemployment rate in Latvia is relatively high (9.6% in November 2016).

Table 3: Share of firms considering particular reaction as likely

Action	BG	EE	HU	LT	LV	RO	SI	Total
fire	20.8	5.8	15.7	3.9	15.7	25.2	2.7	15.0
↓ hiring	-	6.6	42.6	13.5	20.4	39.4	8.5	28.5
↑ product prices	37.5	22.3	50.2	20.6	36.9	52.3	5.1	37.2
↓ other costs	7.2	19.1	47.1	28.6	39.7	59.8	24.2	40.1
↑ wages for others	37.5	18.1	-	23.7	38.4	23.9	7.8	22.1
↑ productivity	26.7	18.3	52.6	39.1	36.1	-	-	41.2

Source: ESCB Wage Dynamics Network interim results; covered period: 2010-2015; contact person: L. Fadejeva, Latvijas Banka.

Now, let us turn to the simulation. In the model, there is neither formal minimum wage nor wage distribution, so we will abstract from any discussion of distributional effects. Also, there is no disutility of work in this model, so we abstract from any discussion of the welfare effects. Rather, we will try to outline the underlying endogenous cost-correction processes at work, that are present in our DSGE model as a reaction to a permanent increase in minimum to average wage. Also, we will sketch out the potential effects on the aggregate economy.

The simulation strategy is to realize that a level shift in the minimum to average wage observed in Figure 5 mimics the result of a permanent increase in worker bargaining power, whereas firms are pushed to increase wages permanently above the initial level. This is to be contrasted with a case when a minimum wage adjusts to a change in the average wage so, that a minimum to average wage stays unaffected in a medium term, since in that case such a policy does not impose additional cost of labor for firms. Therefore, we will study the effects of a permanent increase in worker bargaining power and try to draw conclusions on the effects from a permanent increase in minimum to average wage.

Figure 6 shows impulse responses generated by both the AOB and Nash-Taylor wage models, to a permanent[29] increase in worker bargaining power such that the nominal wage rises to 1% above its initial level in the long run. In a perspective, it would require to increase the minimum wage in Latvia by about 8% to get about 1% increase in an average wage. This is less than an average annual increase in Latvia's minimum wage during 1997-2016, which is 11.1% and less than minimum wage increases in 2008 and 2009 (33.3% and 12.5% respectively), i.e. the period during which a minimum to average wage level shift was observed. A back-of-the-envelope calculation suggests that the effect of the level shift of minimum to average wage from 33% to 41% observed in Figure 5 is congruent to a four-fold effect shown in Figure 6.

[29]The shock to worker bargaining power is long enough to allow the economy to converge to a new steady state.

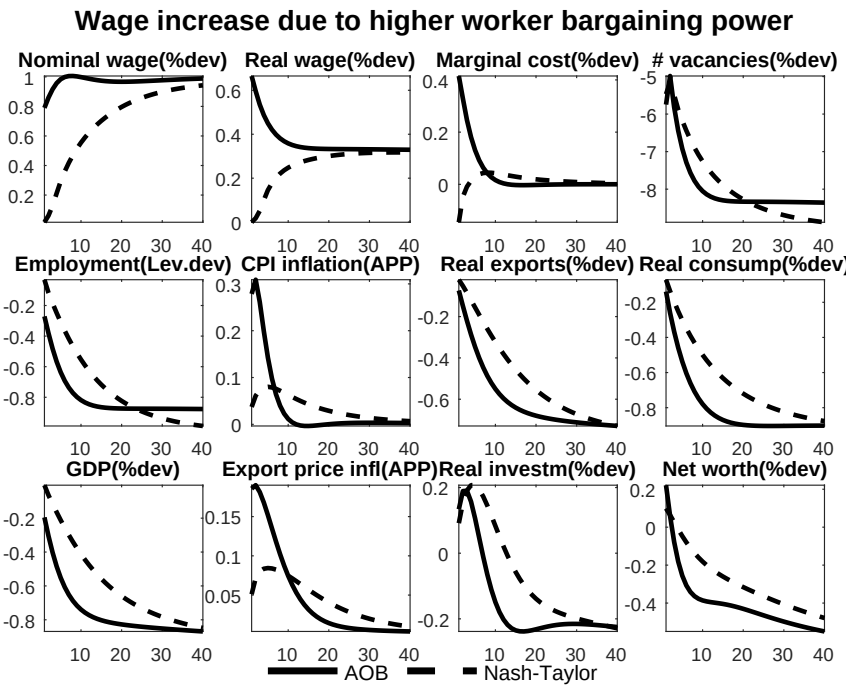

Figure 6: Impulse responses to a permanent increase in worker bargaining power

Note: Units on y-axis are either in terms of percentage deviation (% dev.) from the steady state, annual percentage points (APP) or level deviation (Lev.dev.).

First, we will discuss the AOB model results. The shift in worker bargaining power pushes firms to increase wages in order to maintain workers' interest in being employed. A rise in wages raises firms' marginal costs that leads to a decrease in posted vacancies. A constant separation rate together with a smaller number of hires means a decrease in employment, and an increase in unemployment, which is big enough to cause a decrease in aggregate consumption and GDP. This cost-push shock is transferred also to product prices, yielding an increase in inflation despite a decreasing aggregate demand. Thus, the real wage is only about 0.35% above its initial level in the long run. A rise in wages cannot compensate for a drop in employment (by 0.8pp in the long run), thus the aggregate consumption and output decline by about 0.8% percent in the long run. A rise in the export price worsens the terms of trade and reduces real exports. Meanwhile, firms try to substitute labor with relatively cheaper capital, thus investment increases in the first few years but subsequently drops with a declining aggregate demand.

Thus, the model identifies three endogenous reactions to an increase in the cost of labor: i) increase in product prices, ii) reduction of hiring, and iii) substitution of labor with capital, all of which are supported by the survey evidence regarding responses to the minimum wage increases, discussed above.[30]

The Nash-Taylor wage model supports the long-run effects obtained from the AOB model but produces slow-growing wages due to exogenous wage rigidity. As a result,

[30]The survey results suggest that firms would try to reduce costs unrelated to wages, which could be modeled as an exogenous decrease in markups. However, it is discussable whether such a decrease in markups would be a permanent phenomenon or only a temporary solution. If it is temporary, then the long-run effects remain unaltered.

inflation is also more dampened.[31]

To sum up, both models predict that a 1% permanent increase in nominal wage forced upon firms reduces the aggregate output by about 0.8 percent and employment - by about 0.8pp in the long run. Thus, the economic cost of permanently increasing minimum to average wage ratio can be large. Particularly, the increase of minimum to average wage from 33% to 41%, as seen in Latvia might have cost a 3% loss of output in the long run.

The above result differs from CET findings that an (temporary) increase in unemployment benefits (that raises the worker bargaining power) in the presence of zero lower bound (ZLB) can have positive effects on employment. CET argue that, at the ZLB, a rise in inflation results in a decrease in the real interest rate and thus can have a positive effect on consumption and investment. In our model, the Latvian economy has no effect on the ECB policy rate, thus, in a sense, the Latvian economy works in a ZLB environment. Still, as we see above, any positive effect from a higher inflation is not sufficient to compensate for the negative effects, as both consumption and investment drop in the long run. The difference might come from the fact that CET consider a temporary increase of worker bargaining power, while this paper considers a permanent increase in order to capture a permanent increase in the minimum to average wage ratio as observed in the Latvian data. Also, the external competitiveness channel, which is absent from the CET analysis, is important for a small and open economy like Latvia. Another channel absent from the CET model is the financial accelerator; as shown in Figure 6, net worth of firms deteriorates and it has an additional downward pressure on economic activity via the credit channel as it gets costlier for firms to finance investment. Yet, it is helpful to be aware that an active monetary policy rule could either amplify or dampen these negative effects, depending on the assumed weights on inflation and output gap in the policy rule.

5 Summary and conclusions

The goal of the paper is to replace the Nash wage bargaining with the Taylor-type wage inertia in the model built for policy analysis and forecasting of Latvijas Banka (Buss, 2015) with an alternative specification that would be both more realistic and simple. Specifically, the major hurdles to using the model is the bulky coding of the Taylor-type wage inertia (see Buss (2015) or CTW) and ragged wage IRFs.

Therefore, the paper introduces a new version of the model where the Nash wage bargaining with the Taylor type wage inertia is replaced by AOB of Hall and Milgrom (2008) and Christiano, Eichenbaum and Trabandt (2016), without adding exogenous wage rigidity. The paper also studies alternative specifications of labor market modeling: i) the Nash wage bargaining without exogenously imposed wage inertia, ii) a reduced form sharing rule, and iii) a simple reduced form wage rule.

It turns out that the AOB model without exogenous wage rigidity is among the best performing specifications. First, Latvian firm survey data show that the frequency of

[31] The most noticeable difference between the short-term effects of the two models occurs for marginal costs, where the Nash-Taylor wage model predicts a decrease in marginal costs in the first few quarters. Given that in the Nash-Taylor wage model firms are not able to elastically move wages, but at the same time the shadow wage, that enters in the marginal costs equation, decreases right away due to expectations in wage formation, there is a short-lived decrease in marginal costs for the benchmark model.

wage change is not unimodal and fixed in time, so Taylor or Calvo-type wage rigidity is a too strict modeling construct for Latvia. Rather, a mechanism allowing firms to change wages whenever they find optimal to do so is deemed more suitable. Second, the AOB mechanism seems more plausible than the Nash bargaining mechanism. Nash bargaining implies that a worker and an employer threat each other to end their co-operation every quarter, which might not be a realistic description of an established worker-employer relationship. Instead, the AOB's threat is to merely extend the bargaining process rather than end it. Third, the AOB model's wage forecasts exhibit no excess volatility, and the model's forecasting performance is among the best considered in the paper. Particularly, it tends to outcompete the Nash-flexible wage model in terms of wage forecasts. Fourth, the coding of AOB is simple, facilitating a further expansion of the model. Fifth, the structure of the model remains strongly micro-theory based.

The paper ends with a simulation of the effects of a permanent increase in minimum to average wage ratio as seen in the Latvian data. The model captures three endogenous reactions of firms, all being supported by survey evidence: increasing product prices, reduced hiring, and substitution of labor with capital. The simulation results suggest that the economic effects of permanently increasing the minimum to average wage ratio are negative and potentially sizable in the long run. Thus, caution is needed in further raising the minimum wage in Latvia.

Appendix A Calibration and estimation details

A.1 Calibration

The calibrated values are displayed in Tables 4 and 5. These are the parameters that are typically calibrated in the literature and related to "great ratios" and other observable quantities related to steady state values. The values of parameters are selected such that they would be specific to the data at hand. Sample averages are used when available. I am using the calibrated values equal or similar to those used by Buss (2015) for the parameters common for the new and the benchmark model.

Table 4: Calibrated parameters

Parameter	Value	Description
		Core block
α	0.400	Capital share in production
β	0.995	Discount factor
δ	0.030	Depreciation rate of capital, quarterly
ω_c	0.450	Import share in consumption goods
ω_i	0.650	Import share in investment goods
ω_x	0.300	Import share in export goods
$\tilde{\phi}_a$	0.010	Elasticity of country risk to net asset position
η_g	0.200	Government spending share of GDP
τ_k	0.100	Capital tax rate
τ_w	0.330	Payroll tax rate
τ_c	0.180	Consumption tax rate
τ_y	0.240	Labor income tax rate
τ_b	0.000	Bond tax rate
μ_z	1.005	Steady state growth rate of neutral technology
μ_ψ	1	Steady state growth rate of investment technology
$\bar{\pi}$	1.005	Steady state gross inflation target
$\lambda_{d;m,c;m,i}$	1.300	Price markup for domestic, imp for cons, imp for inv
$\lambda_{x;m,x}$	1.200	Price markup for exports, imp for exp
$\varkappa^j$	$1-\kappa^j$	Indexation to inflation target for $j = d; x; m, c; m, i; m, x$
$\tilde{\phi}_S$	0	Country risk adjustment coefficient
		Financial frictions block
$100W_e/y$	0.100	Transfers to entrepreneurs
		Labor market block
L	0.864	Steady state fraction of employment (1 - unemployment rate)
σ_m	0.400	Level param, matching f-n (benchmark model only)
φ	1.000	Curvature of hiring and vacancy posting costs
$vshare, \%$	0	Vacancy posting cost as share of GDP

The discount factor, β, and the tax rate on bonds, τ_b, are set to match roughly the sample average real interest rate for the euro area. The capital share, α, is set to 0.4. The quarterly depreciation rate of capital, δ, is fixed to 3%. Import shares are set by consulting the input-output tables and fellow economists and are - 45%, 65% and 30% for the import share in consumption, investment and exports respectively. The government spending share in GDP is set to match the sample average, i.e. 20.2%. The steady state growth rates of neutral technology and inflation are set to 2% annually and correspond to the euro area. The steady state growth rate of investment-specific technology is set to zero. The values of price markups are set to the typical values found in the literature, i.e. to 1.2 for exports and imports for exports, and 1.3 for the domestic good, imports for consumption and imports for investment.

Price indexation parameters are set to get the full indexation and thereby avoid the steady state price and dispersion. There is no wage indexation in the new model with AOB.

Tax rates are calibrated so that they would represent implicit or effective rates. The tax rate on capital income is set to 0.1, the value-added tax on consumption is set to $\tau^c = 0.18$, and the personal income tax rate that applies to labor is set to $\tau^y = 0.24$. The payroll tax rate is set to $\tau^w = 0.33$, down from the official 0.35 (0.24 by employer and 0.11 by employee). The elasticity of country risk to net asset position, $\tilde{\phi}_a$ is set to a small positive number and, in that region, its purpose is to induce a unique steady state for the net foreign asset position. Transfers to entrepreneurs parameter W_e/y is kept the same as in CTW. The country risk adjustment coefficient in the uncovered interest parity condition is set to zero in order to impose the nominal interest rate peg.

For the labor market block, the steady state unemployment rate is set to the sample average.

In the new model, two ratios are chosen to be exactly matched throughout the estimation, and therefore two corresponding parameters are recalibrated for each parameter draw: the steady state real exchange rate, $\tilde{\varphi}$, to match the export share of GDP in the data, and the entrepreneurial survival rate, γ, to match the net worth to assets ratio[32].

Also, the level parameter in the matching function is calculated using the rest of the matching function parameters at their posterior means.

Table 5: Targeted steady states and selected implied parameters

	Description	Nash-Taylor	AOB
	Targeted		
$p_x x\tilde{\varphi}/y$	Exports to gross output	0.462	0.470
$n/(p_{k'}k)$	Net worth to capital	0.600	0.710
$L\varsigma$	Hours per employee	0.240	
	Implied at the posterior mean		
$\tilde{\varphi}$	Real exchange rate	0.89	0.90
A_L	Scaling of disutility of work	1235540.84	
γ	Entrepreneurial survival rate	0.97	0.97
σ_m	Level param, matching f-n		0.584
f	Job finding rate		0.532
v	Vacancy rate (per employed)		0.251
$v/(1+v)$	Vacancy rate (Eurostat approach)*		0.200
$\gamma_b/(\vartheta/60)$	Counter-offer costs per daily revenue		0.723

Note: * Eurostat definition of vacancy rate is $\frac{\text{\# of vacancies}}{\text{\# of occupied posts+\# of vacancies}}$.

