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Heterogeneous Effects of Monetary Policy Shocks: Evidence from the Czech labor market

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Heterogeneous Effects of Monetary Policy Shocks: Evidence from the Czech labor market*

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Abstract

Using unique contract-level data from the Czech labor market, we investigate how monetary policy shocks, identified by the high-frequency surprises in interest rate futures, affect the distribution of wages and hours worked. Consistent with existing literature, our findings indicate that low-wage groups are more impacted by these shocks than high-wage counterparts. The novelty lies in our exploration of the heterogeneous effects across different demographic and sectoral groups. Our results reveal that age, education, sector of employment, and the length of employment contracts play important roles in how wages and working hours respond to policy shocks.

Keywords: monetary policy; heterogeneity; wage inequality;
JEL Classifications: E2, E3, E4, E5

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1 Introduction

The global economy has recently experienced a period of pronounced inflationary pressures and in response, numerous central banks have implemented a more restrictive monetary policy. Such a pace and strength of the monetary contraction were almost inconceivable in previous decades. This tightening, which includes both the reversal of unconventional measures and conventional interest rate hikes, aims to curb inflation by cooling the overheated labor markets and lowering overall economic demand. Nevertheless, a closer examination of economic data indicates that the consequences of these policies are not evenly distributed among individuals.

Employing a comprehensive administrative dataset on wage contracts, we examine the potential heterogeneity in the effects of monetary policy shocks across the wage distribution and among different demographic and sectoral groups. Our dataset provides extensive information across both cross-sectional and temporal dimensions, enabling us to analyze wage distribution percentiles and delve into the diverse sectoral and demographic impacts of monetary policy shocks. Drawing on this detailed individual-level data from the Czech labor market, we document five key findings:

1. Contractionary monetary policy shocks have a stronger negative impact on hourly wages and hours worked at the left tail of the wage distribution, with a smaller decline in hours at the right tail.

2. Hourly wages of higher educated workers are more resistant to the effects of contractionary monetary policy shocks.

3. Contractionary monetary policy has a more pronounced negative impact on the wages of young and mid-age workers.

4. Manufacturing jobs tend to respond to tighter monetary policy with wage reductions, whereas the service and agricultural sector is more likely to adjust by reducing

working hours.

5. The impact of monetary policy shocks on wages and hours does not vary materially by gender.

Our paper is related to the growing literature on the heterogeneous effects of monetary policy shocks. Earlier papers in this literature primarily relied on survey data, despite their significant limitations. Coibion *et al.* (2017) identify earnings heterogeneity as a key driver of rising inequality following expansionary monetary policy. The results from Mumtaz and Theophilopoulou (2017) suggest that lower-income groups are disproportionately affected by monetary tightening. These findings are also supported by Ampudia *et al.* (2018) and Lenza and Slacalek (2018) for the Euro Area. Madeira and Salazar (2023) examine the impact of contractionary monetary shocks on labor productivity and employment participation across sectors and demographic groups using survey data for Chile, while Zens *et al.* (2020) explore whether monetary policy effects on unemployment vary across different occupation groups in the US using data from the current population survey.

Our study is part of the more recent literature that focuses on estimating the distributional effects of monetary policy using granular administrative, individual-level data. The findings of Andersen *et al.* (2022) on Danish data suggest that the income response to an expansionary monetary policy shock increases monotonically across the wage distribution. Our results support those of Amberg *et al.* (2022), who analyse Swedish data and Hubert and Savignac (2023) who use French data. Their papers find that the income effects exhibit a U-shaped pattern over the income distribution. However, in an advance over these papers, our study provides new evidence on the role of demographic and sectoral heterogeneity in understanding these distributional effects.

While our findings are based on the Czech context, their relevance likely extends to other small, open, and developed economies. Czechia shares characteristics with these economies, including an industrial focus, consistent GDP growth, global market integration, and EU membership. Its economic performance (2.4% average annual GDP growth from 2002-2020), resilience during crises, and reliance on exports are common traits. In terms of within-country income distribution, income inequality in the Czech Republic has mirrored the broader trend in developed countries, marked by significant increases in both the Gini coefficient and top-income shares. Similarly, the Czech National Bank's inflation-targeting strategy and institutional framework resemble those of other central banks. Despite experiencing volatility from global events, Czechia's inflation has remained relatively stable. Furthermore, the online appendix demonstrates similarities in wage distribution between Czechia, the US, and Sweden, suggesting broader implications for our findings.[1]

The rest of the paper is organized as follows: Section 2 describes the data and illustrates some stylized facts. Section 3 details the estimation methods and the construction of the monetary policy shock series. We present and discuss the results in Section 4, while Section 5 concludes the paper.

2 Data – labor market characteristics

To analyze the response of the wage distribution to monetary policy shocks, we explore the universe of granular, contract-level data from the Czech labor market. This data is accessed via the administrative ISPV[2] dataset, which provides rich contract-level information at annual frequency from 2002 to 2011 and bi-annual thereafter to 2020. The

[1]In particular, we follow Guvenen *et al.* (2017) and construct 'worker betas'-the correlation between wage growth and aggregate GDP growth in each wage percentile. As shown in the online appendix, the distribution of these worker betas has a clear U-shape matching the findings for the US and Sweden reported by Guvenen *et al.* (2017) and Amberg *et al.* (2022). This provides further evidence that results based on Czech data have more general policy implications. See the online appendix for more details on the Czech economy and this analysis.

[2]Informační systém o průměrném výdělku (Average Earnings Information System), https://www.ispv.cz/en/homepage.aspx

data is collected by the Czech Ministry of Labor and Social Affairs as the main source of information on average earnings and is used for budgetary planning of social security expenditure.

In each data vintage, the variables include the average wage per-hour and its structure over the relevant period (including bonuses and other types of compensation), hours worked (with details on paid and unpaid leave, sick leave, etc.), employee characteristics, such as gender, age, and education level, and also characteristics of the employer, such as location and number of employees (full-time-equivalent). To gather more information on employers, we merge the data with the RES[3] Business Register database, which provides information on the prevailing business sector in which the employer operates.

The data covers a large proportion of Czech labor market contracts, with around 1.5 million cross-sectional units (contracts) in the most recent vintages. While many contracts appear and disappear during the observed time sample, we can still follow the duration of each contract, which is a separate data entry. The inclusion of a contract in the sample depends on the size of the firm. Firms with 250+ employees are included in each vintage, while smaller firms are covered on a rotational basis to reduce the administrative burden on small businesses. To correct for any bias this may cause, the under-sampled smaller firms are assigned a higher weight to represent those which were omitted from the vintage.

The data on hours worked reflects two main sources of variation. The first comes from the coverage of part-time agreements in the data. Out of 1.2 million contracts covered in the 2022 vintage of the data, close to 77% are full-time. The rest comprises of contracts recorded as part-time contracts (close to 23%). However, a significant portion of these contracts is close to full-time.[4] Hours are adjusted for absence (paid and unpaid), overtime and sickness. The dataset also includes contracts, which start or terminate during the respective year. The variation coming from this source, however, does not provide much

[3] Registr ekonomických subjektů (Business Register), https://www.czso.cz/csu/res/business_register

[4] About 11% of these contracts have hours above 0.95 of full-time hours.

information about the supply of labor. Therefore, we extrapolate the hours worked under such contracts as if the contract lasted for the whole year. For example, if there were x hours worked under a contract terminated after a half of a year, we multiply these by 2.

The administrative character of the dataset, together with its wide coverage, overcomes the usual pitfalls of survey data, such as imperfect coverage of the upper and lower tails of the wage distribution. However, the data has several limitations. The contract-level and anonymous nature of the granular data do not allow us to follow an individual through different employments. For the same reason, we also do not have access to information about the total income of individuals, who may have a substantial non-wage income or be employed under several simultaneous contracts. We therefore focus on wage inequality as a distinct channel of total income inequality. While we do not have information about employees' contract history, we can measure their turnover rate by observing the average length of the present contract.

Figure 1 shows the characteristics of employees and respective contracts along the wage distribution (i.e. percentiles of the average hourly wage), averaged over the period 2002–2020. Higher wage percentiles are associated with a higher education level, and the relationship is strictly increasing. Gender inequality is illustrated by lower shares of females in higher wage percentiles and by decreasing shares of females toward the higher end of the wage distribution. Both tails of the wage distribution are associated with a higher average age, marking the line between workers who were able to climb the seniority ladder and increase their wages over lifetime and those who struggled to do so, leaving them with a lower wage toward the end of their working lives. As a result, wage inequality increases with age. Contract lengths are longer at the right tail of the wage distribution.

The data reveal other several notable characteristics of the Czech labour market, which we present in more detail in the online appendix. First, the service sector stands out with high female representation, while, men dominate all other sectors. Second, the average