[32]The net worth to assets ratio for Latvia, if the definition of CTW is taken, yields about 0.15. However, the model fit favors a much larger number, 0.7, which is used in calibration of the new model. The latter number might be rationalized if the net worth was measured not only by the share price index but if it included also the real estate value.

A.2 Shocks and measurement errors

In total, there are 16 estimated exogenous stochastic variables in the new model: three technology shocks - stationary neutral technology shock, ϵ, stationary marginal efficiency of investment shock, Υ, and unit-root neutral technology shock, μ_z, - a shock to consumption preferences, ζ^c, a shock to government spending, g, and a country risk premium shock that affects the relative riskiness of foreign assets compared to domestic assets, $\tilde{\phi}$. There are five markup shocks, one for each type of intermediate good, τ^d, τ^x, $\tau^{m,c}$, $\tau^{m,i}$, $\tau^{m,x}$ (d - domestic, x - exports, m, c - imports for consumption, m, i - imports for investment, m, x - imports for exports). The financial frictions block has one more shock, i.e. shock to entrepreneurial wealth, γ. There are also shocks to each of the foreign observed variables - foreign GDP, y^*, foreign inflation, π^*, and foreign nominal interest rate, R^*. The employment frictions block adds one shock, i.e. shock to match survival rate, ρ.

The stochastic structure of the exogenous variables is the following: 7 of these evolve according to AR(1) processes:

$$\epsilon_t, \Upsilon_t, \zeta_t^c, g_t, \tilde{\phi}_t, \gamma_t, \rho_t.$$

Five shock processes are i.i.d.:

$$\tau_t^d, \tau_t^x, \tau_t^{m,c}, \tau_t^{m,i}, \tau_t^{m,x}$$

and four shock processes are assumed to follow SVAR(1):

$$y_t^*, \pi_t^*, R_t^*, \mu_{z,t}.$$

In addition to the above stochastic processes, there are measurement errors except for the domestic interest rate and the foreign variables. The variance of the measurement errors is calibrated to correspond to 10% of the variance of each data series.

A.3 Priors-posteriors: foreign block

The priors-posteriors for the domestic block are shown in the main text Table 1, whereas those for the foreign SVAR block - below in Table 6. The priors common to the benchmark model are taken from Buss (2015).

Table 6: Estimated foreign SVAR parameters

	Parameter description	Prior			Posterior		HPD int.	
		Distr.	Mean	st.d.	Mean	st.d.	10%	90%
ρ_{μ_z}	Persistence, unit-root tech.	β	0.50	0.075	0.590	0.063	0.487	0.696
a_{11}	Foreign SVAR parameter	N	0.90	0.05	0.913	0.034	0.852	0.977
a_{22}	Foreign SVAR parameter	N	0.50	0.05	0.521	0.055	0.438	0.605
a_{33}	Foreign SVAR parameter	N	0.90	0.05	0.954	0.023	0.919	0.989
a_{12}	Foreign SVAR parameter	N	-0.10	0.10	-0.165	0.091	-0.314	-0.016
a_{13}	Foreign SVAR parameter	N	-0.10	0.10	-0.045	0.054	-0.124	0.037
a_{21}	Foreign SVAR parameter	N	0.10	0.10	0.181	0.043	0.097	0.260
a_{23}	Foreign SVAR parameter	N	-0.10	0.10	-0.090	0.055	-0.183	-0.008
a_{24}	Foreign SVAR parameter	N	0.05	0.10	0.078	0.041	0.009	0.146
a_{31}	Foreign SVAR parameter	N	0.05	0.10	0.080	0.029	0.032	0.131
a_{32}	Foreign SVAR parameter	N	-0.10	0.10	-0.095	0.058	-0.198	0.002
a_{34}	Foreign SVAR parameter	N	0.10	0.10	0.108	0.026	0.068	0.149
c_{21}	Foreign SVAR parameter	N	0.05	0.05	0.021	0.040	-0.048	0.088
c_{31}	Foreign SVAR parameter	N	0.10	0.05	0.145	0.031	0.094	0.196
c_{32}	Foreign SVAR parameter	N	0.40	0.05	0.374	0.053	0.286	0.459
c_{24}	Foreign SVAR parameter	N	0.05	0.05	0.065	0.046	-0.003	0.135
c_{34}	Foreign SVAR parameter	N	0.05	0.05	0.048	0.034	-0.002	0.101
	Shock standard deviations							
$100\sigma_{\mu_z}$	Unit root technology	Inv-Γ	0.25	inf	0.328	0.052	0.248	0.406
$100\sigma_{y^*}$	Foreign GDP	Inv-Γ	0.50	inf	0.317	0.055	0.219	0.415
$1000\sigma_{\pi^*}$	Foreign inflation	Inv-Γ	0.50	inf	0.593	0.118	0.394	0.805
$100\sigma_{R^*}$	Foreign interest rate	Inv-Γ	0.075	inf	0.067	0.008	0.054	0.079

Note: Based on a single Metropolis-Hastings chain with 100 000 draws after a burn-in period of 900 000 draws. Informative priors are used to generate plausible IRFs. The structure of SVAR is described in Appendix of Buss (2016).

A.4 Model and data moments

Table 7: Data and model moments (first-order approximated; %)

Variable	Explanation	Mean			Standard deviation		
		Data	Model Nash-Taylor	AOB	Data	Model Nash-Taylor	AOB
π	GDP deflator infl.	6.08	2.00	2.00	8.39	8.19	9.35
π^c	CPI inflation	5.69	2.00	2.00	5.63	7.22	8.10
π^i	Investment inflation	6.78	2.00	2.00	51.45	52.12	52.93
R	Nom. interest rate	7.06	6.04	6.04	5.86	6.26	7.40
Δh	Total hours growth	0.02	0.00	0.00	2.20	3.16	5.56
Δy	GDP growth	1.37	0.50	0.50	2.31	3.94	4.46
Δw	Real wage growth	1.04	0.50	0.50	2.33	2.80	2.46
Δc	Consumption growth	1.47	0.50	0.50	2.84	3.50	3.40
Δi	Investment growth	1.73	0.50	0.50	16.32	19.86	18.32
Δq	Real exch. rate growth	-0.90	0.00	0.00	2.42	1.91	2.10
Δg	Gov. spending growth	0.44	0.50	0.50	5.46	5.36	5.23
Δx	Export growth	2.19	0.50	0.50	3.41	3.60	3.56
Δm	Import growth	2.22	0.50	0.50	6.30	9.71	9.98
Δn	Stock market growth	1.32	0.50	0.50	10.38	15.23	15.88
spread	Interest rate spread	4.29	2.84	4.29	2.25	5.74	4.86
Δu	Unemployment growth	-0.64	0.00	0.00	9.75	11.15	35.18
u	Unemployment rate	0.14	0.14	0.14	0.04	0.04	0.09
Δv	Vacancy growth	1.04		0.00	16.04		109.76
χ	Hiring rate	0.08		0.08	0.02		0.06
$1-\rho$	Separation rate	0.08		0.08	0.02		0.03
Δy^*	Foreign GDP growth	0.26	0.50	0.50	0.61	0.52	0.52
π^*	Foreign inflation	2.01	2.00	2.00	0.72	0.88	0.88
R^*	Foreign nom. int. rate	3.16	6.04	6.04	1.61	2.58	2.58

Note: The inflation and interest rates are annualized.

A.5 Conditional variance decomposition

Table 8: Conditional variance decomposition at 8 quarters forecast horizon (%, posterior mean)

	Description	Model	R	π^c	GDP	C	I	$\frac{\text{NX}}{\text{GDP}}$	H	w	q	N	Spread	U	$\frac{H}{L}$
ϵ_t	Stationary technology	Nash-T	0.1	3.9	8.6	0.6	0.1	2.3	8.3	5.4	3.2	0.5	0.4	6.3	6.9
		AOB	0.1	2.9	2.5	3.2	0.1	0.8	6.3	1.7	2.7	0.4	0.1	4.3	
Υ_t	MEI	Nash-T	0.3	0.5	2.9	0.2	34.8	8.3	3.5	4.3	0.4	17.1	17.6	4.4	1.2
		AOB	0.5	0.4	3.3	1.0	42.8	6.7	3.4	3.5	0.3	16.1	16.9	3.4	
ζ_t^c	Consumption prefs	Nash-T	0.8	1.3	4.1	82.4	0.2	24.5	6.8	2.4	1.1	0.4	0.2	15.9	53.2
		AOB	2.5	1.0	2.2	69.1	0.2	22.1	1.4	5.3	0.9	0.2	0.2	8.1	
g_t	Govt spending	Nash-T	0.0	0.2	2.1	0.0	0.0	0.4	1.9	1.6	0.2	0.1	0.1	1.6	1.4
		AOB	0.0	0.0	3.7	0.0	0.0	0.1	2.9	1.3	0.0	0.0	0.0	2.2	
τ_t^d	Markup, domestic	Nash-T	0.0	35.0	1.4	0.1	0.2	0.1	1.9	47.2	29.0	0.8	0.0	10.0	0.5
		AOB	0.1	22.6	4.3	1.2	0.1	0.8	4.2	14.4	21.2	0.7	0.1	14.4	
τ_t^x	Markup, exports	Nash-T	0.0	0.3	1.4	0.0	0.0	0.1	1.7	2.1	0.2	0.1	0.1	3.7	0.9
		AOB	0.0	0.0	1.3	0.0	0.0	0.0	1.0	0.6	0.0	0.0	0.0	0.9	
τ_t^{mc}	Markup, imp. for cons.	Nash-T	0.0	40.5	0.7	0.1	0.0	0.4	0.8	3.6	34.6	0.1	0.0	1.9	0.3
		AOB	0.2	57.7	1.3	0.6	0.1	1.4	1.0	2.6	54.0	0.1	0.0	2.0	
τ_t^{mi}	Markup, imp. for inv.	Nash-T	0.1	2.5	9.9	0.0	6.9	5.1	22.5	5.5	2.1	11.2	9.1	6.8	8.3
		AOB	1.7	4.1	27.1	0.0	17.5	21.8	39.6	28.1	3.8	21.1	15.8	23.2	
τ_t^{mx}	Markup, imp. for exp.	Nash-T	0.1	1.5	54.5	0.0	0.1	6.0	43.3	12.4	1.3	0.6	0.5	10.0	16.4
		AOB	1.2	0.3	41.5	1.1	0.3	11.1	32.6	14.6	0.3	0.4	0.1	24.2	
γ_t	Entrepreneurial wealth	Nash-T	1.4	0.7	8.6	0.2	42.2	38.4	1.5	2.4	0.6	51.4	68.2	5.9	3.8
		AOB	2.1	0.5	3.1	0.6	26.1	16.4	0.2	0.4	0.5	47.1	58.8	1.2	
$\tilde{\phi}_t$	Country risk premium	Nash-T	90.3	0.3	1.2	1.7	6.9	10.7	1.8	4.1	0.3	12.0	1.6	13.1	5.1
		AOB	80.6	0.1	1.3	7.1	4.0	11.1	0.7	2.1	0.1	5.1	0.6	5.3	
$\epsilon_{\rho,t}$	Match survival rate	Nash-T													
		AOB	0.0	0.2	0.2	0.2	0.0	0.1	0.2	7.5	0.2	0.0	0.0	2.1	
$\mu_{z,t}$	Unit-root technology	Nash-T	1.6	0.0	0.3	0.0	0.1	1.3	0.0	0.4	0.3	0.1	0.0	0.0	0.2
		AOB	1.3	0.0	0.2	0.0	0.0	0.8	0.1	2.5	0.1	0.0	0.0	0.2	
$\epsilon_{R^*,t}$	Foreign interest rate	Nash-T	1.6	0.1	0.1	0.2	0.3	0.7	0.1	0.2	0.0	0.3	0.0	0.8	0.5
		AOB	1.4	0.0	0.0	0.4	0.1	0.5	0.0	0.1	0.0	0.1	0.0	0.2	
$\epsilon_{y^*,t}$	Foreign output	Nash-T	3.6	0.3	0.1	0.6	0.2	1.7	0.1	0.2	0.3	0.0	0.0	0.4	1.3
		AOB	3.1	0.3	0.0	0.8	0.1	1.2	0.0	0.0	0.1	0.0	0.0	0.1	
$\epsilon_{\pi^*,t}$	Foreign inflation	Nash-T	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
		AOB	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	

Note: R - nominal interest rate, π^c - CPI inflation, C - real private consumption, I - real investment, $\frac{\text{NX}}{\text{GDP}}$ - net exports to GDP ratio, H - total hours worked, w - real wage, q - real exchange rate, N - net worth, Spread - interest rate spread, $\frac{H}{L}$ - hours per employee, U - unemployment rate.

A.6 Historical shock decomposition

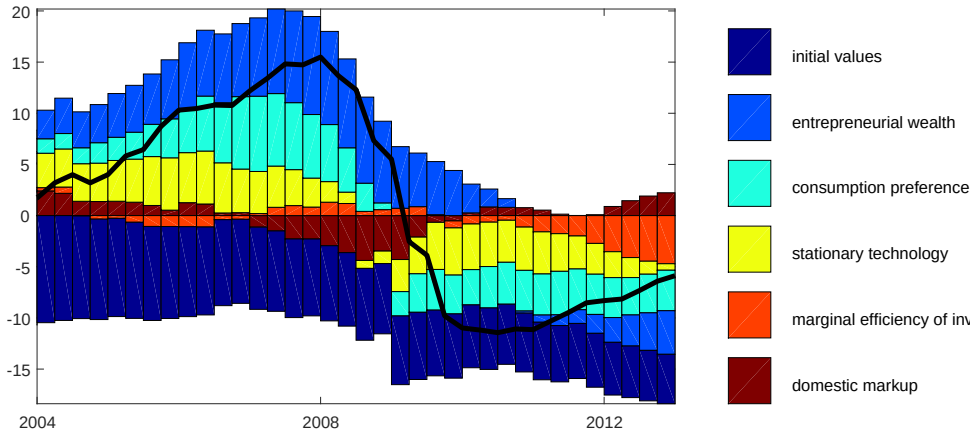

Figure 7: Decomposition of GDP (levels; 2004Q1-2012Q4)

Note: The AOB model. Only six shocks with the greatest influence are shown.

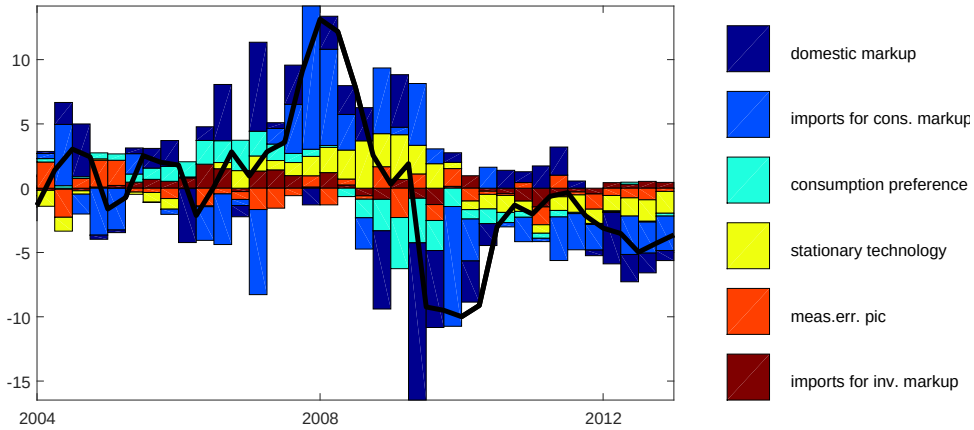

Figure 8: Decomposition of CPI (annualized quarterly growth rates; 2004Q1-2012Q4)

Note: The AOB model. Only six shocks with the greatest influence are shown.

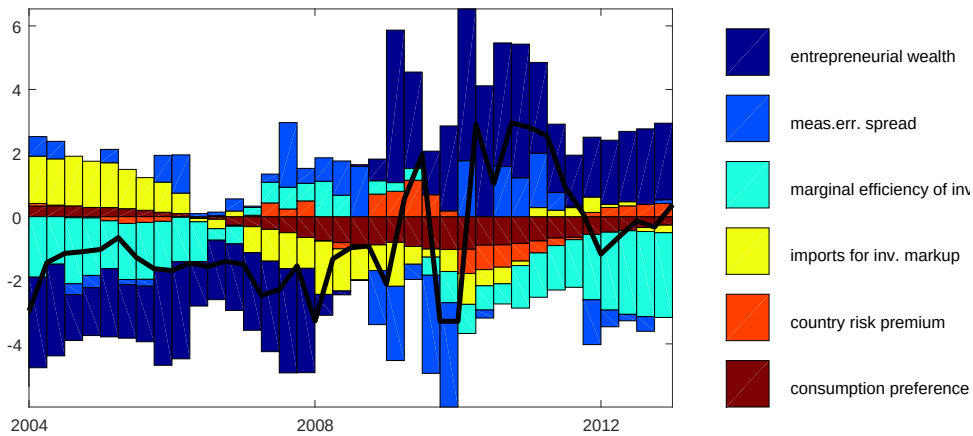

Figure 9: Decomposition of interest rate spread ($Z_{t+1} - R_t$; 2004Q1-2012Q4)

Note: The AOB model. Only six shocks with the greatest influence are shown.

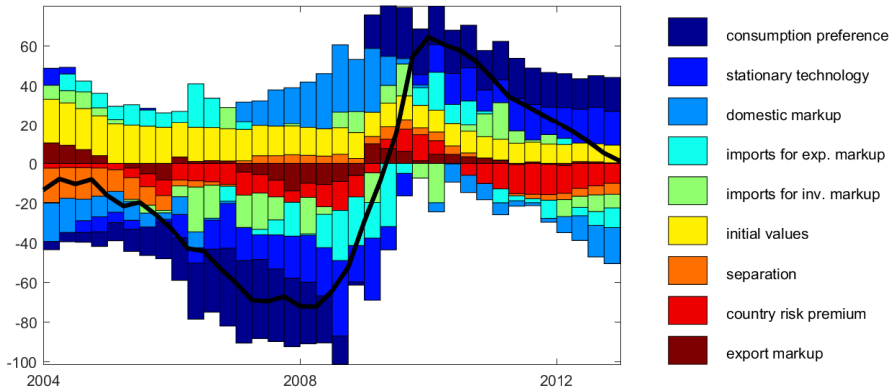

Figure 10: Decomposition of unemployment rate ($1 - L_t$; 2004Q1-2012Q4)

Note: The AOB model. Only nine shocks with the greatest influence are shown.

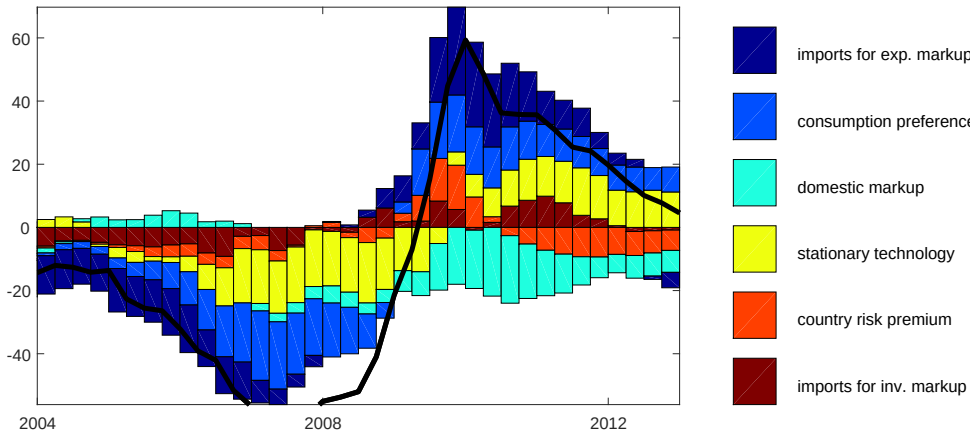

Figure 11: Decomposition of unemployment rate ($1 - L_t$; 2004Q1-2012Q4)

Note: The Nash-Taylor model. Only six shocks with the greatest influence are shown.

A.7 One-step ahead forecasts

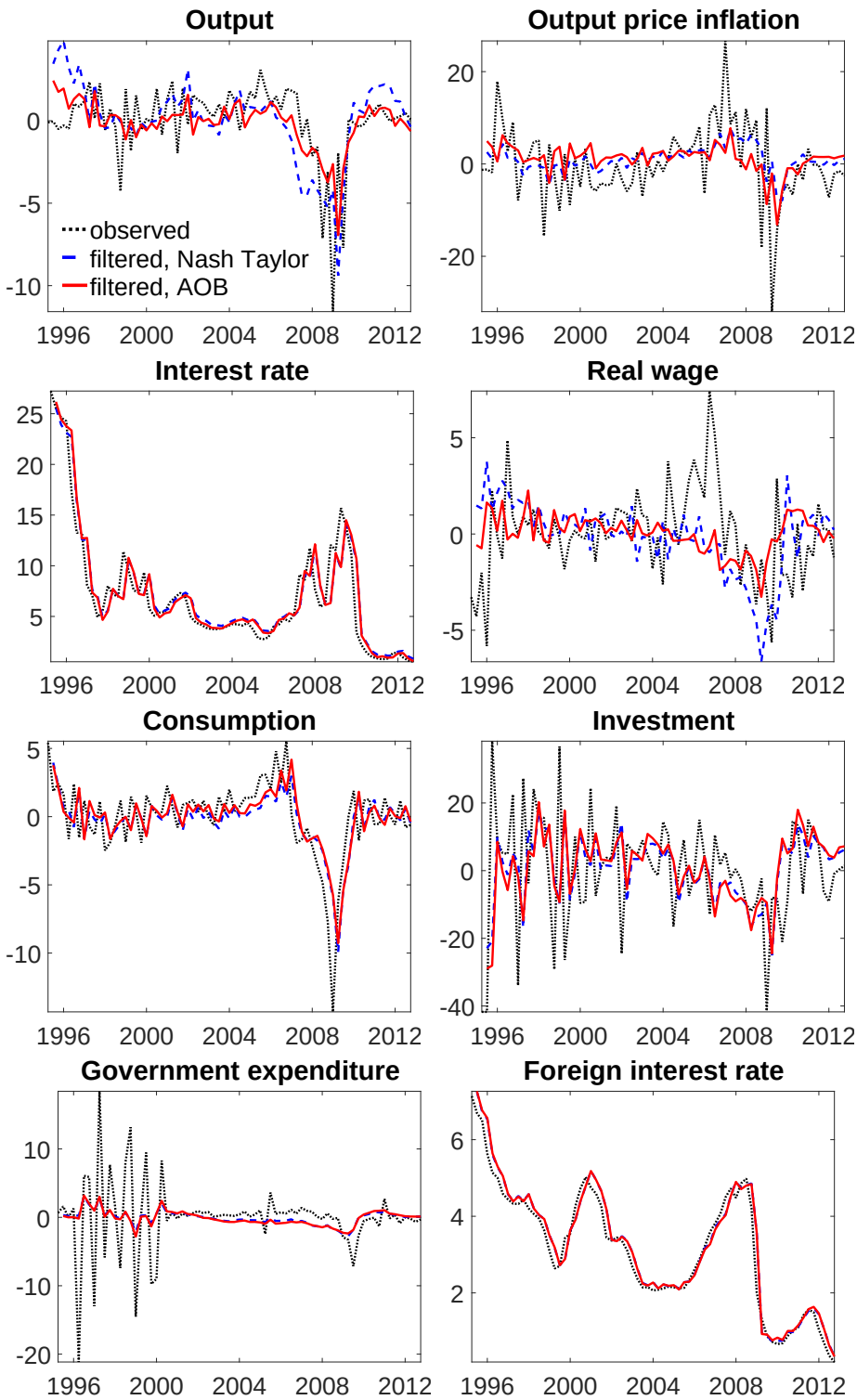

Figure 12: One-step ahead forecasts

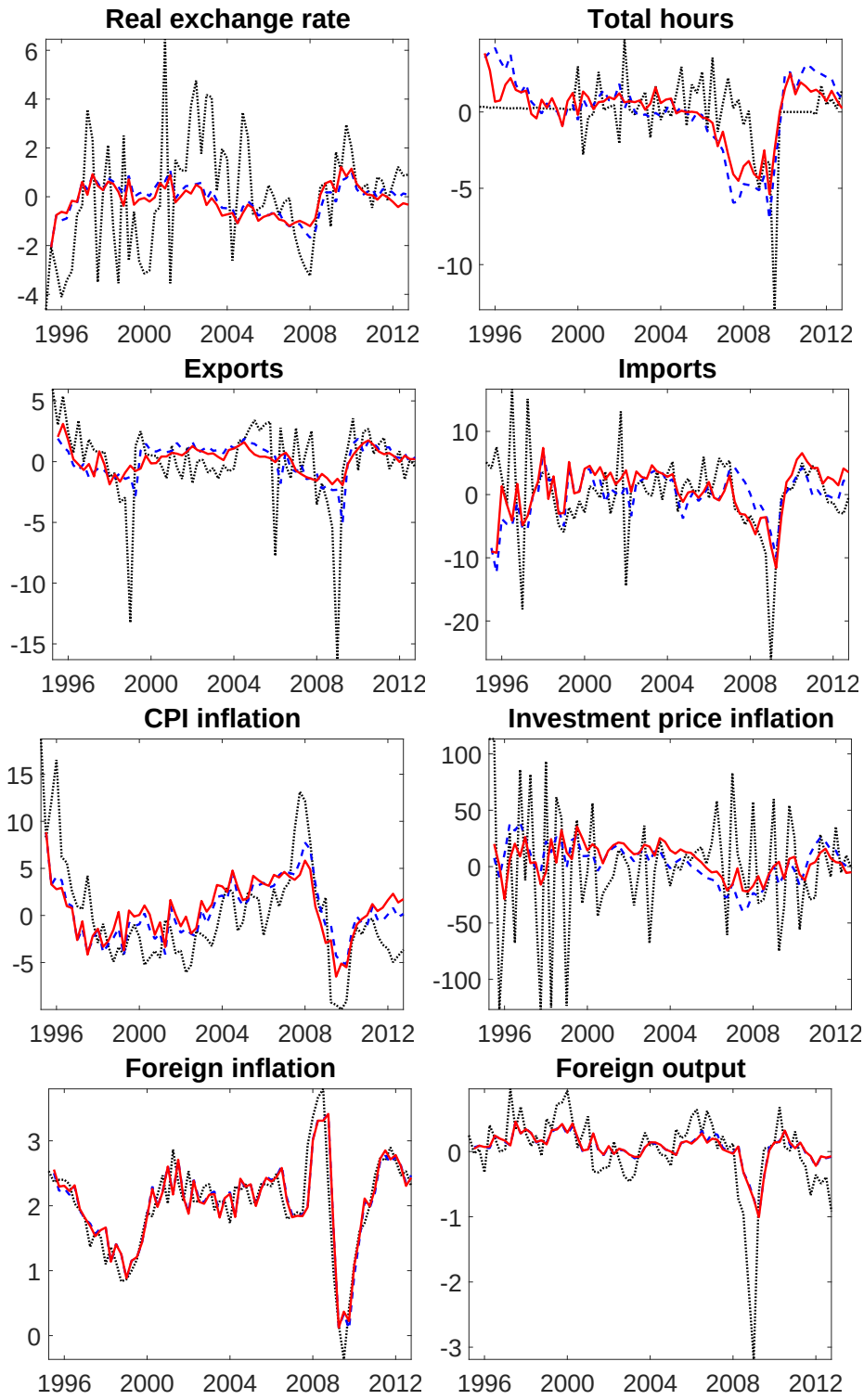

Figure 13: One-step ahead forecasts (continued)