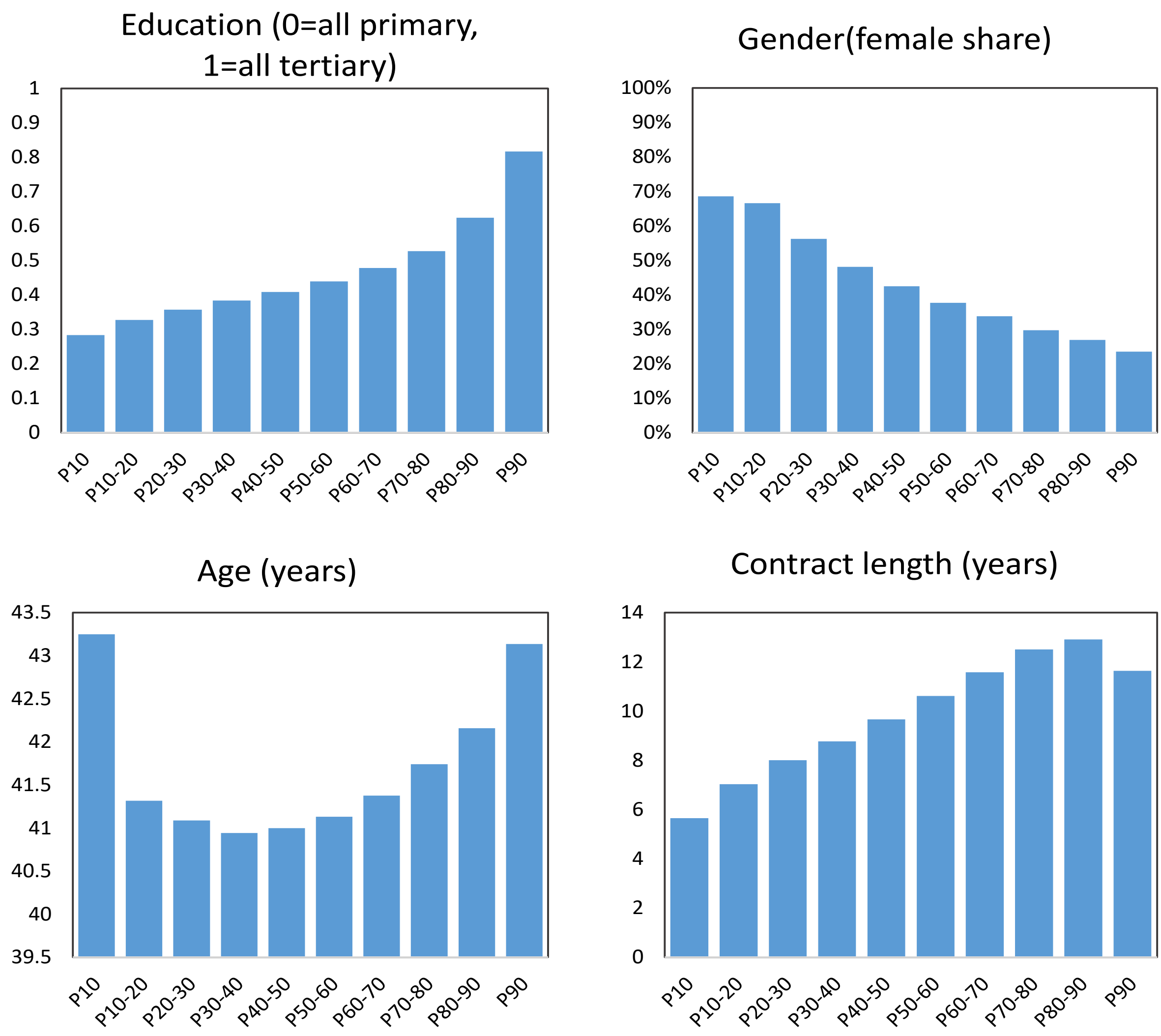

Figure 1: Characteristics of employees and contracts along the wage distribution. P10 to P90 on the X-axis denotes the percentiles of the wage distribution

hourly wage is slightly higher in the manufacturing sector, where the wage distribution is also more uniform, with most workers earning around the median wage or slightly above. In contrast, the service sector has a higher share on the tails of wage distribution. Third, workers tend to have more stable long-term employment relationships in manufacturing and the agriculture sector, while in the service sector, the observed shorter contract lengths demonstrates more flexibility. Finally, older workers tend to have longer contracts. The average contract length for a worker under the age of 35 is less than 4 years, for a worker between the ages of 35 and 50, it is 10 years, and for workers above 50, the average length of their contract is close to 16 years.[5]

3 Empirical model

Our benchmark model is the following mixed-frequency Vector Autoregression (VAR):

$$Y_t = c + \sum_{p=1}^{P} Y_{t-p} B_p + v_t \tag{1}$$

where $v_t \sim N(0, \Sigma)$ and Y_t is a $1 \times N$ matrix of endogenous variables that includes the following variables:

$$Y_t = \begin{pmatrix} m_t & r_t & y_t & p_t & u_t & s_t & \hat{z}_t \end{pmatrix}' \tag{2}$$

where m_t is a measure of the monetary policy shock described below. The short-term interest rate, the log of GDP, the log of the GDP deflator, the unemployment rate, and the log of the dollar exchange rate are denoted by r_t, y_t, p_t, u_t, and s_t, respectively. The data for these variables is quarterly and runs from 2002Q1 to 2019Q4.[6] Finally, z_t denotes wages per-hour or hours worked averaged for the survey participants, who fall within groups defined either by percentile of the wage distribution, or characteristics such as industry of employment, gender, and education. We provide details on the definition of the groups in the empirical analysis below. Note that wages are deflated by CPI to convert them to real terms.

[5] Additional characteristics of the Czech labor market can be seen in the Section 3 of the online Appendix.

[6] All series are obtained from the FRED data base. The Fred mnemonics are CLVMNACSCAB1GQCZ, CZECPIALLQINMEI, IR3TIB01CZM156N, LRHUTTTTCZM156S and CCUSMA02CZM618N for real GDP, CPI, short-term interest rate, unemployment rate and the exchange rate, respectively.

3.1 Mixed frequency

The vector of endogenous variables contains quarterly macroeconomic variables and survey-based variables, which are available at a lower frequency. The survey-based variables z_t are observed in the fourth quarter of every year before 2012 and are then available twice a year. Following Schorfheide and Song (2015), we treat the quarterly observations of z_t as unobserved states. These are denoted by $\hat{z}_t$ in equation 2. The VAR model is augmented with the following observation equation:

$$Z_t = H \underbrace{\begin{pmatrix} Y_t \\ Y_{t-1} \\ Y_{t-2} \\ Y_{t-3} \end{pmatrix}}_{\beta_t} + \begin{pmatrix} E_t \\ 0 \\ 0 \\ 0 \end{pmatrix} \tag{3}$$

where $Z_t = \begin{pmatrix} m_t & r_t & y_t & p_t & u_t & s_t & z_t \end{pmatrix}'$ and $E_t = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & \tilde{v}_t \end{pmatrix}'$. Note that z_t is missing in $Q1$ to $Q3$ of each year and is observed only in $Q4$. in the sample before 2012. After 2012, z_t equals the missing value in $Q1$ and $Q3$ and is observed in the remaining quarters. If z_t is missing, then:

$$H = \begin{pmatrix} I_{N-1} & 0_{N-1,N} & 0_{N-1,N} & 0_{N-1.N} \\ 0_{1,N} & 0_{1,N} & 0_{1,N} & 0_{1,N} \end{pmatrix}$$

where I_N and $0_{N,N}$ denote the $N \times N$ identity matrix and an $N \times N$ matrix of zeros, respectively. Note that $var\left(\tilde{v}\right)$ is set to a large number in this case. When z_t is observed once a year:

$$H = \begin{pmatrix} I_{N-1} & 0_{N-1,N} & 0_{N-1,N} & 0_{N-1.N} \\ e_N & e_N & e_N & e_N \end{pmatrix}$$

with $e_N = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{4} \end{pmatrix}$ and $var\left(\tilde{v}\right)$ is set to 0. In this case, the observation equation implies that $z_t = \sum_{i=0}^{3} \frac{\hat{z}_{t-i}}{4}$ – i.e., the observed value is assumed to be the average of the unobserved values in the current and the last three quarters. When z_t is observed twice a year:

$$H = \begin{pmatrix} I_{N-1} & 0_{N-1,N} & 0_{N-1,N} & 0_{N-1.N} \\ e_N & e_N & 0 & 0 \end{pmatrix}$$

with $e_N = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{2} \end{pmatrix}$ and $var\left(\tilde{v}\right)$ is set to 0. In this case, the observed value is the average of the current and previous quarter.

3.2 High frequency identification of the monetary policy shock

Following recent papers such as Gertler and Karadi (2015), Miranda-Agrippino and Ricco (2015), and Jarocinski and Karadi (2020), we adopt a high-frequency approach to identify the monetary policy shock. In particular, we use daily data on three-month Prague interbank Libor rate futures (Pribor) at maturities of 1, 3, 6, and 9 months. We calculate the daily changes in these futures around monetary policy meetings.

As shown in the left panel of Figure 2, the change in future rates at the nine-month horizon shows the largest volatility, with large spikes occurring during the 2008-2010 period. It is also noticeable that the change in future rates is highly correlated. In fact, 91 percent of the cross-sectional variation in the futures is explained by the first two principal components. Given this feature, we follow Gürkaynak *et al.* (2005) and use these principal components $\mathcal{P}_t$ to characterize monetary policy shocks. As discussed in Gürkaynak *et al.* (2005), the cross-section of futures captures multiple dimensions of monetary policy and contains information regarding the market reaction to expected changes in current rates and their future path. We follow the approach of Gürkaynak *et al.* (2005) and rotate the principal components $\mathcal{P}_t$ to obtain factors $\mathcal{P}_t^*$. This orthogonal rotation imposes the