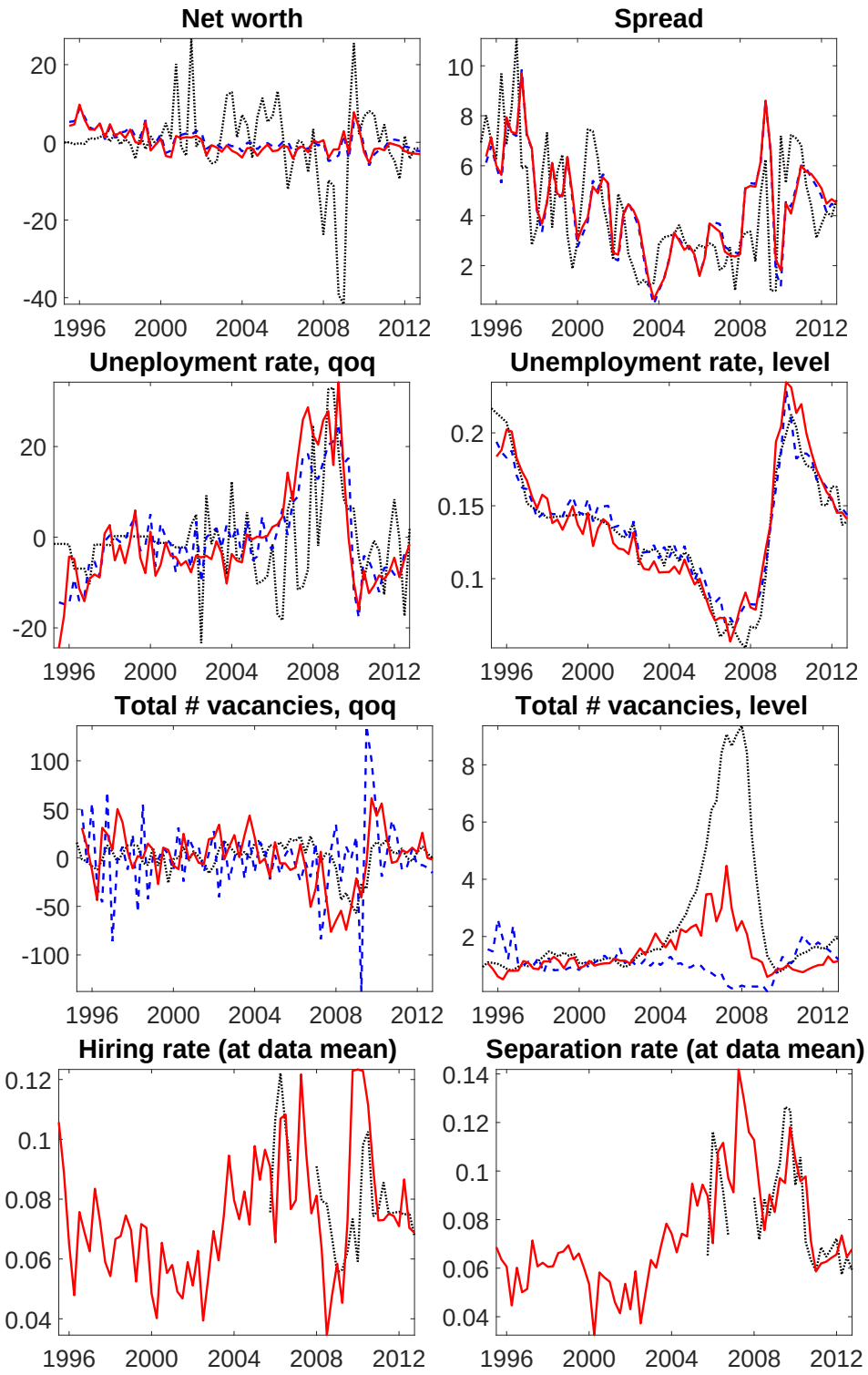

Figure 14: One-step ahead forecasts (continued)

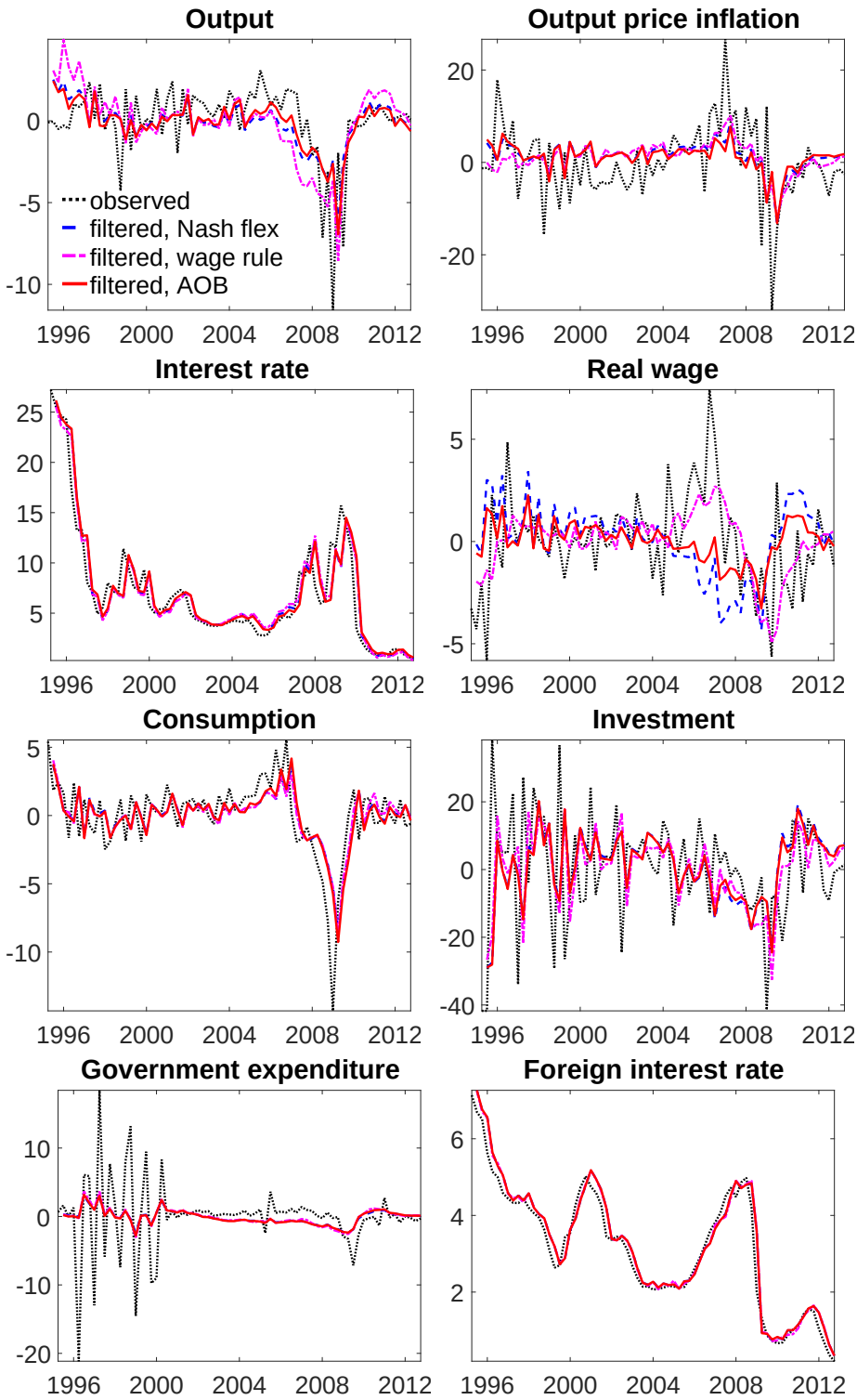

Figure 15: One-step ahead forecasts, alternative specifications

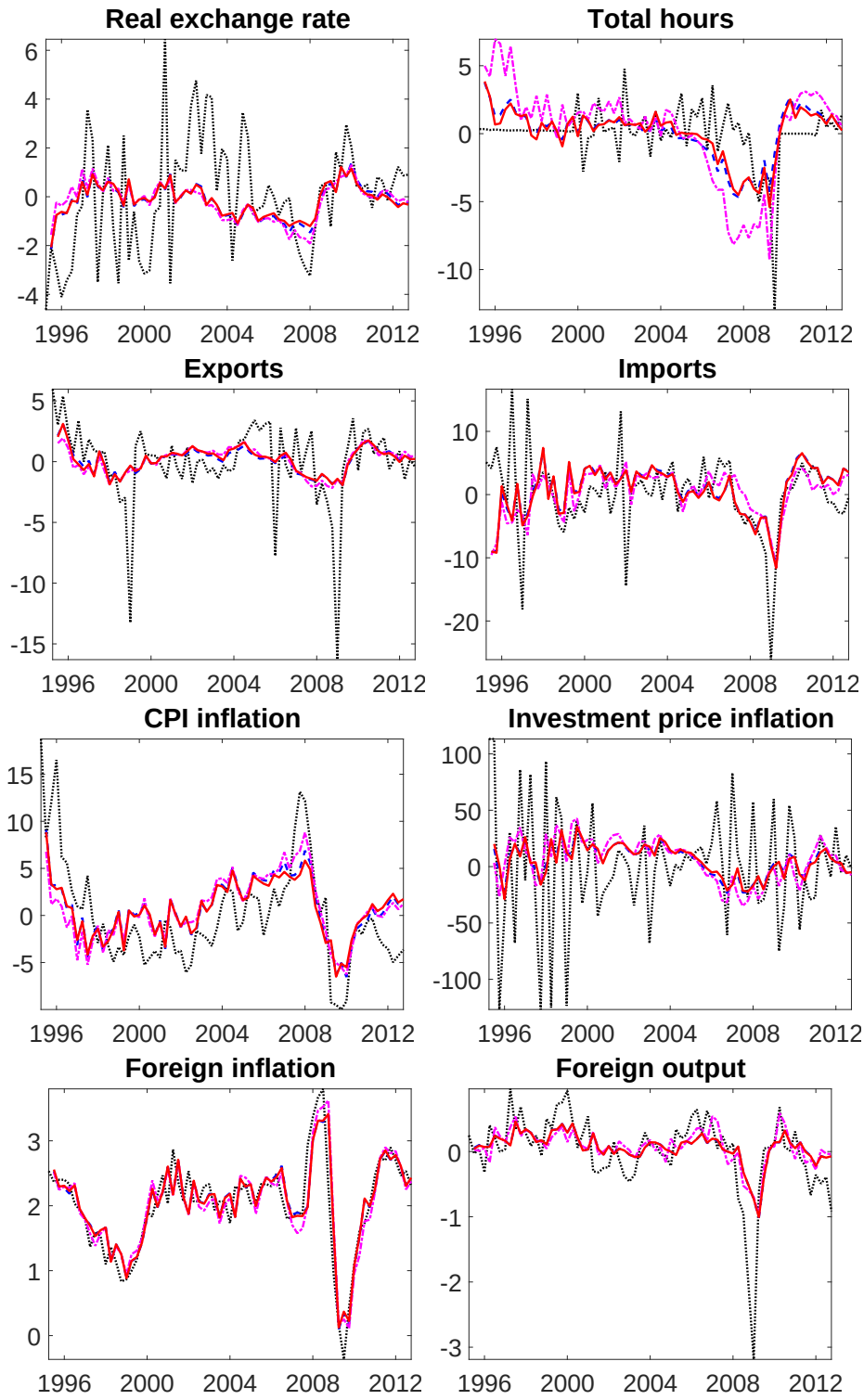

Figure 16: One-step ahead forecasts, alternative specifications (continued)

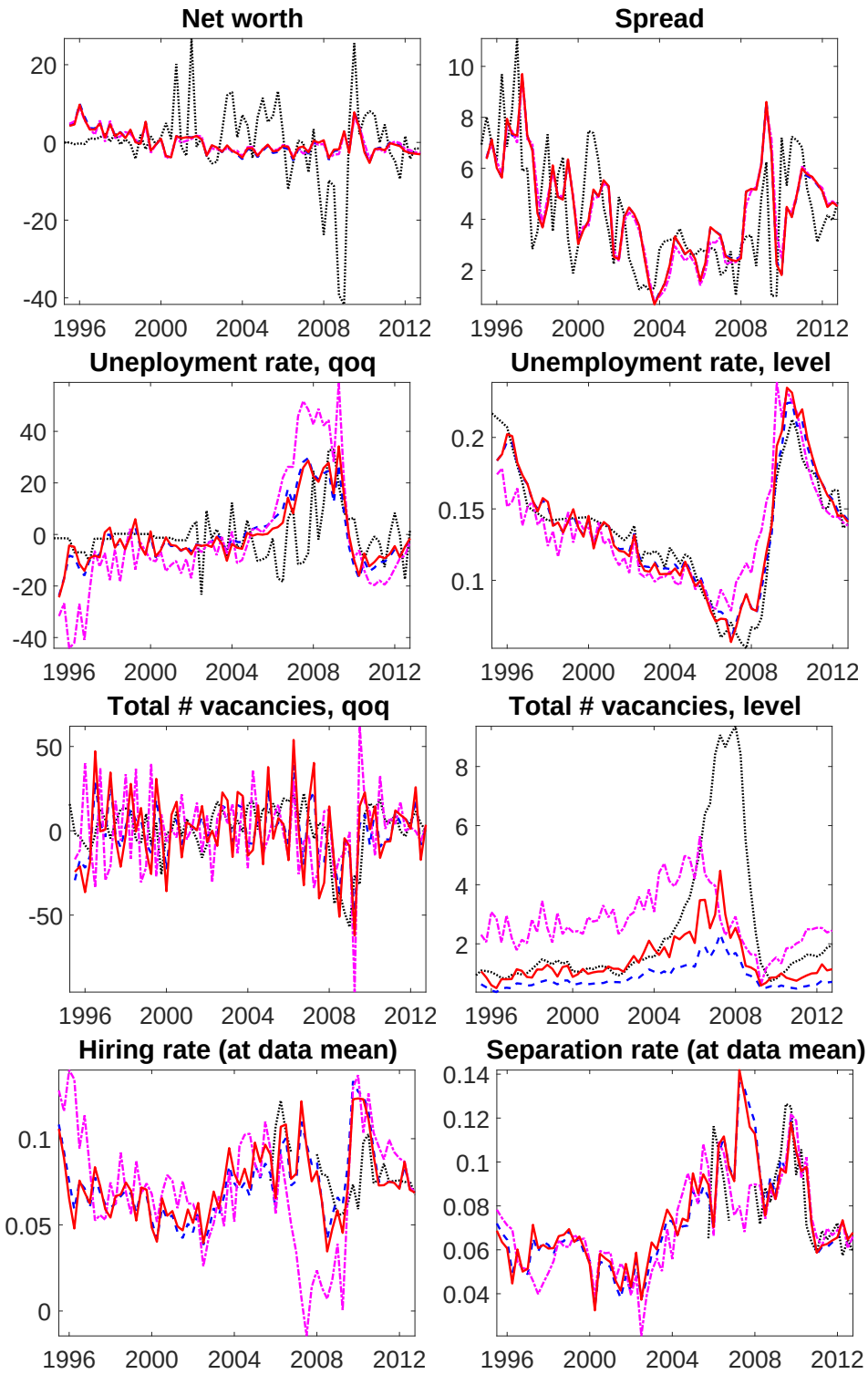

Figure 17: One-step ahead forecasts, alternative specifications (continued)

A.8 Impulse response functions

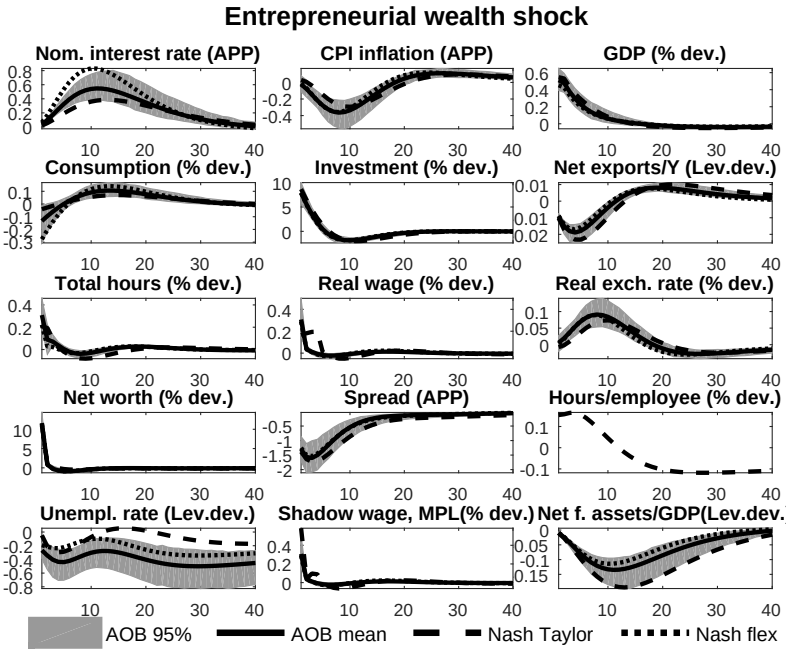

Figure 18: Impulse responses to the wealth shock, γ_t

Note: Units on y-axis are either in terms of percentage deviation (% dev.) from the steady state, annual percentage points (APP) or level deviation (Lev.dev.).

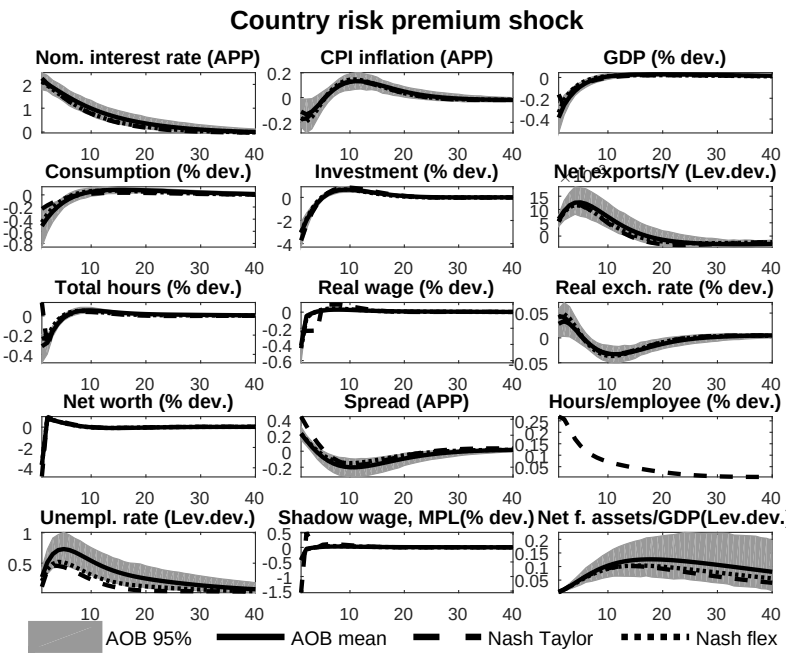

Figure 19: Impulse responses to the country risk premium shock, $\tilde{\phi}_t$

Note: Units on y-axis are either in terms of percentage deviation (% dev.) from the steady state, annual percentage points (APP) or level deviation (Lev.dev.).

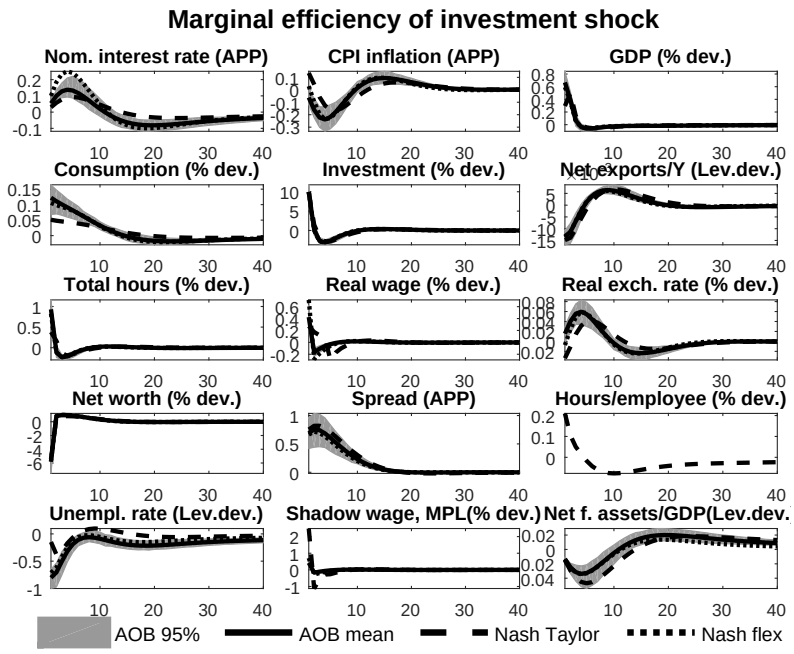

Figure 20: Impulse responses to the marginal efficiency of investment shock, Υ_t

Note: Units on y-axis are either in terms of percentage deviation (% dev.) from the steady state, annual percentage points (APP) or level deviation (Lev.dev.).

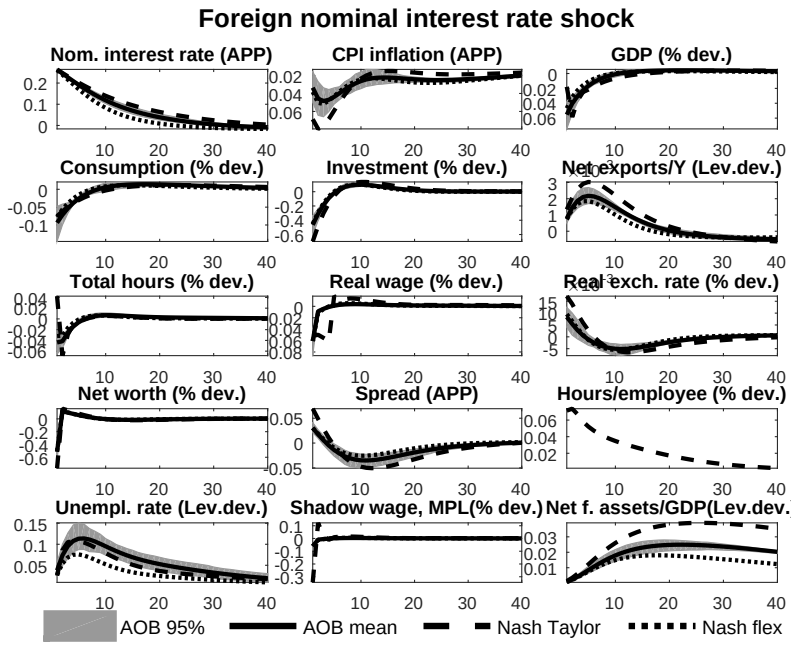

Figure 21: Impulse responses to the foreign nominal interest rate shock, $\epsilon_{R^*,t}$

Note: Units on y-axis are either in terms of percentage deviation (% dev.) from the steady state, annual percentage points (APP) or level deviation (Lev.dev.).

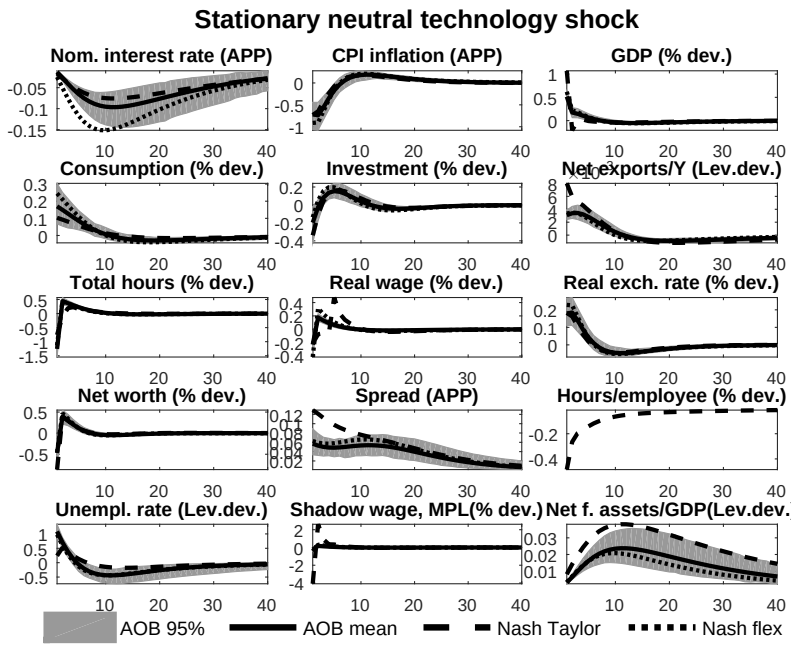

Figure 22: Impulse responses to the stationary neutral technology shock, ϵ_t

Note: Units on y-axis are either in terms of percentage deviation (% dev.) from the steady state, annual percentage points (APP) or level deviation (Lev.dev.).

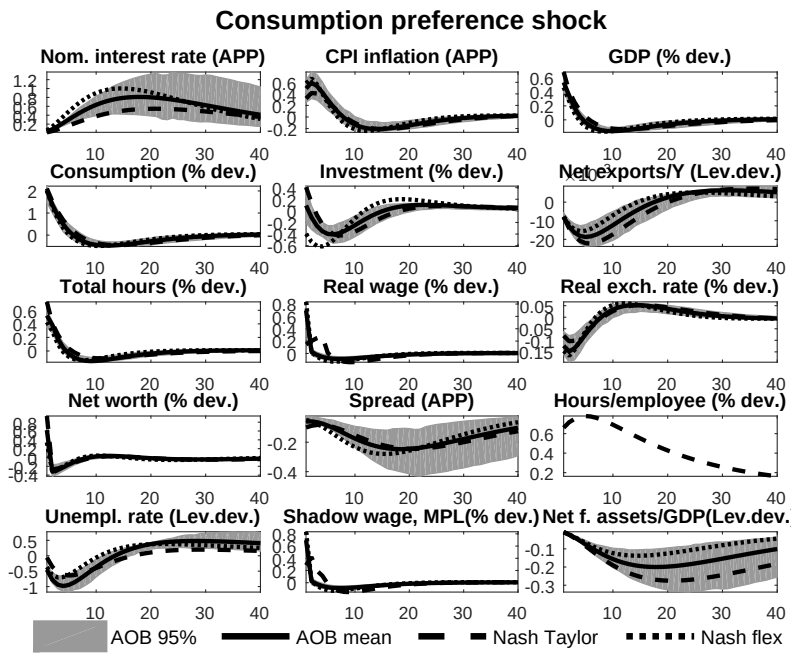

Figure 23: Impulse responses to the consumption preference shock, ζ_t^c

Note: Units on y-axis are either in terms of percentage deviation (% dev.) from the steady state, annual percentage points (APP) or level deviation (Lev.dev.).

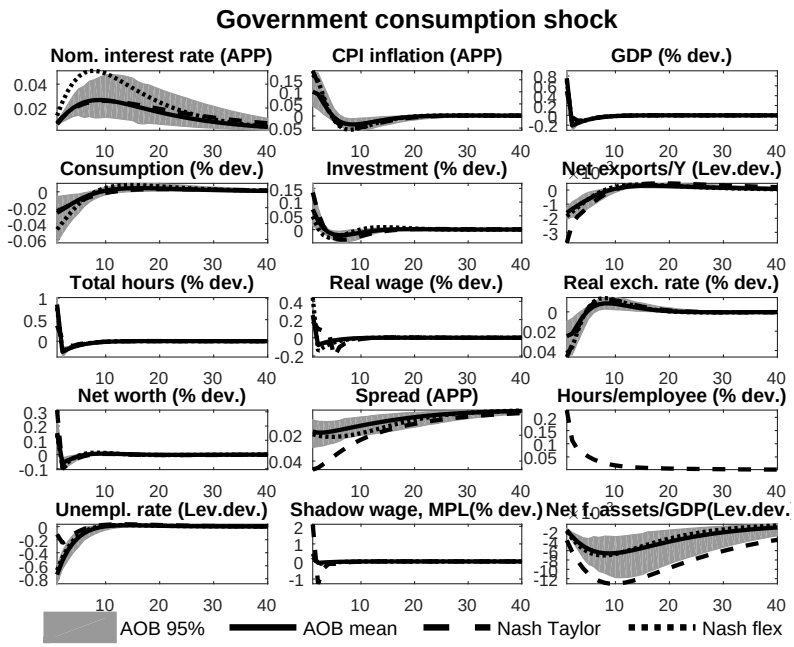

Figure 24: Impulse responses to the government consumption shock, g_t

Note: Units on y-axis are either in terms of percentage deviation (% dev.) from the steady state, annual percentage points (APP) or level deviation (Lev.dev.).

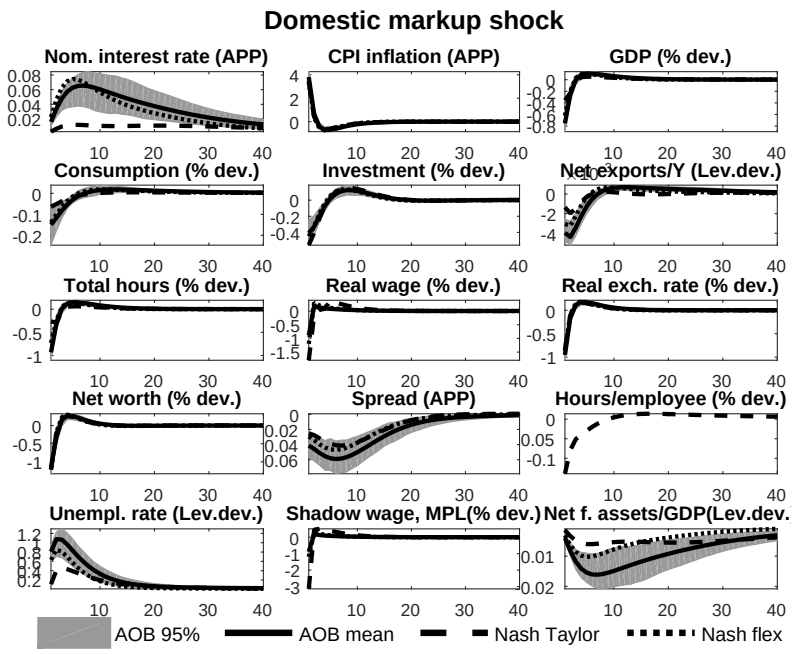

Figure 25: Impulse responses to the domestic markup shock, τ_t^d

Note: Units on y-axis are either in terms of percentage deviation (% dev.) from the steady state, annual percentage points (APP) or level deviation (Lev.dev.).

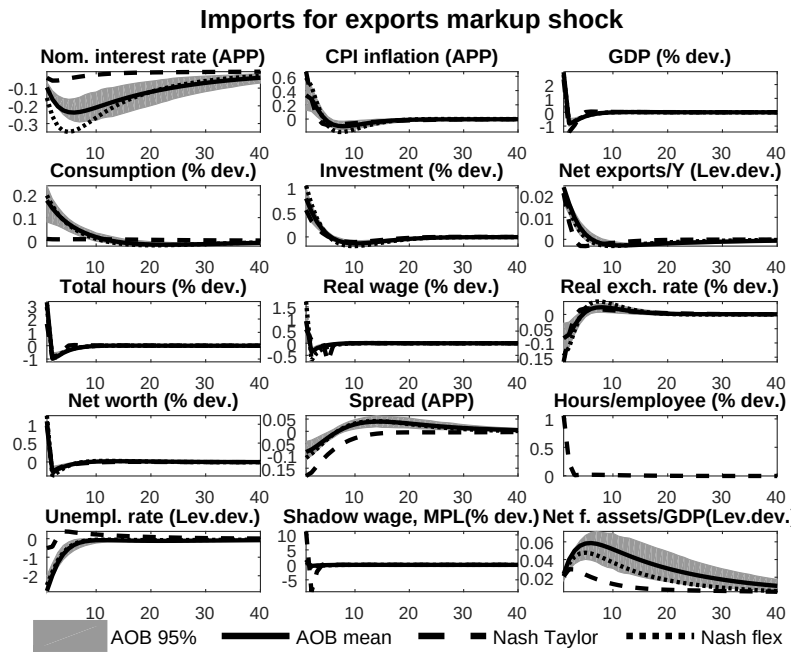

Figure 26: Impulse responses to the imports for exports markup shock, τ_t^{mx}

Note: Units on y-axis are either in terms of percentage deviation (% dev.) from the steady state, annual percentage points (APP) or level deviation (Lev.dev.).