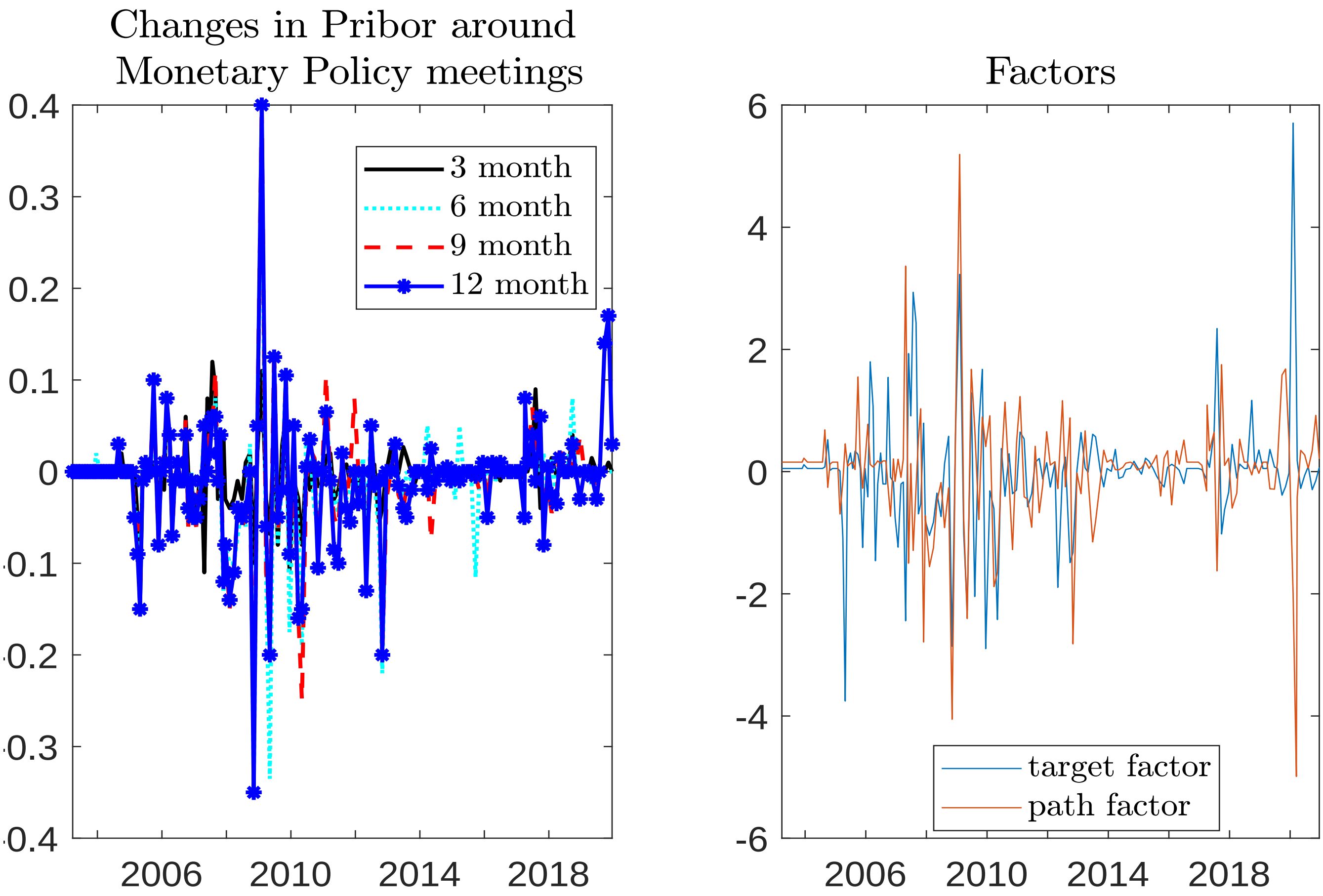

Figure 2: Changes in Pribor futures around meetings of the monetary policy distribution (left panel). Estimated target and path factors (right panel)

restriction that the second factor in $\mathcal{P}_t^*$ has a zero loading at the one-month maturity. Therefore, this factor can be interpreted as a "statement" or a "path" factor that captures changes in guidance on future policy rates. In contrast, the first factor in $\mathcal{P}_t^*$ that is allowed to load at the one-month maturity is the "target" factor and is a proxy for current policy surprise.

One may be concerned that the use of daily windows allows these factors to be con-

Date	Event	Target Factor	Path Factor
6th Feb 2020	unexpected 25bp hike	5.71	-2.00
26th Sep 2018	partially expected 25bp hike	1.17	-0.05
3rd Aug 2017	partially expected 25bp hike	2.34	-1.62
3rd May 2012	stability, cut was implied by the forecast and voted for by the governor	-1.89	-0.28
6th May 2010	cut 25bp by narrow majority, partially expected	-2.42	-1.65
16th Dec 2009	cut 25bp by narrow majority, partially expected	-2.90	0.40
5th Feb 2009	cut 50bp, but more was expected	3.23	5.19
6th Nov 2008	cut 75bp, less was expected	-2.86	-4.05
30th Aug 2007	partially expected 25bp hike, by narrow majority	2.43	-0.26
26th Jul 2007	partially expected 25bp hike	2.93	-1.29
26th Apr 2007	stability by narrow majority, hike partially expected	-2.44	3.36
28th Apr 2005	cut 25bp by narrow majority, partially expected	-3.76	0.45

Table 1: Twelve Largest Observations of the Target and Path Factors

taminated with news other than monetary policy.[7] However, the movements of $\mathcal{P}_t^*$ (right panel of Figure 2) accord well with the narrative of monetary policy events in Czechia.[8] The extreme values of the target and path factors identified from interest rate futures can be directly linked to surprising decisions at the relevant monetary policy meetings. For example, the monetary policy meeting on Feb 6, 2020 brought an unexpected 25 bp hike (a spike in the target factor), and the market expected this move to be corrected later on (a concurrent drop in the path factor). To give another example, the meeting on Feb 5, 2009 resulted in a cut of 50 bp, but a larger amount of easing had been expected, leading to a restrictive shock captured by a spike in the target factor. Additionally, a surprisingly

[7]Ideally, we would like to use intra-day data to calculate these changes. However, this data is not available for a sufficiently long time-period for Czechia.

[8]Moreover, we show in the robustness analysis that an alternative identification scheme based on sign restrictions produces estimates of the effects of monetary policy that are very similar to the benchmark results.

hawkish rate forecast led to a positive spike in the path factor as well. Table 1 reports other prominent monetary policy decisions that are accurately captured by the target and path factors.

In our empirical analysis, our interest lies on conventional monetary policy. We, therefore, use the target factor as our instrument m_t. As in Jarocinski and Karadi (2020), the instrument is added directly to the VAR model, and impulse responses are calculated using a Cholesky decomposition with m_t ordered first. Plagborg-Møller and Wolf (2021) prove that the impulse responses obtained via this approach are asymptotically equivalent to those obtained using the instrumental variable or proxy VAR approach. Given our small sample size and the presence of missing data, we prefer the simpler approach of the recursive VAR.

3.3 Model specification and estimation

Based on the Schwarz information criterion, the lag length of the VAR model is set to 2. The mixed frequency VAR model is estimated using Bayesian techniques. In particular, we use the Gibbs sampling algorithm devised by Schorfheide and Song (2015). In short, each iteration involves sampling from the conditional posterior distributions of b, Σ, and $\hat{z}$, respectively, where b denotes the VAR coefficients in vectorized form. The first two conditional posterior distributions are standard in the Bayesian VAR literature. Draws from the conditional posterior distribution of the state variables $\hat{z}$ can be obtained using the simulation smoother of Durbin and Koopman (2002). The online appendix provides details of the conditional posteriors and prior distributions that are standard. We use 21,000 iterations, dropping the first 1,000 as burn-in. Every fifth remaining iteration is saved for inference. We provide evidence for convergence of the algorithm in the online appendix.

4 Results

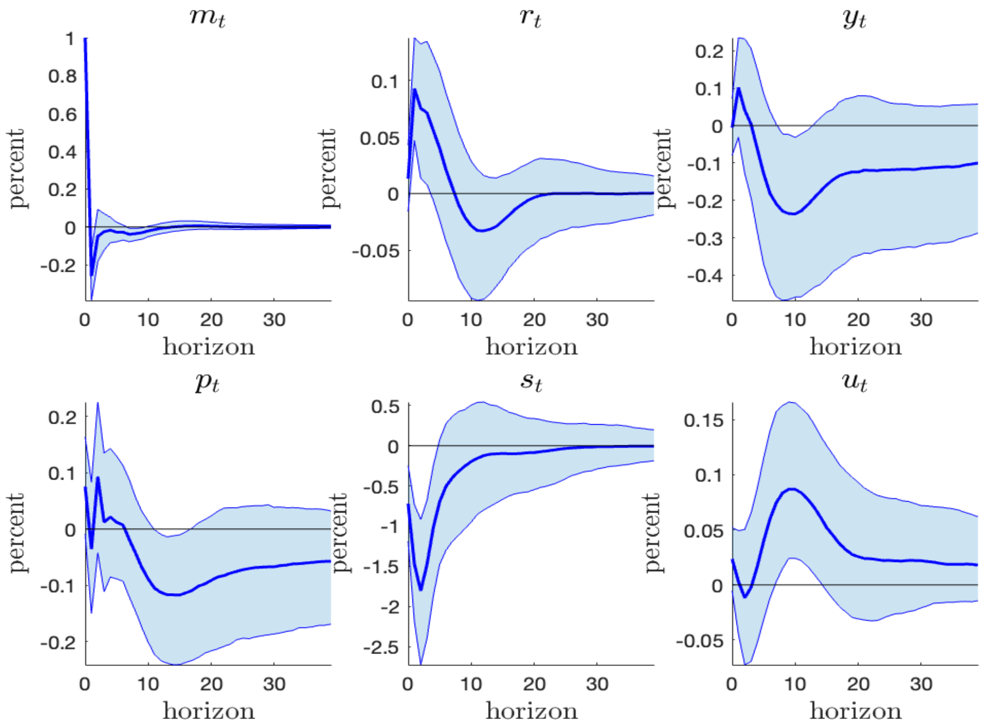

Figure 3: Response of macroeconomic variables to a monetary policy shock. The solid line shows the median response while the shaded area shows the 68% error band

4.1 The macroeconomic effects of a monetary policy shock

Before describing the impact of monetary policy shocks on the distribution of wages and hours worked, we show that the responses of the main macroeconomic variables are plausible and accord well with the theory.

Figure 3 demonstrates that a contractionary shock leads to an increase in the short-term interest rate r_t of about 0.1 percent. Both GDP and the GDP deflator fall in response to the shock, while the unemployment rate rises. The decline in GDP is sharp, with the peak response occurring at a three-year horizon and this coincides with the peak increase in the unemployment rate. The fall in the price index occurs more slowly, with prices declining by about 0.2 percent after four years. The exchange rate appreciates sharply and s_t declines by 1.5 percent one quarter after the shock. To sum up, a contractionary monetary policy shock impacts the interest rate and exchange rate variation mostly in the short run; the effect on GDP and the price index peaks at a medium horizon.

4.2 Monetary policy shocks and the distribution of wages

We augment the benchmark model with data on average wages per-hour and hours in each percentile. These variables are added one by one and the mixed-frequency VAR model is estimated in each case.[9] The granular nature and number of observations included in our dataset means that average wages and hours worked within each percentile are estimated precisely. Therefore, unlike survey-based studies, we can examine the impulse responses at a finer level and, importantly, we can illustrate the behavior of the distribution at the tails, which may not be evident from a more aggregate analysis.

Figure 4 displays the cumulative response of wages and working hours over 20 quarters to the contractionary monetary policy shock in each percentile group.[10] The figure shows that within five years after the monetary contraction, the wage is depressed across almost the whole distribution. The largest adverse effect occurs at the left tail of the distribution. For low earners, the wage declines cumulatively by about 5 percent, while the wage of top earners is largely unaffected. The contractionary policy shock tends to reduce the number of working hours at the right tail of the distribution. While hours decline sharply for the first percentile, there is some evidence of an increase in hours in the remainder of the first decile providing some support to the results reported for the US by Cantore *et al.* (2022).[11] It is important to investigate what drives this apparent heterogeneity in the

[9]While it would be preferable to add these variables jointly, the small sample size and large number of unobserved state variables make this computationally infeasible.

[10]The cumulated response of these variables at different horizons is shown in Figure 5 in the online appendix.

[11]Note that the results in Cantore *et al.* (2022) are based on actual hours worked from the CPS. The measure of hours in this paper corresponds to usual hours.