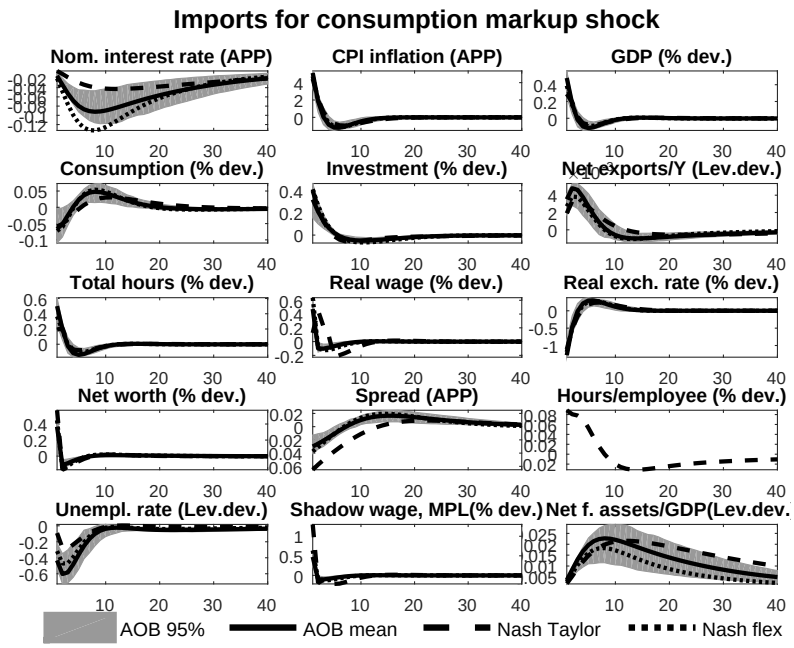

Figure 27: Impulse responses to the imports for consumption markup shock, τ_t^{mc}

Note: Units on y-axis are either in terms of percentage deviation (% dev.) from the steady state, annual percentage points (APP) or level deviation (Lev.dev.).

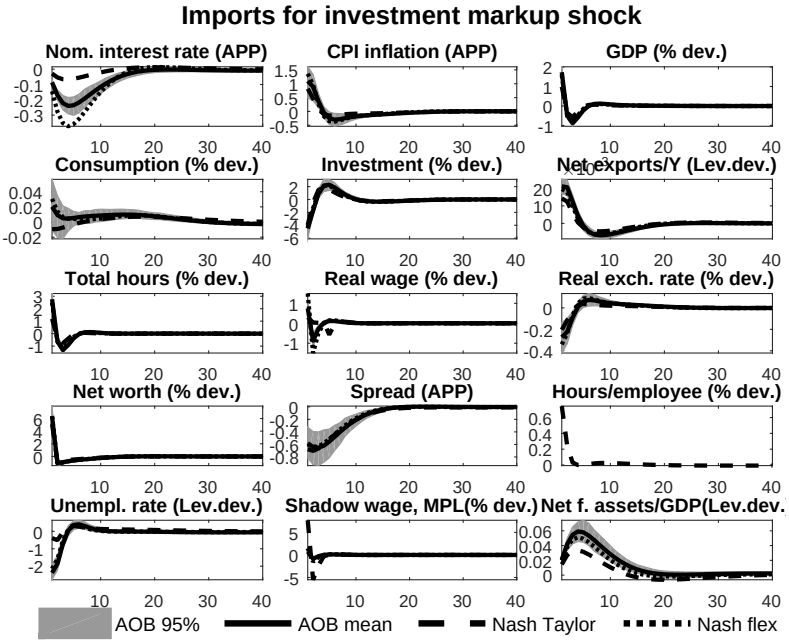

Figure 28: Impulse responses to the imports for investment markup shock, τ_t^{mi}

Note: Units on y-axis are either in terms of percentage deviation (% dev.) from the steady state, annual percentage points (APP) or level deviation (Lev.dev.).

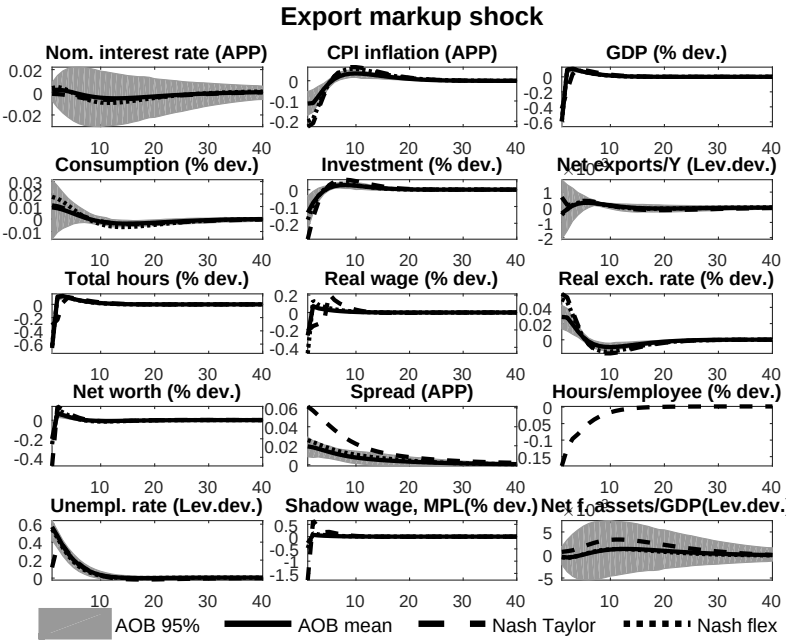

Figure 29: Impulse responses to the export markup shock, τ_t^{x}

Note: Units on y-axis are either in terms of percentage deviation (% dev.) from the steady state, annual percentage points (APP) or level deviation (Lev.dev.).

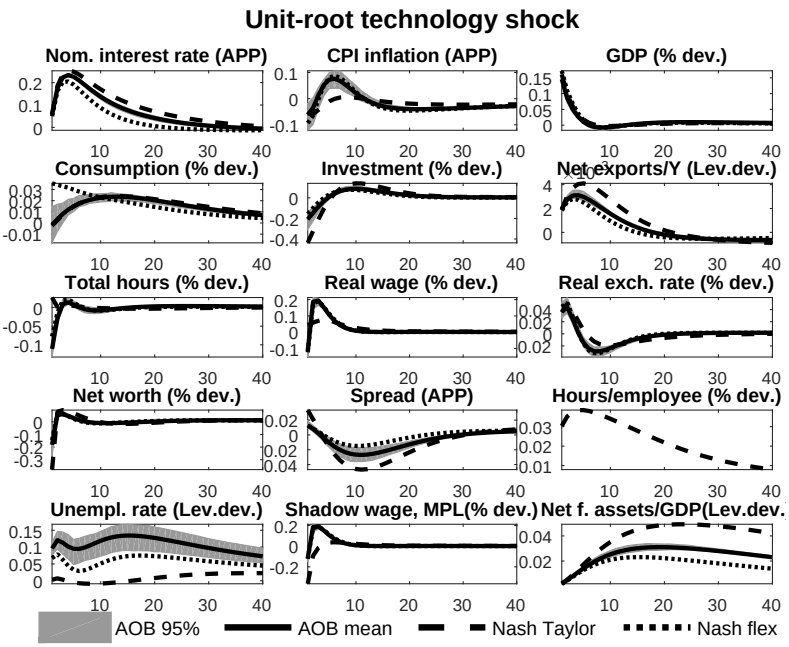

Figure 30: Impulse responses to the unit-root technology shock, $\mu_{z,t}$

Note: Units on y-axis are either in terms of percentage deviation (% dev.) from the steady state, annual percentage points (APP) or level deviation (Lev.dev.).

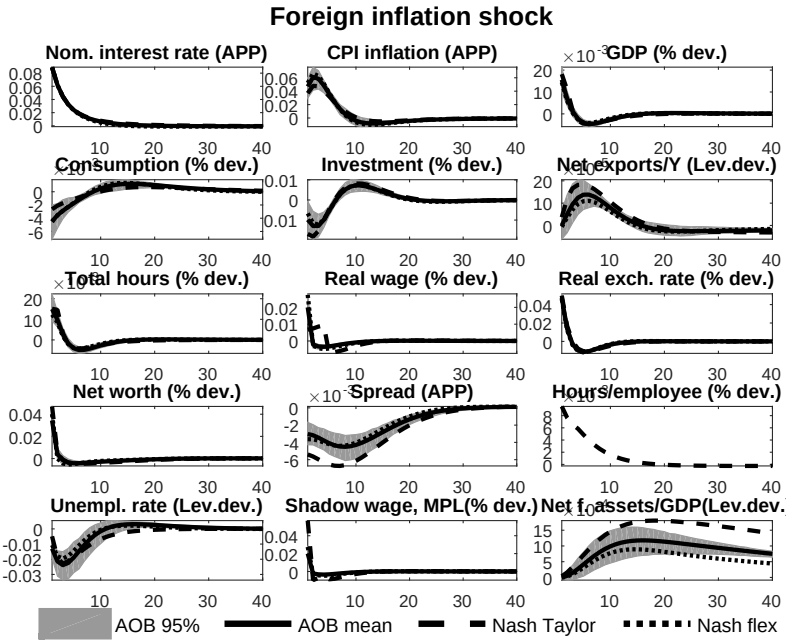

Figure 31: Impulse responses to the foreign inflation shock, $\epsilon_{\pi^*,t}$

Note: Units on y-axis are either in terms of percentage deviation (% dev.) from the steady state, annual percentage points (APP) or level deviation (Lev.dev.).

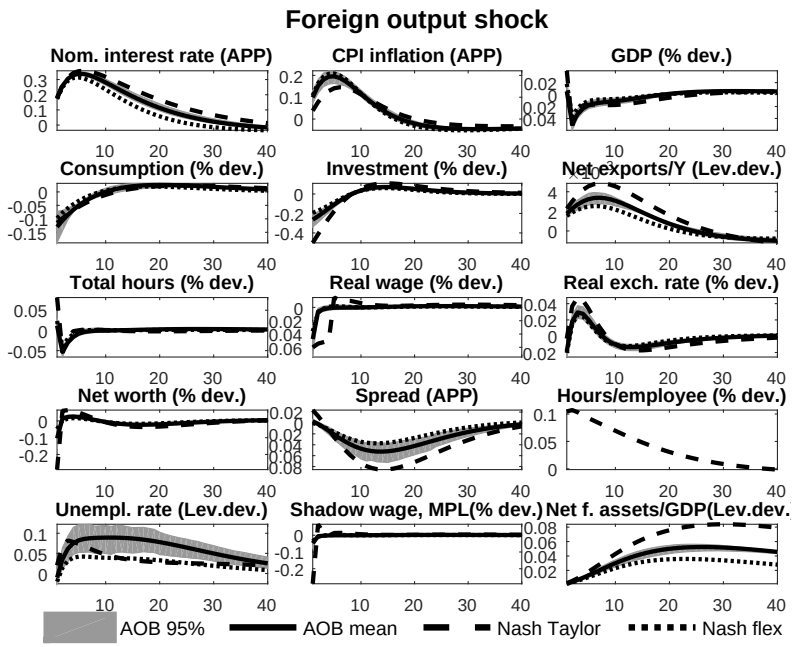

Figure 32: Impulse responses to the foreign output shock, $\epsilon_{y^*,t}$

Note: Units on y-axis are either in terms of percentage deviation (% dev.) from the steady state, annual percentage points (APP) or level deviation (Lev.dev.).

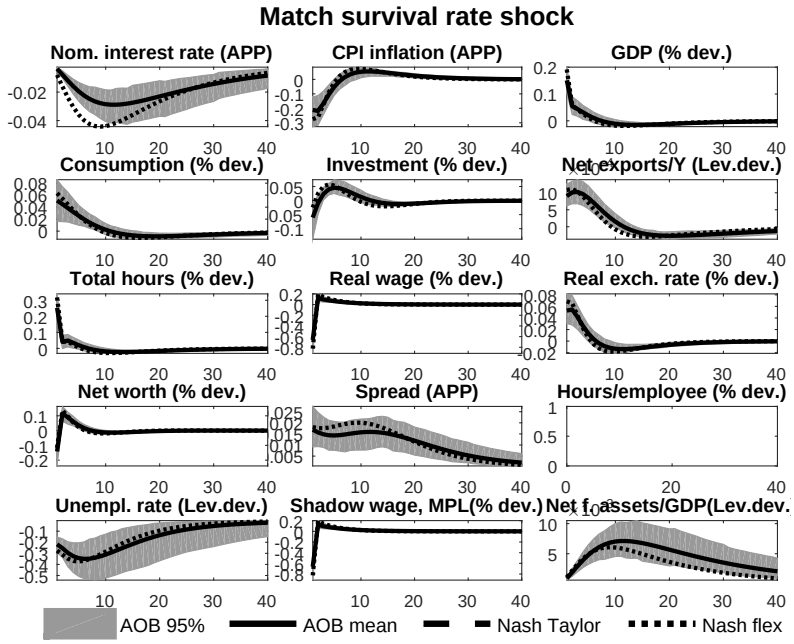

Figure 33: Impulse responses to the match survival rate shock, $\epsilon_{\rho,t}$

Note: Units on y-axis are either in terms of percentage deviation (% dev.) from the steady state, annual percentage points (APP) or level deviation (Lev.dev.).