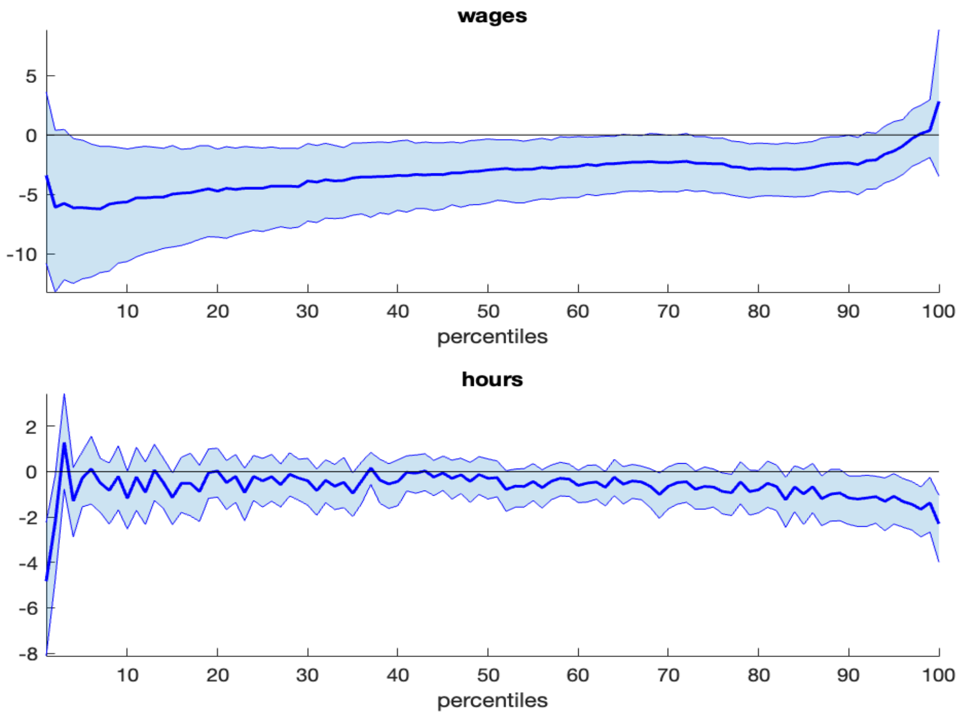

Figure 4: Cumulated response of wage and working hours to monetary policy shock at 20 quarter horizon. The shock is a 1 unit contractionary monetary policy shock which increases the interest rate by about 10 basis points. The solid lines are posterior medians while the shaded area represents the 68% error band.

reaction to monetary policy shocks. To conduct a more thorough examination of these questions, in the following subsection we explore the reaction by demographic groups and sectors.[12]

4.2.1 Demographic and sectoral analysis

The structure of our dataset allows us to extract primary demographic characteristics of employees, such as gender, age, and education. We also know the prevailing business sector in which the employer operates. In this section, we consider the role played by these characteristics in driving the heterogeneous response of wages and hours worked. In particular, we estimate the VAR model, adding average wages or hours in different

[12]As shown in the online appendix, the monetary policy shock also contributes to the forecast error variance for wages and working hours mainly at the tails of the distributions.

demographic or sectoral groups one by one to the core set of 6 quarterly variables. Note that by limiting the low frequency data to one series, we ensure that the number of state-variables in the model remain manageable.[13]

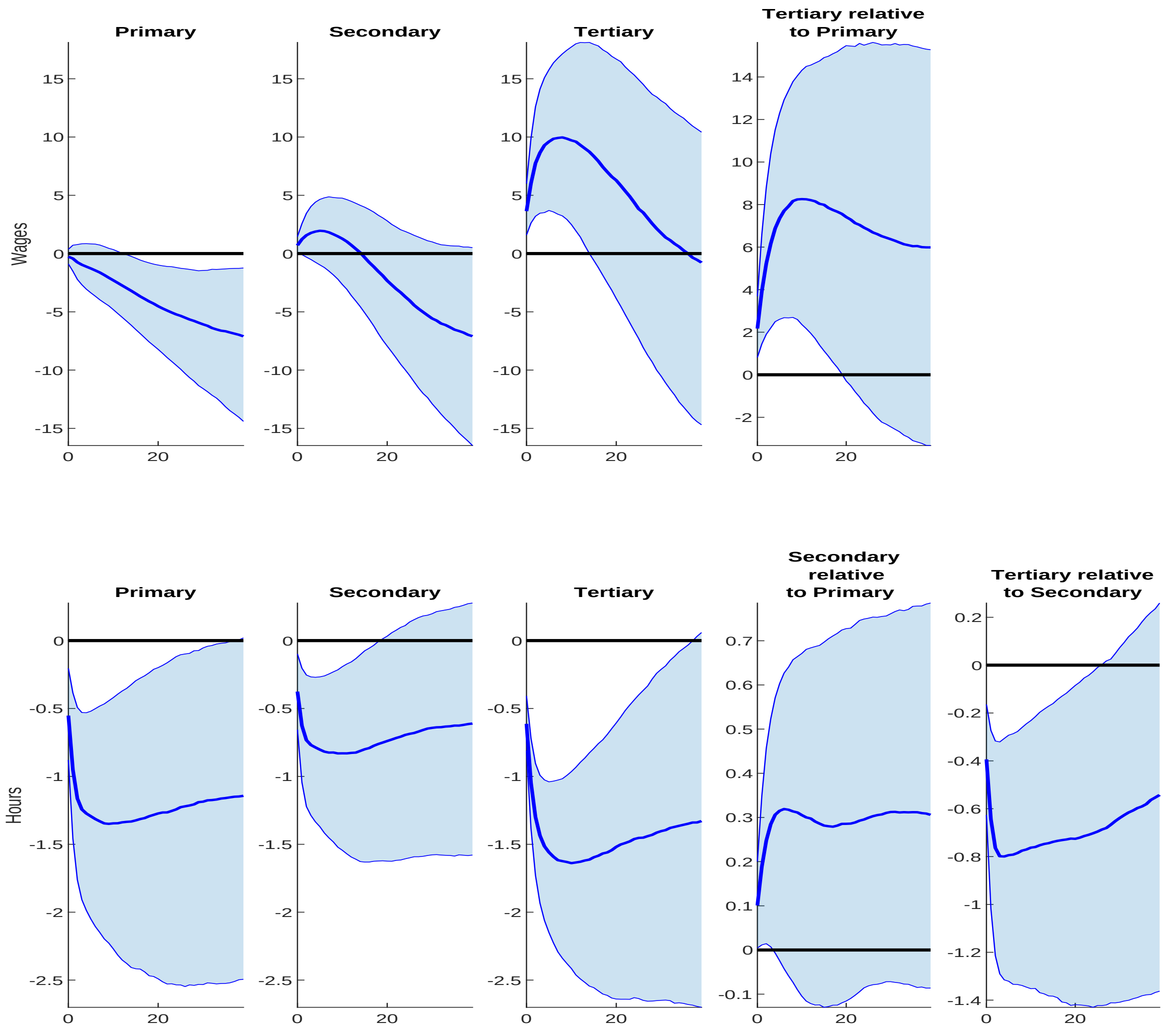

Figure 5: Cumulated Response of wages and hours by level of education. The shock is a 1 unit contractionary monetary policy shock which increases the interest rate by about 10 basis points. The solid lines are posterior medians while the shaded area represents the 68% error band. The X-axis denotes the horizon in quarters.

[13]To check if differences across groups are statistically different from zero, we estimate additional VAR models where average hours or wages in groups of interest in deviation from a benchmark group are added as the low frequency series in the model.

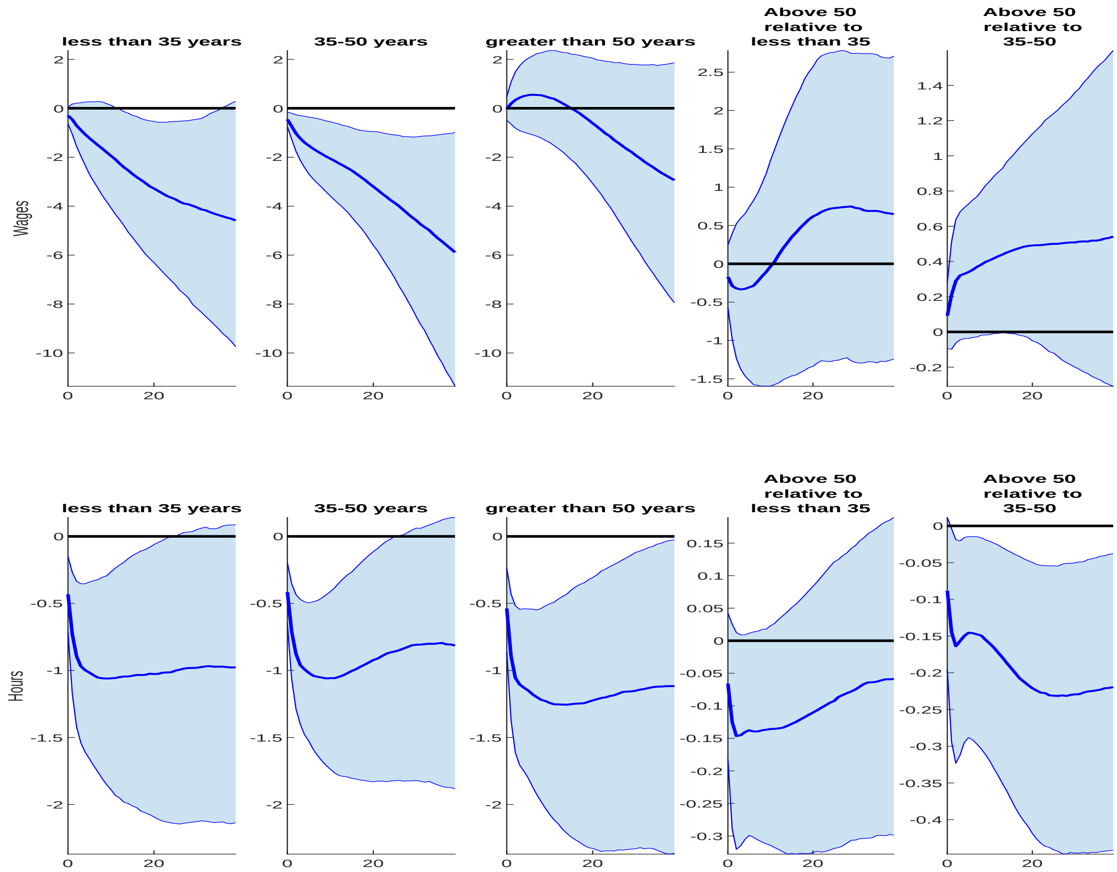

Figure 6: Cumulated Response of wages and hours by age. The shock is a 1 unit contractionary monetary policy shock which increases the interest rate by about 10 basis points. The solid lines are posterior medians while the shaded area represents the 68% error band. The X-axis denotes the horizon in quarters.

Education The top panel of Figure 5 shows the cumulative response of average real wages to a contractionary monetary policy shock for individuals with primary, secondary or tertiary levels of education. As in the benchmark case, the shock is scaled to increase the interest rate by about 10 basis points. The shock reduces wages for individuals with primary education. In contrast, highly educated individuals experience a rise in their real wages per hour. The last column of the top row of the figure shows the response of the wage of individuals with tertiary level of education in deviation with those with primary education. The response of this series is positive and statistically different from zero,

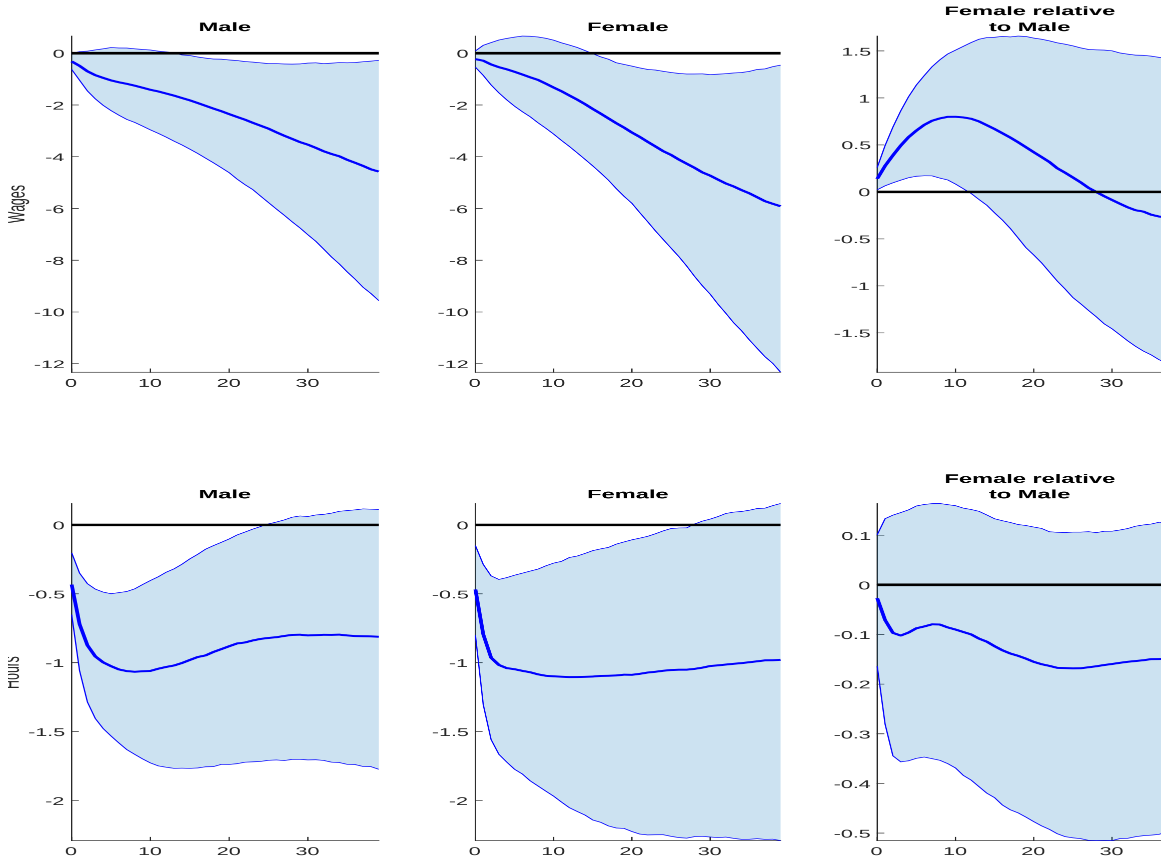

Figure 7: Cumulated Response of wages and hours by gender. The shock is a 1 unit contractionary monetary policy shock which increases the interest rate by about 10 basis points. The solid lines are posterior medians while the shaded area represents the 68% error band. The X-axis denotes the horizon in quarters.

indicating that the difference across these groups is statistically different from zero.

The bottom panel of Figure 5 shows that the shock is associated with a larger decline in hours for individuals with primary and tertiary education– the last columns show that the difference between the tertiary and the secondary group is statistically different from zero.

Age Figure 6 presents impulse responses for average wages and hours in groups formed by age of the individual. The results provide some evidence that the decline in wages

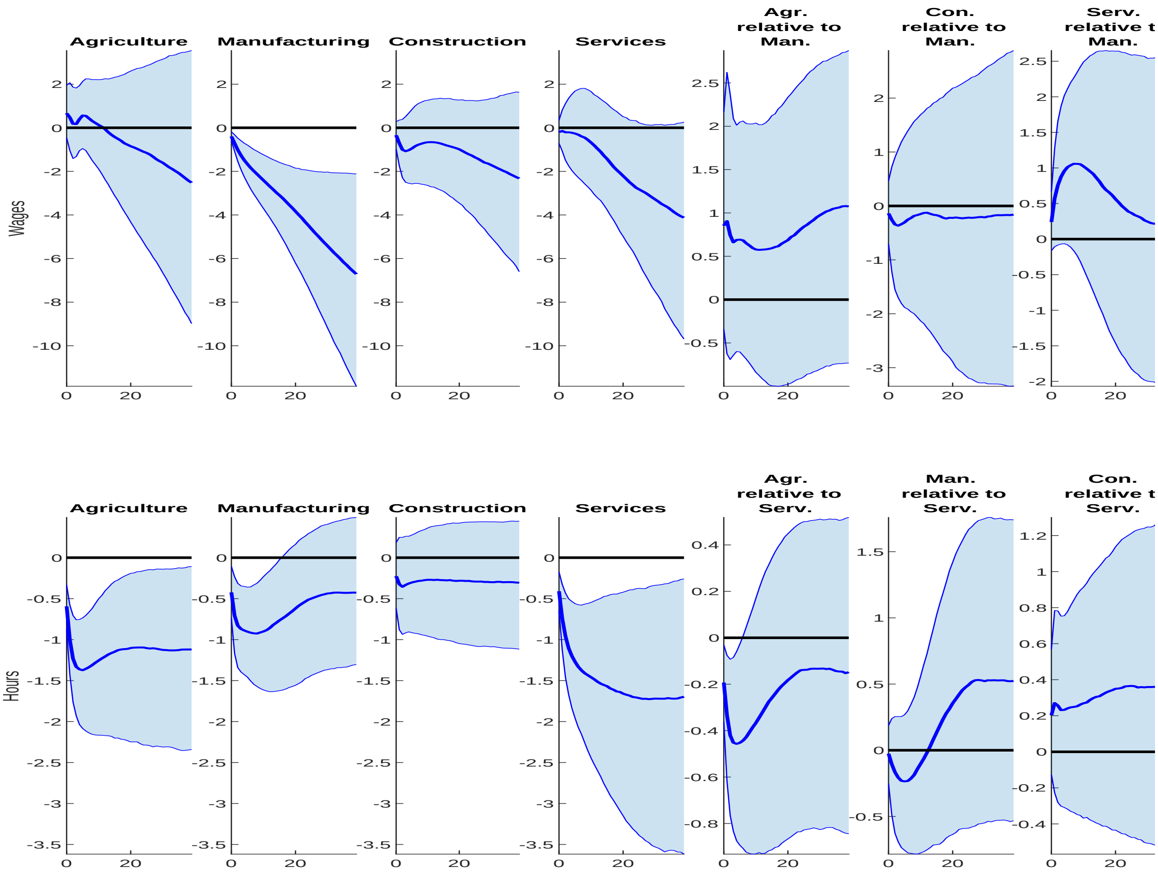

Figure 8: Cumulated Response of wages and hours by sector. The shock is a 1 unit contractionary monetary policy shock which increases the interest rate by about 10 basis points. The solid lines are posterior medians while the shaded area represents the 68% error band. The X-axis denotes the horizon in quarters.

following a contractionary monetary policy shock is concentrated in lower age groups. The top panel shows that real wages decline for individuals younger than 50 years with the estimated responses statistically different from zero at medium term horizons. The response of wages for individuals older than 50 years is imprecisely estimated over the entire horizon.[14]

The bottom panel of the figure shows that hours decline by about 1 % for all groups. However, as shown in the last column, the decline for older individuals is slightly larger

[14]This imprecision implies that differences in the impulse responses between this group and younger individuals are not statistically different from zero (see the last two columns in the top row).