A.9 Smoothed shock processes, prior-posterior densities and convergence statistics

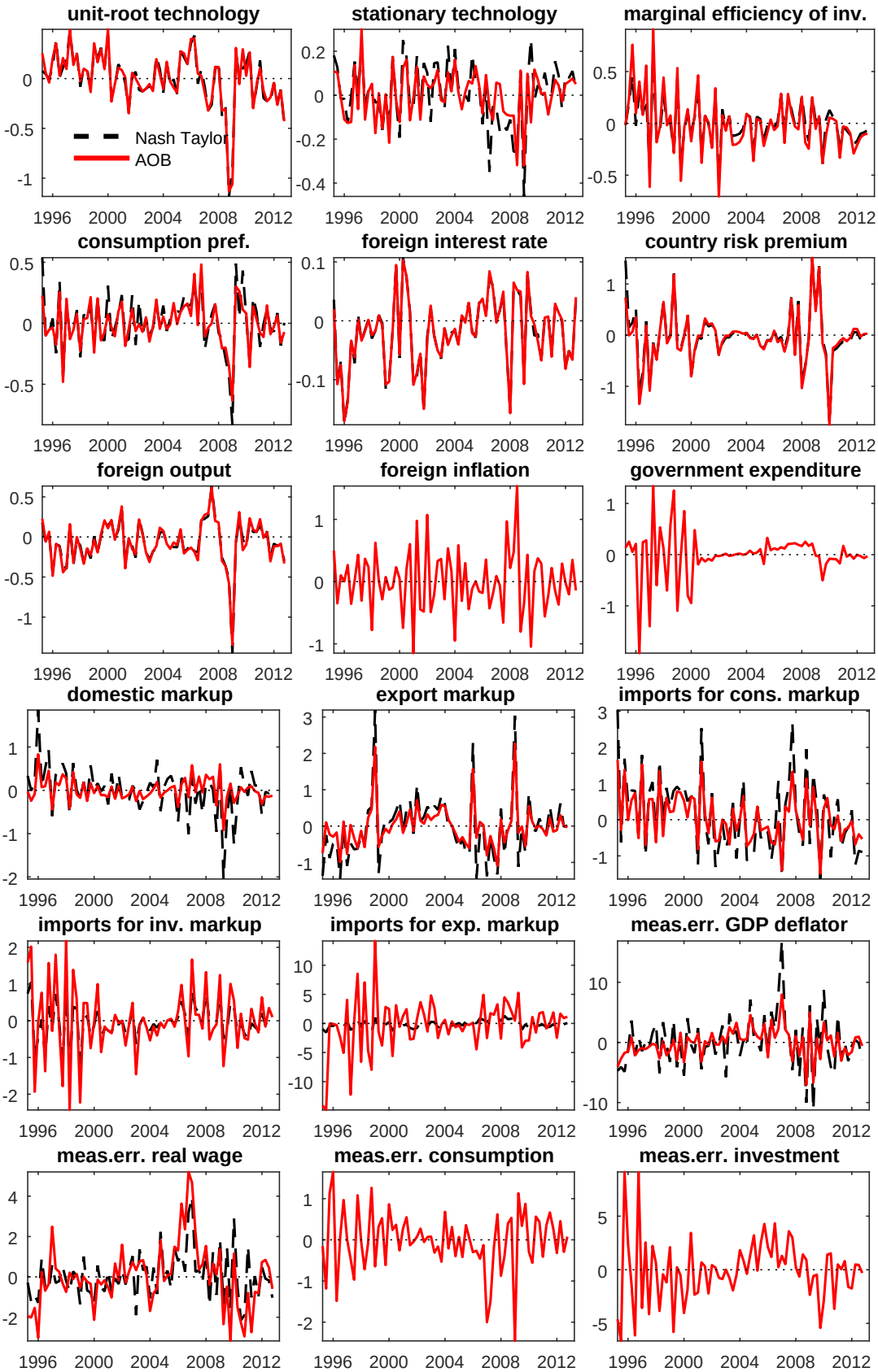

Figure 34: Smoothed shock processes and measurement errors

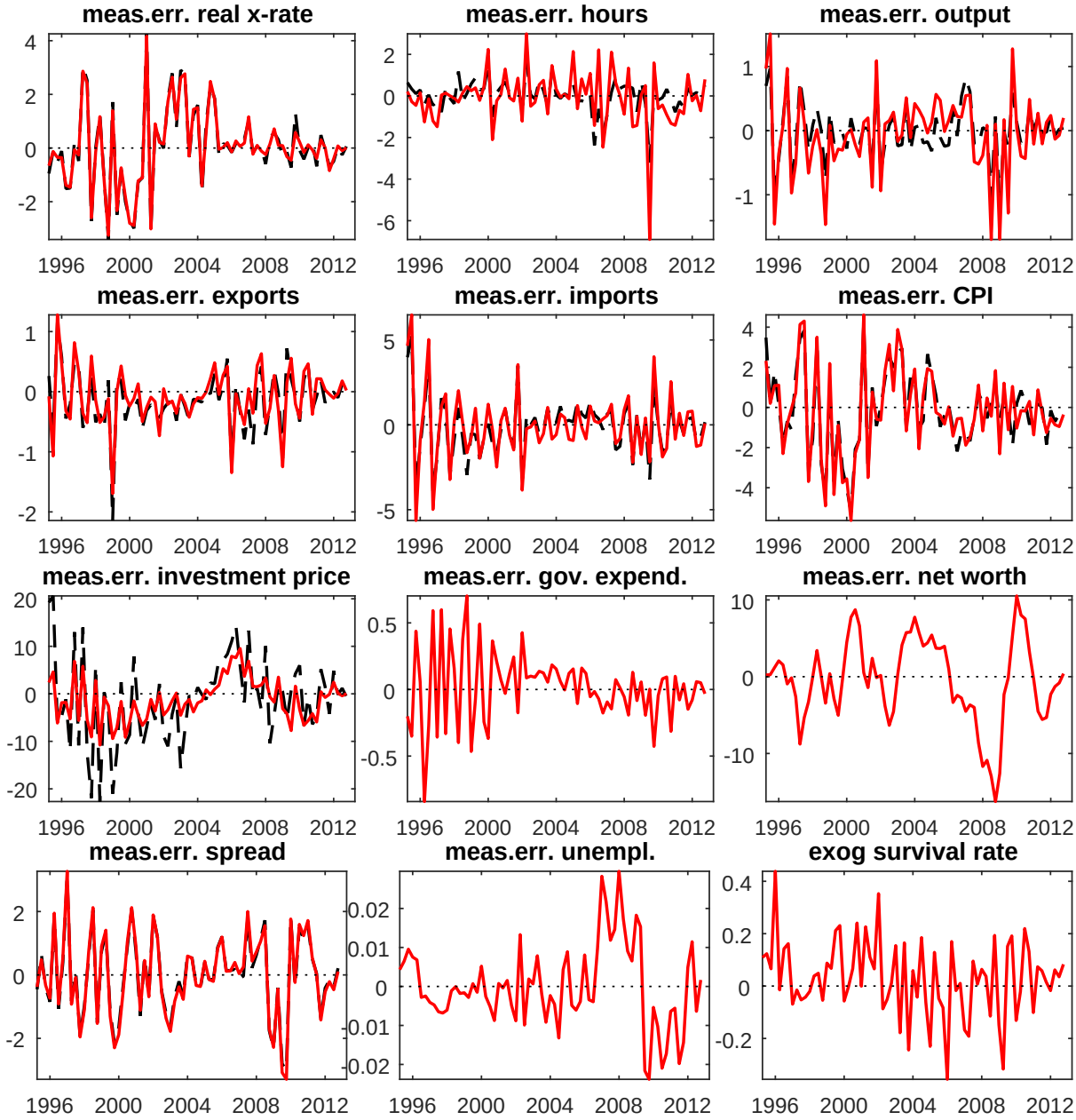

Figure 35: Smoothed shock processes and measurement errors (continued)

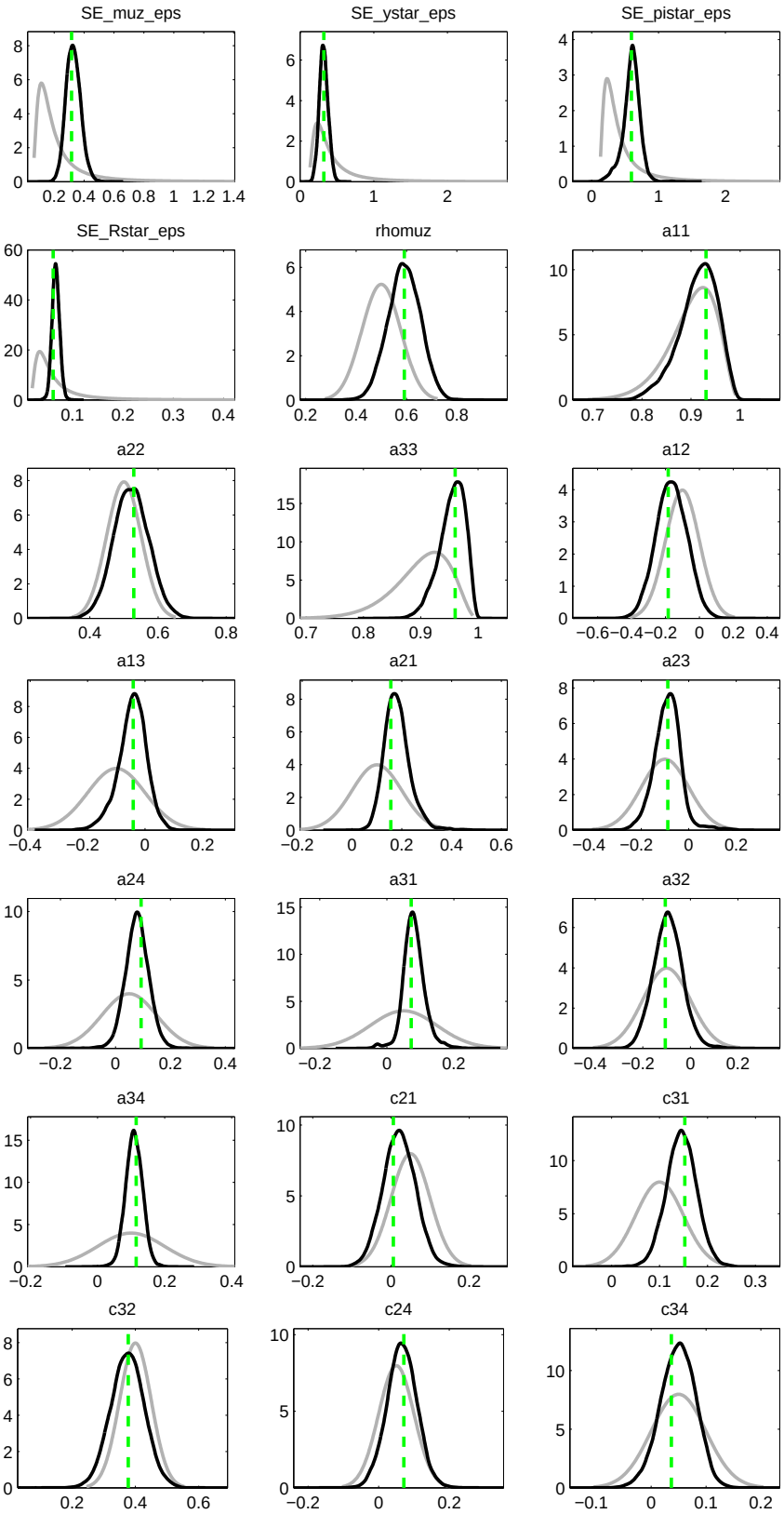

Figure 36: SVAR priors and posteriors

Note: Prior distribution in gray, simulated distribution in black, and the computed posterior mode in dashed green.

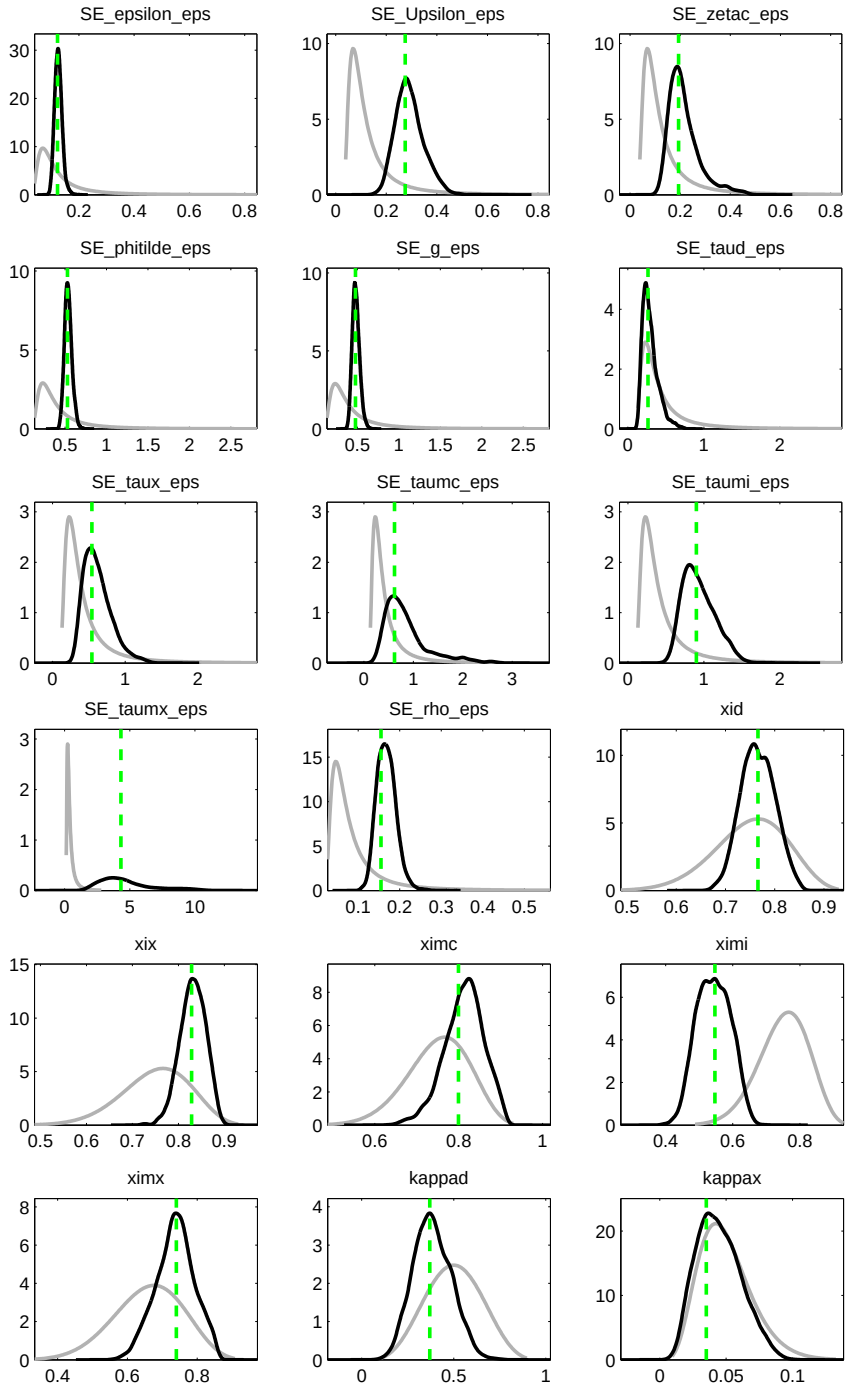

Figure 37: Priors and posteriors, domestic block

Note: The AOB model. Prior distribution in gray, simulated distribution in black, and the computed posterior mode in dashed green.