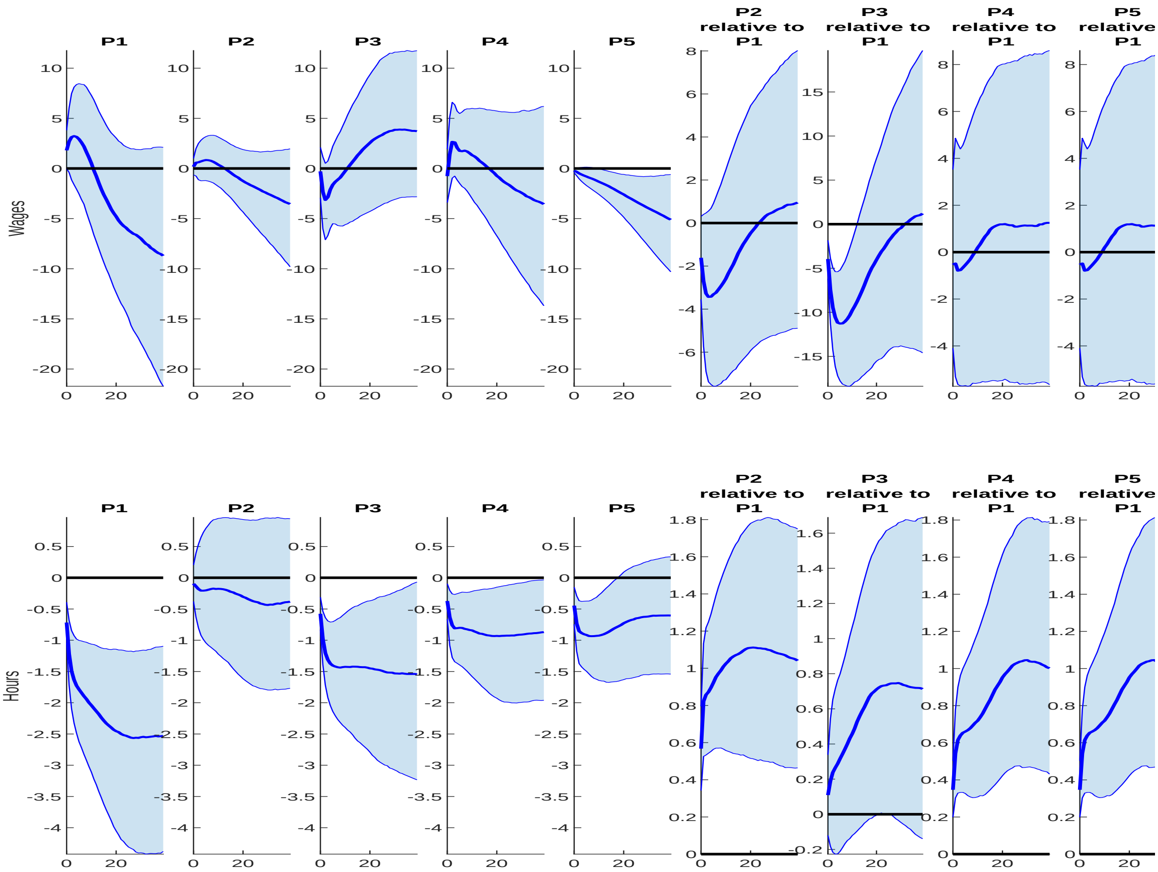

Figure 9: Cumulated Response of wages and hours by contract duration. P1 to P5 refers to groups based on quintiles. The shock is a 1 unit contractionary monetary policy shock which increases the interest rate by about 10 basis points. The solid lines are posterior medians while the shaded area represents the 68% error band. The X-axis denotes the horizon in quarters.

than the 35-50 group.

Gender The top panel of Figure 7 shows that the response of real wages for males and females is negative. There is some evidence that the initial decline for females is slightly smaller. We find that the difference in the magnitude of response of hours across these groups is minimal.

Sectors Figure 8 displays the impulse response to the policy shock by sector of employment. The top panel shows that the largest decline in real wages occurs in the manufacturing sector, while the effect in the remaining sectors is imprecisely estimated. The shock reduces hours across sectors, with the median response showing the largest decrease in services and agriculture.

Contract duration In Figure 9 we show the impulse responses of real wages and hours by duration of employment contracts. The responses are displayed for average hourly wages and hours in 5 groups formed by quintiles: $P1$ includes contracts below the 20^{th} percentile, $P2$ includes contracts between the 20^{th} percentile and the 40^{th} percentile and so on. The top panel of the figure shows limited evidence that the decline in wages occurs for workers with the longest contracts. In contrast, as the bottom row of the figure shows, the adjustment in hours mainly takes place through large declines at the left tail of the contract length distribution.

We can summarize our main findings as follows.

1. Contractionary monetary policy shocks have a larger negative effect on hourly wages at the left tail of the wage distribution. Hours drop substantially at the left tail of this distribution in response to this shock, but also show a smaller decline at the right tail.

2. Wages of workers with higher education are more resistant to the effects of contractionary monetary policy shocks. As shown in Figure 1 in Section 2, highly educated workers tend to dominate the right tail of the wage distribution which also coincides with longer contract durations. This might provide these individuals higher bargaining power to protect their wages in the event of negative shocks. Our results suggest that adjustment for these workers takes place through a stronger decline in

hours.

3. The analysis suggests that the wage of young and mid-age workers responds more negatively to a contractionary monetary policy shock than that of the senior workers. As discussed in Section 2, contracts of older workers are renegotiated less often. Our results suggest that older workers tend to react by reducing hours worked in the face of a negative shock.

4. While jobs in manufacturing react to the restrictive shock with a reduction in wages, in services and agriculture the response is more likely to materialize via fewer hours worked. This finding relates to the two types of labor proposed by Kaplan and Zoch (2020), (production-type and expansionary-type) and their different reactions to shocks.

5. Despite the prevailing gender pay gap, we do not find a significant gender difference in the response to monetary policy shocks. This may result from two counteracting forces, as men are typically more represented in manufacturing jobs, which show a more pronounced wage response to the shock, while the gender pay gap suggests that women are more concentrated in the low-wage brackets, where the reaction to the shock is also stronger.[15]

4.3 Further results and Robustness analysis

We carry out an extensive sensitivity analysis which is described in the online appendix. In this section we present a summary of these results:

1. Unconventional monetary policy: Our benchmark model focuses on conventional monetary policy shocks. The Czech national bank used the exchange rate as an additional policy instrument from November 2013 to April 2017. We show in the

[15]See the online appendix for a discussion of these characteristics of the data.

online appendix that the path factor extracted from an extended high frequency data set that includes changes in the exchange rate, captures this unconventional policy. Adding this factor to the benchmark VAR does not materially alter the benchmark results (see Figures 14 and 15 in the online appendix). Shocks to this path factor are estimated to have a smaller effect on the distribution of wages and hours than the conventional shock.

2. Sign restrictions: We use contemporaneous sign restrictions as an alternative identification scheme for the monetary policy shock. We assume that a contractionary monetary policy shock is associated with an increase in short-term interest rates, a decline in output and prices, a real exchange rate appreciation, and a rise in the unemployment rate. Figure 8 in the online appendix shows the estimated response of hours and wages. As in the benchmark case, wages decline substantially at the left tail of the distribution and wage inequality rises.

3. Model specification: We add the following variables to the benchmark model: (1) Euro-area GDP, (2) Euro-area CPI and (3) Oil prices. As shown in Figure 9 in the online appendix, the key results are unaffected. The contractionary monetary policy shock still has a disproportionately large effect on wages at the left tail of the wage distribution.

5 Concluding Remarks

This paper analyzes the heterogeneous effects of monetary policy on labor markets, particularly regarding wage distribution and hours worked, with an emphasis on the sectoral and demographic characteristics of workers. We use unique contract-level administrative data from the Czech labor market, which covers around 1.5 million contracts in recent data vintages. In order to identify monetary policy shocks, we employ a high-frequency approach, deriving surprises from interest rate futures data around monetary policy meetings. By exploring the maturity spectrum of futures, we differentiate between the interest rate target factor (surprise in rate decisions) and the path factor (surprise in guidance), using the target factor as a measure of conventional monetary policy shocks.

Embedding this information in a mixed-frequency monetary policy VAR model, we documented several new facts about the distributional effects across different demographic and sectoral groups. Our results indicate that contractionary monetary policy shocks have the largest effects on the wages of low-wage workers. The decline in hours is largest at the left tail of the wage distribution but hours also decline for workers on the highest wages. Higher-educated workers show greater resilience to monetary policy shocks, while younger and mid-aged workers are more negatively affected than older workers, who experience reduced hours instead of wage cuts, possibly due to less frequent contract renegotiation. While wage reductions occur in manufacturing jobs, workers in the service and agriculture sectors primarily respond by reducing hours. Furthermore, despite the gender pay gap, we do not find significant gender differences in responses to monetary policy shocks.

These insights deepen our understanding of the complex interactions between monetary policy and labor market dynamics, offering novel findings not only in the context of the Czech labor market but also from an international perspective. Future research could aim to develop a theoretical explanation for the heterogeneous responses of wages and hours to monetary policy shocks.

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Heterogeneous Effects of Monetary Policy Shocks: Evidence from the Czech labor market. Online Appendix*

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1 The Czech economy

Our study uses administrative data on wages per hour and hours for Czechia. However there are a number of reasons to suggest that the relevance of our findings transcends the Czech context and are more generally applicable.

First, despite certain unique aspects, the characteristics of the Czech economy are similar to those of any small, open and developed economy. Czechia has an industrially-focused economy with a consistent record of steady GDP growth. Following the Velvet Revolution in 1989 and peaceful dissolution of Czechoslovakia in 1993, the early years were

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marked by transition and reform. Since then, the Czech economy underwent significant restructuring, and integrated itself into the global market. In 2004, Czechia became a part of the EU and in the following decade, the economy experienced notable expansion and deeper integration with the union. It demonstrated resilience by recovering effectively from the global financial crisis of 2008 and maintained steady growth predominantly fueled by robust exports to Germany and other EU countries. During the analysed years 2002-2020 the GDP grew on average 2.4% per-annum and the real national income per capita nearly rose steadily by adding 60 % in total over the period. Income inequality in the Czech Republic has mirrored the broader trend in developed countries, marked by significant increases in both the Gini coefficient and top-income shares.

In the past decades, the Czech Republic attracted substantial foreign direct investment, which played a crucial role in modernizing its industrial sector and boosting the demand for labor force. With an average unemployment rate of 5.7% between 2000 and 2020 and a female labor force participation rate exceeding 70%, the Czech economy aligns with other developed countries. Although producing 50 % of GDP, services absorb about 60 % of the overall labor force. Manufacturing sector is proportionally less labor-intensive, with 30 % of labor force it produces above 40 % of GDP. The labor force participation in the industry sector is the highest in the EU (where it is on average 25 %), while the share of service sector is significantly lower (EU 70 %). The public sector, encompassing primarily education and healthcare, employs one-fifth of the workforce. With these characteristics, the Czech economy stands as part of the developed world, broadly similar to other developed open economies.

Secondly, the Czech National Bank (CNB) has implemented a monetary policy based on an inflation-targeting strategy since 1998. Since then, the CNB has operated within an institutional framework similar to those of other central banks such as the Fed, ECB or the Bank of England. In 2010, the CNB adopted an inflation target of 2%. Although the Czech inflation generally fluctuates around the inflation target with the average inflation of 2.08% over the period analysed, the economy experienced significant volatility due to domestic and international factors, primarily the global financial and economic crisis and the Euro Area debt crisis. In response to the Global Financial Crisis, the CNB was one of the first central banks to cut interest rates, starting in the summer of 2008. As the interest rates approached the zero lower bound, the CNB began using the exchange rate as an additional tool for easing monetary policy in November 2013, committing to keeping the Czech koruna exchange rate above 27 CZK per euro. This currency depreciation contributed to inflation returning to the target. The CNB ended its exchange rate commitment in April

2017 and raised interest rates four months later. Despite of the four-year exchange rate commitment period, the Czech koruna appreciated by 30% against the US dollar during the analyzed time.
In the technical appendix, we show that the cross-sectional characteristics of the wage distribution in Czechia match those reported for the US by Guvenen *et al.* (2017) and for Sweden by Amberg *et al.* (2022). In particular, we follow Guvenen *et al.* (2017) and construct 'worker betas'-the correlation between wage growth and aggregate GDP growth in each wage percentile. As shown in the appendix, the distribution of these worker betas has a clear U-shape matching the findings for the US and Sweden. This provides further evidence that results based on Czech data have more general policy implications.

2 Replication of Guvenen et al. (2017)

For the purpose of supporting the external validity of our results, we provide supplementary evidence for the fact the Czech labor market in fact observes similar distributional elasticities such as that of the United States (Guvenen *et al.* (2017)) and also Sweden (Amberg *et al.* (2022), Appendix C). We replicate the estimates of "worker betas" from these papers using Czech data. The worker (or wage) betas estimate the wage income elasticity of each worker to aggregate income fluctuations. As the computation is very data intensive, each of the papers used a simplification, usually sampling from the full granular dataset to reduce the number of observations included in each estimation and streamline data handling. As our granular data point is not a worker, but a contract, our dataset can be characterised more as a repeated cross-section rather than a true panel. In effect, we don't have an option to follow an individual worker across time and therefore we don´t have the access to the wage growth on individual level (we observe the wage itself for each contract, but not its change, since we are not able to consistently match contracts across different data vintages). Therefore, we present here the results from an estimation identified using time-variation of average wage inside of each income percentile. The method relies on a regression run for each percentile, regressing the wage growth on the GDP growth.

We present the results, the worker betas across the wage income distribution, in Figure 1. The shape shows similar U-shaped pattern as in Guvenen *et al.* (2017) and Amberg *et al.* (2022). Wages at the top end and bottom end of the wage distribution show the highest correlations to cyclical macroeconomic fluctuations. There is no apparent difference in worker betas across age groups. These findings support the claim that the general elasticities of wage distribution on the Czech labour market behave similarly to other developed labour markets and therefore the main results of this paper could extend to other countries and should be of general interest.

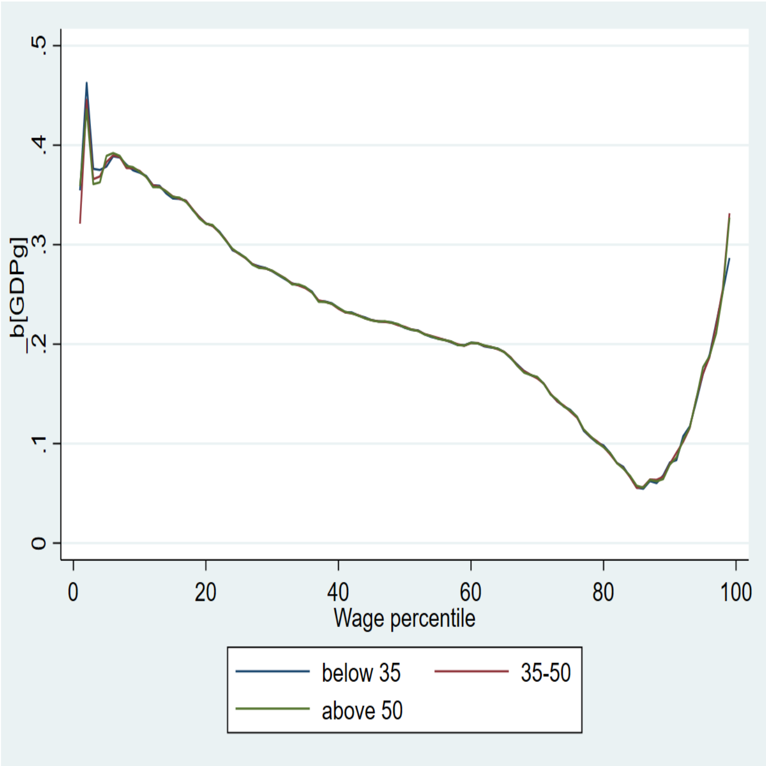

Figure 1: Worker betas for each percentile of wage. The Y-axis shows the coefficient obtained from a regression of the wage growth on aggregate GDP growth

3 Further details on the data set

The data offers many important insights into the structure of the Czech labor market. Figure 2 shows the histogram of the log average hourly wage distribution in the last data vintage used in this paper – 2020. The data on hours worked shows two main sources of variation. First, part-time agreements: of the 1.2 million contracts in the 2022 data, about 77% are full-time, while nearly 23% are part-time. A notable portion of part-time contracts (11%) has hours close to full-time (above 0.95 of full-time hours). Second, actual hours worked account for absences (paid or unpaid), overtime, and sickness. The dataset also includes contracts starting or ending within the year, but we extrapolate these as if the contract lasted the full year to better assess labor supply. Following figures illustrates several notable trends in the Czech labor market mentioned in the text. Figure 3 shows

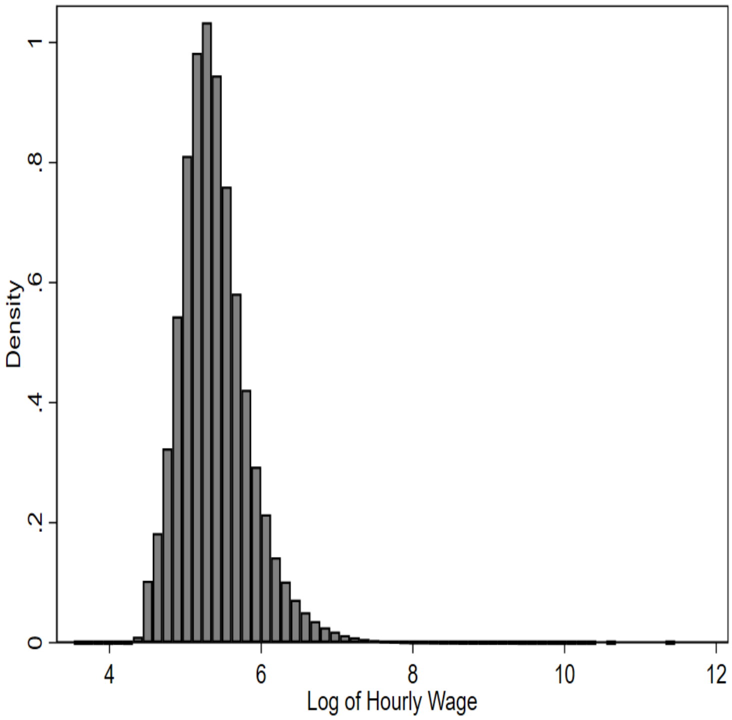

Figure 2: Log average hourly wage distribution in 2020

that the service sector has the highest female representation, with women making up more than half of its workforce. Thus, men dominate all other sectors, comprising 65% of the workforce in the industrial sector. The highest average wage is generally reported in the construction sector, closely followed by services and manufacturing. However, it is worth noting that reporting in the construction sector may be influenced by a potentially significant share of the shadow economy, especially for the less qualified labor force. The service sector, followed by construction, requires a relatively higher level of education.

Figure 4 illustrates the wage distribution in different sectors. The average hourly wage is slightly higher in the industrial sector than in the service sector. However, the wage distribution in industry is more uniform, with most workers earning around the wage median or slightly above. In contrast, the service sector has a higher share in the lowest and the highest wage percentiles. Considering the statistics in Figure 3 , this is related on the one hand to the high share of female workers in the lower wage percentiles, and on the other hand to the high average level of education in services compared to other sectors.

In Figure 5 we show that the older the workers are, the longer their working contracts tend to be. This demonstrates a significant characteristic of the Czech labor market:

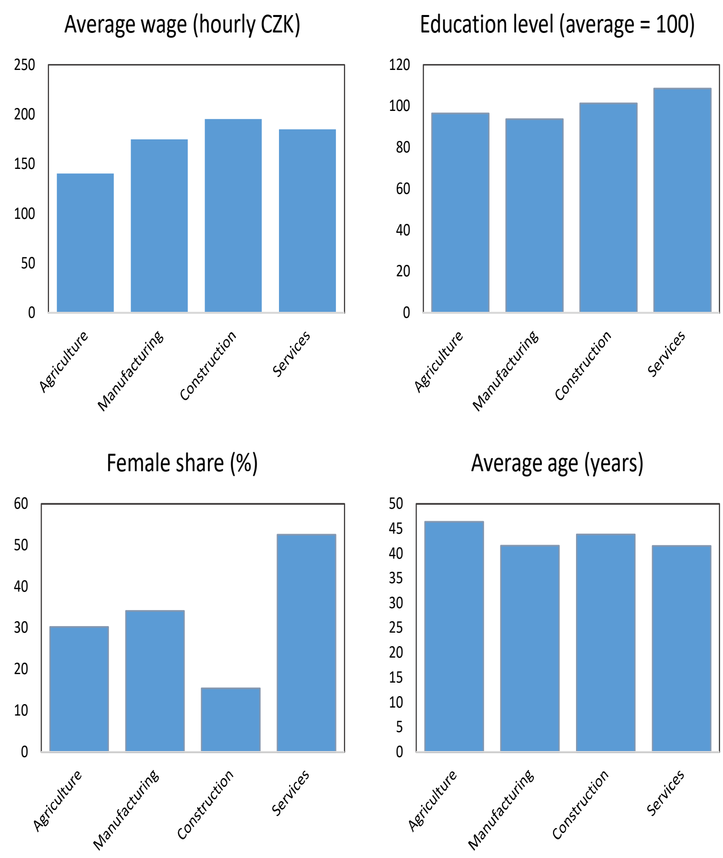

Figure 3: Characteristics of employees across different business sectors

workers are opting for stable, long-lasting working relationships. This trend is even more pronounced in the agriculture sector, particularly in the countryside where there are fewer job opportunities, and less pronounced in the service sector, which is typically found in larger urban agglomerations.