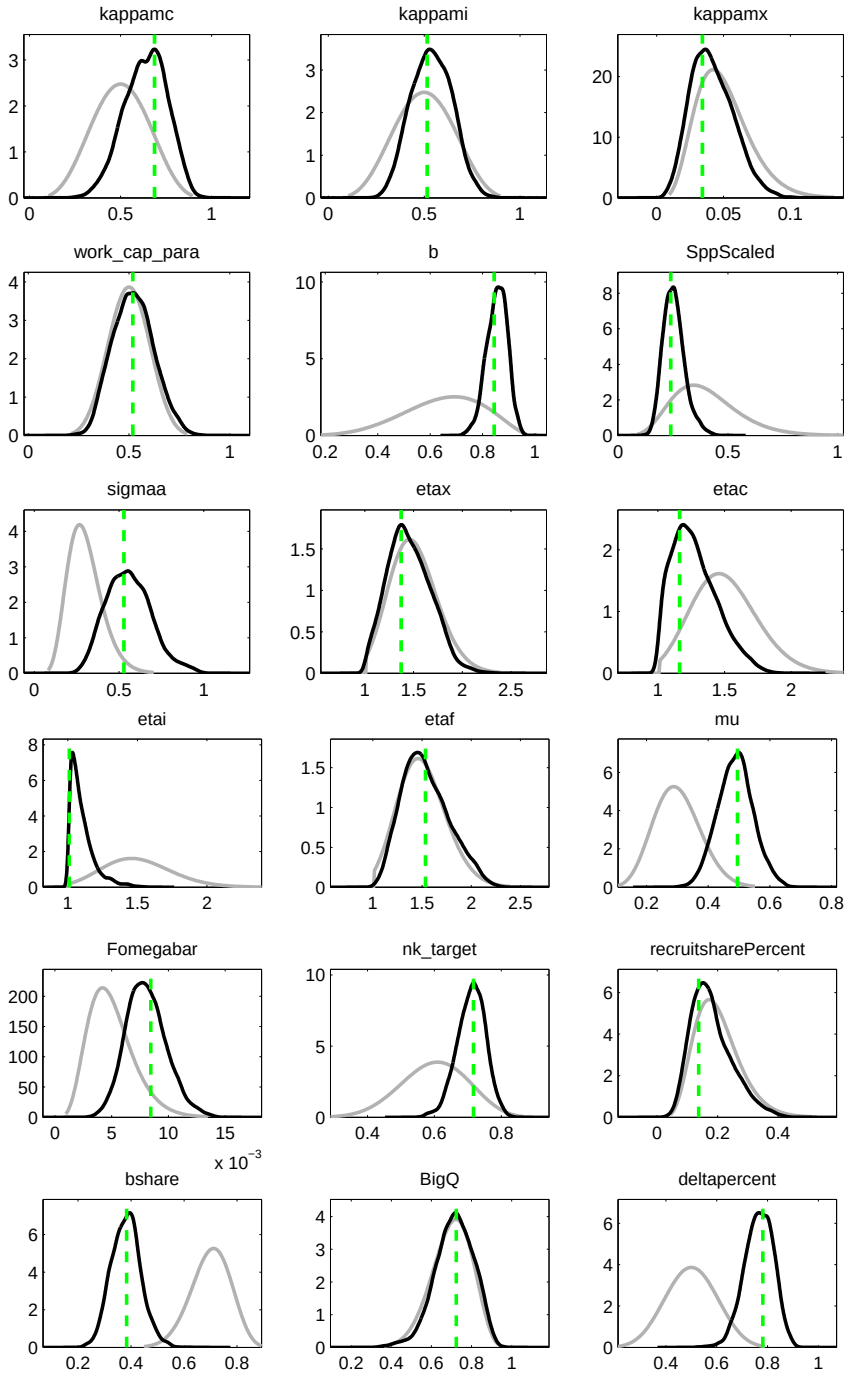

Figure 38: Priors and posteriors, domestic block (continued)

Note: The AOB model. Prior distribution in gray, simulated distribution in black, and the computed posterior mode in dashed green.

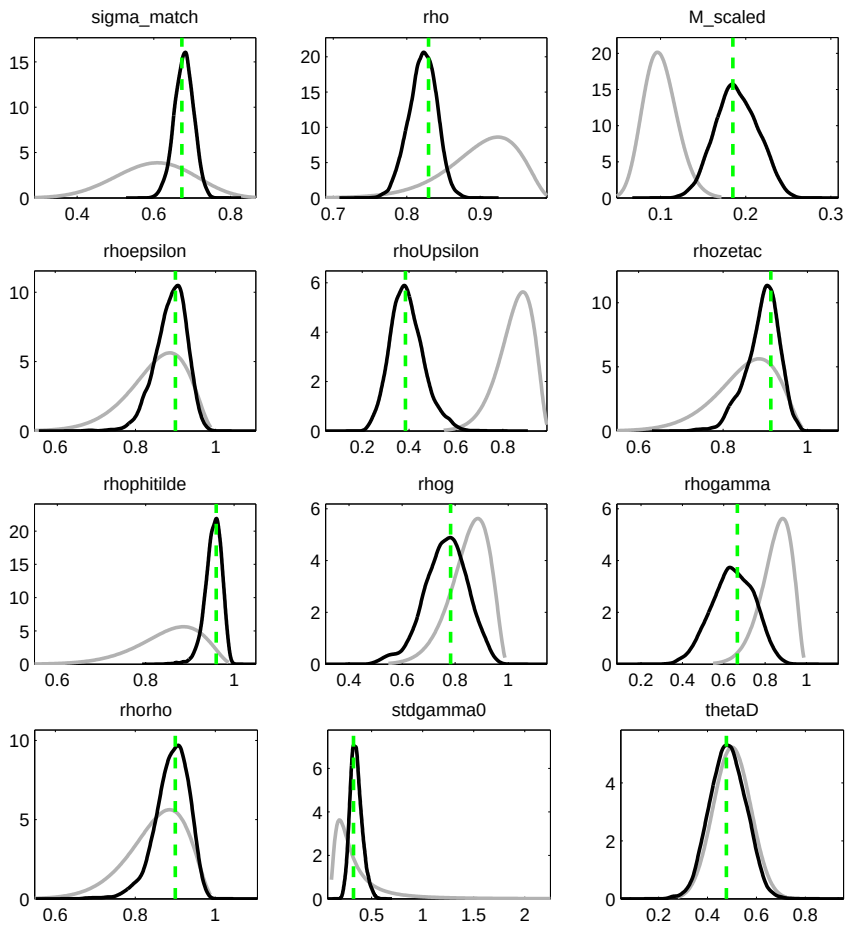

Figure 39: Priors and posteriors, domestic block (continued)

Note: The AOB model. Prior distribution in gray, simulated distribution in black, and the computed posterior mode in dashed green.

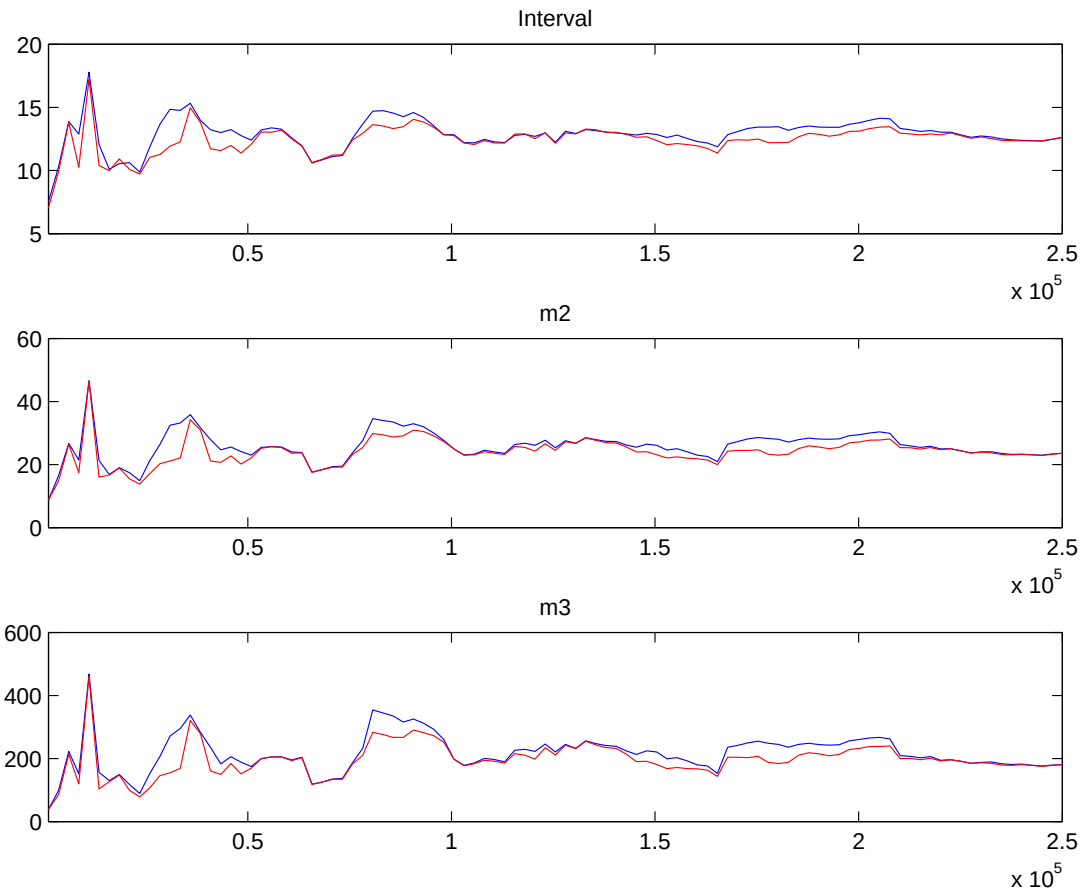

Figure 40: Convergence statistics of a 2-chain MCMC (AOB model)

A.10 Measurement equations

Below are the measurement equations linking the model to the data. The data series for inflation and interest rates are annualized in percentage terms, so the same transformation is made for the model variables, i.e. multiplying by 400. Here $\varepsilon_{i,t}^{me}$ denotes measurement errors for the respective variables. The data for interest rates and foreign inflation are not demeaned. The domestic inflation rates are demeaned.

Nominal interest rate:

$$R_t^{data} = 400(R_t - 1)$$

Foreign nominal interest rate:

$$R_t^{*,data} = 400(R_t^* - 1)$$

GDP deflator inflation:

$$\pi_t^{d,data} = 400 \log \pi_t - 400 \log \pi + \varepsilon_{\pi,t}^{me}$$

CPI inflation:

$$\pi_t^{c,data} = 400 \log \pi_t^c - 400 \log \pi^c + \varepsilon_{\pi^c,t}^{me}$$

Investment deflator inflation:

$$\pi_t^{i,data} = 400 \log \pi_t^i - 400 \log \pi^i + \varepsilon_{\pi^i,t}^{me}$$

Foreign inflation as measured by foreign CPI inflation:

$$\pi_t^{*,data} = 400 \log \pi_t^*$$

Hours worked:

$$\Delta \log H_t^{data} = 100 \Delta \log H_t + \varepsilon_{H,t}^{me}$$

GDP:

$$\Delta \log Y_t^{data} = 100(\log \mu_{z^+,t} + \Delta \log y_t^{gdp}) - 100(\log \mu_{z^+}) + \varepsilon_{y,t}^{me}$$

Foreign GDP:

$$\Delta \log Y_t^{*,data} = 100(\log \mu_{z^+,t} + \Delta \log y_t^*) - 100(\log \mu_{z^+})$$

Private consumption:

$$\Delta \log C_t^{data} = 100(\log \mu_{z^+,t} + \Delta \log c_t) - 100(\log \mu_{z^+}) + \varepsilon_{c,t}^{me}$$

Exports:

$$\Delta \log X_t^{data} = 100(\log \mu_{z^+,t} + \Delta \log x_t) - 100(\log \mu_{z^+}) + \varepsilon_{x,t}^{me}$$

Real exchange rate:

$$\Delta \log q_t^{data} = 100 \Delta \log q_t + \varepsilon_{q,t}^{me}$$

Imports:

$$\begin{aligned}
\Delta \log M_t^{data} &= 100(\log \mu_{z^+,t} + \Delta \log Imports_t) - 100(\log \mu_{z^+}) + \varepsilon_{M,t}^{me} \\
&= 100 \left[\log \mu_{z^+,t} + \Delta \log \begin{pmatrix} c_t^m (\mathring{p}_t^{m,c})^{\frac{\lambda_{m,c}}{1-\lambda_{m,c}}} \\ +i_t^m (\mathring{p}_t^{m,i})^{\frac{\lambda_{m,i}}{1-\lambda_{m,i}}} \\ +x_t^m (\mathring{p}_t^{m,x})^{\frac{\lambda_{m,x}}{1-\lambda_{m,x}}} \end{pmatrix} \right] - 100(\log \mu_{z^+}) + \varepsilon_{M,t}^{me}
\end{aligned}$$

Investment:

$$\Delta \log I_t^{data} = 100[\log \mu_{z^+,t} + \log \mu_{\psi,t} + \Delta \log i_t] - 100(\log \mu_{z^+} + \log \mu_\psi) + \varepsilon_{I,t}^{me}$$

Note that neither measured GDP nor measured investment includes investment goods used for capital maintenance. To calculate measured GDP I also exclude monitoring, recruitment and vacancy posting costs.

Government spending:

$$\Delta \log G_t^{data} = 100(\log \mu_{z^+,t} + \Delta \log n_{Gt} + \Delta \log g_t) - 100(\log \mu_{z^+}) + \varepsilon_{g,t}^{me}$$

where n_{Gt} is a trend diffusion term.
Real wage:

$$\Delta \log (W_t/P_t)^{data} = 100(\log \mu_{z^+,t} + \Delta \log w_t) - 100(\log \mu_{z^+}) + \varepsilon_{W/P,t}^{me}$$

Net worth as measured by the stock market index:

$$\Delta \log N_t^{data} = 100(\log \mu_{z^+,t} + \Delta \log n_t) - 100(\log \mu_{z^+}) + \varepsilon_{N,t}^{me}$$

Demeaned interest rate spread between lending and risk-free rate:

$$Spread_t^{data} = \left(\frac{\bar{\omega}_{t+1} R_{t+1}^k}{1 - \frac{n_{t+1}}{p_{k',t} \bar{k}_{t+1}}} - R_t \right) - \left(\frac{\bar{\omega} R^k}{1 - \frac{n}{p_{k'} \bar{k}}} - R \right) + \varepsilon_{Spread,t}^{me}$$

Unemployment rate:

$$Unemp_t^{data} = (1 - L_t) + \varepsilon_{Unemp,t}^{me}$$

Total number of vacancies:

$$\Delta \log V_t^{data} = 100 \Delta \log v_t^{tot} + \varepsilon_{v,t}^{me}$$

Hiring rate, demeaned:

$$Hiring_t^{data} = \chi_t - \chi + \varepsilon_{hiring,t}^{me}$$

Separation rate, demeaned:

$$Separation_t^{data} = 1 - \rho_t - \chi + \varepsilon_{separation,t}^{me}$$

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