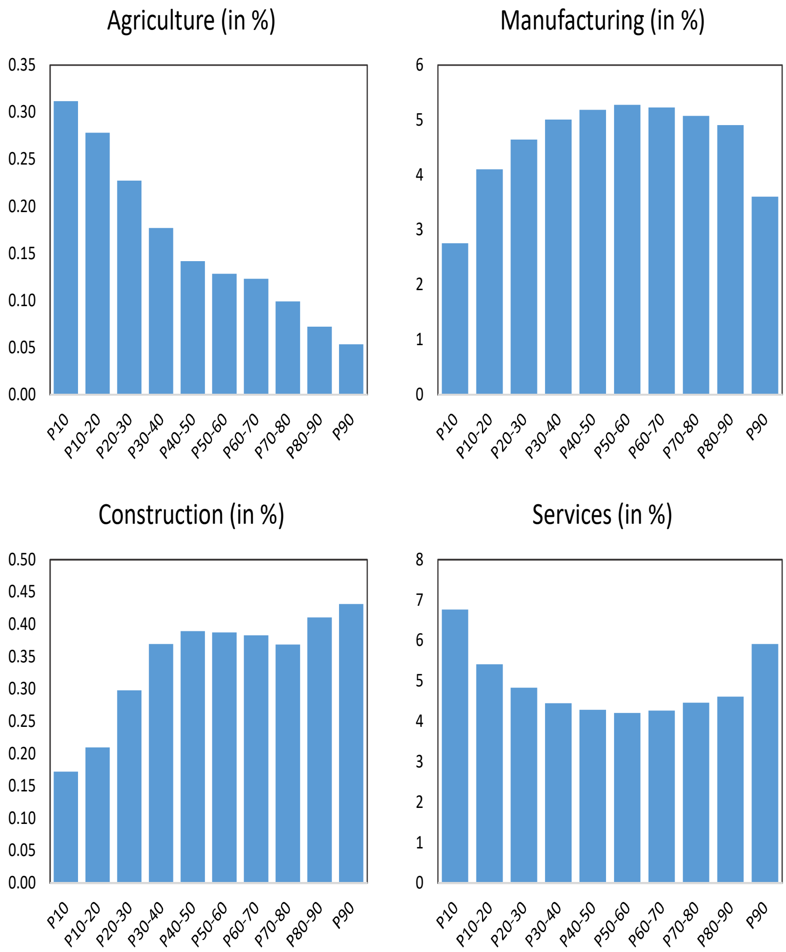

Figure 4: Characteristics of employees across sectors along the wage distribution. Note that the bars add up to 10 % across sectors

4 Estimation

The observation equation of the model is defined as:

$$Z_t = H \underbrace{\begin{pmatrix} Y_t \\ Y_{t-1} \\ Y_{t-2} \\ Y_{t-3} \end{pmatrix}}_{\beta_t} + \begin{pmatrix} E_t \\ 0 \\ 0 \\ 0 \end{pmatrix} \tag{1}$$

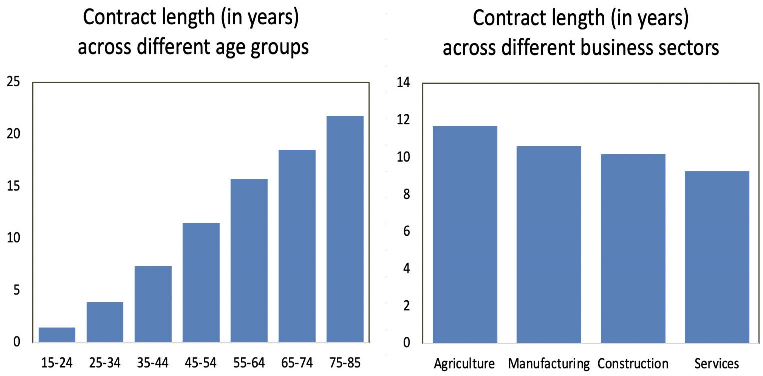

Figure 5: Contract length in years across different age groups and across sectors along the wage distribution

The transition equation is

$$\beta_t = \mu + F\beta_{t-1} + V_t \tag{2}$$

Note that the transition equation is the companion form of the VAR model described in the text:

$$Y_t = c + \sum_{p=1}^{P} Y_{t-p} B_p + v_t \tag{3}$$

where $v_t \tilde{} N(0, \Sigma)$.

The disturbances are normally distributed:

$$E_t \tilde{} N(0, R)$$
$$V_t \tilde{} N(0, Q)$$

As discussed above, R is a known parameter and $Q = diag\left(\Sigma, 0_{3N,3N}\right)$

4.1 Priors

1. Let b denote the coefficients of the VAR model given in equation 3 in vectorized form. We use a Minnesota type prior for b implemented using dummy observations (see Banbura *et al.* (2010)): $p(b) \tilde{} N(b_0, S_0)$. The parameter that controls the tightness of the prior is set to the typical value of 0.1.

2. The prior for Σ is inverse Wishart: $IW\left(\Sigma_0, t_0\right)$ where the scale matrix $\Sigma_0 = I_N$ and degrees of freedom $t_0 = N + 2$.

4.2 Gibbs algorithm

The Gibbs algorithm samples from the following conditional posterior distributions in each iteration:

1. $G(\hat{z}_t|b,\Sigma)$. Conditional on b,Σ, the model is a linear Gaussian state-space model. We use the simulation smoother of Durbin and Koopman (2002) to draw the state $\hat{z}_t$ from its conditional posterior distribution.

2. $G(b|\hat{z}_t,\Sigma)$. Conditional on $\hat{z}_t$ the model collapses to a Bayesian VAR. Given a normal prior for b, the conditional posterior is also normal: $N(M,V)$:

$$M = \left(S_0^{-1} + \Sigma^{-1} \otimes X_t' X_t\right)^{-1} \left(S_0^{-1} b_0 + \Sigma^{-1} \otimes X_t' X_t \hat{b}\right)$$

$$V = \left(S_0^{-1} + \Sigma^{-1} \otimes X_t' X_t\right)^{-1}$$

where $\hat{b}$ denotes the OLS estimates of the coefficients in vectorized form and X collects the regressors on the RHS of the equations in the VAR model 3.

3. $G(\Sigma|b,\hat{z}_t)$. The conditional posterior is inverse Wishart: $IW(\Sigma_1, t_1)$

$$\Sigma_1 = \Sigma_0 + v_t' v_t$$
$$t_1 = t_0 + T$$

We employ 21,000 iterations, with 1,000 discarded as burn-in. We save every fifth of the remaining draws for inference.
Figure 6 presents the inefficiency factors (averaged across the 100 estimated models for each wage percentile). These are significantly lower than 20 providing strong evidence for convergence of the algorithm.

5 FEVD

Figure 7 shows the contribution of the monetary policy shock to the variance of the forecast error of the main macroeconomic variables. The shock is significantly important in explaining the variation of all observed variables. The shock contributes more to the interest rate variation (around 7 percent) and the exchange rate variation (up to 12 percent) in the short run. The contribution to GDP and the price index peaks rather in the long run (2.5 years) at 5 percent.

Figure 8 shows the contribution of the monetary policy shock to the forecast error variance of wages and hours worked in each percentile of the distribution. It is noticeable that the monetary policy shock contributes more to wages and to hours worked at the right and left tails of the distribution. It explains up to 9 percent in the low income percentile and up to 7 percent in the top income percentile.

The contribution of the monetary policy shock to the variation in hours worked is even more profound. It explains more than one third of the variance at the right tail and about 10 percent at the left tail, particularly at early horizons of up to two years.

6 Robustness Checks

We carry out the following robustness checks

1. Sign restrictions: We use contemporaneous sign restrictions as an alternative identification scheme for the monetary policy shock. We assume that a contractionary monetary policy shock is associated with an increase in short-term interest rates, a decline in output and prices, a real exchange rate appreciation, and a rise in the unemployment rate. Figure 9 shows the estimated response of hours and wages. As in the benchmark case, wages decline substantially at the left tail of the distribution and wage inequality rises.

2. Model specification: We add the following variables to the benchmark model: (1) Euro-area GDP, (2) Euro-area CPI and (3) Oil prices. As shown in Figure 10 shows that the key results are unaffected. The contractionary monetary policy shock still has a disproportionately large effect on wages at the left tail of the wage distribution.

6.1 Unconventional Policy shock

The Czech central bank used the exchange rate as a policy instrument from November 2013 to April 2017. In this section we present some preliminary evidence on the impact of this shock. First we extend the estimation of the factors from the daily yield curve data to incorporate the unconventional shock. We do this by adding the change in the CZK/Euro exchange rate around policy meetings to the 4 Pribor future rates as an additional indicator. As before, we extract 2 principal components from these 5 series and rotate them in to 2 factors, restricting the second factor not to have an effect on the 3

month rate.
Figure 13 displays the estimated loadings on the two factors. It is clear that the path factor has the largest loading on the change in the exchange rate (ER). We therefore interpret the path factor as a proxy for unconventional policy that captures the exchange rate policy used over the period 2013 to 2017. This is clear from figure 14 which shows that the path factor tracks the movements in the exchange rate (around policy meetings) closely and captures the large change observed at the start of the policy of using the exchange rate as a policy instrument. We have also tried to implement the method of Swanson (2021) to estimate three factors with an explicit factor for unconventional policy that is identified by minimising its variance in the pre-November 2013 period. However, the factor estimated using this procedure does not load strongly on the exchange rate and fails to explain the movement in the exchange rate in November 2013. We therefore use the simpler approach involving two factors in this analysis.
We re-estimate the VAR model including the target and the path factors as the first two endogenous variables. Figure 15 shows the response of aggregate variables to the target and path factors. First, the response to the target factor is similar to the benchmark case shown in Figure 3 in the paper. The shock increase short-rate and is associated with a decline in real activity, prices, and a exchange rate appreciation. The shock to the path factor (our proxy for unconventional policy) has similar effects. However, the impact of this shock on real activity and prices appears to peak at a longer horizon than the conventional policy shock.
Figure 16 presents the response of the distribution of wages and hours to the two shocks. These are estimated using the mixed frequency VAR where we include both the target and path factors as the first two endogenous variables and add the percentiles one by one (as in the benchmark). The estimated impact of the conventional shock follows the pattern discussed in the benchmark. Wages are affected adversely at the left tail and the decline in hours is concentrated at the tails. The median response of wages to the unconventional shock follows a similar pattern at the 20 year horizon. However, the effect of the shock is smaller in magnitude and less precise. Similarly, the response of hours to the unconventional shock is erratic.

6.2 Range of estimates

We estimate the mixed frequency VAR 200 times to obtain the response of wage and hour percentiles. In Figure 17 we show the range of the posterior median response of the macro variables across these 200 estimations. Broadly speaking, the pattern of the responses supports the conclusions reached in the main text regarding the impact of the monetary policy shock. The contractionary shock reduces output and prices at the medium horizon and leads to an appreciation and an increase in the unemployment rate. As these IRFs are estimated using the mixed frequency VAR (rather than a standard BVAR with just 6 macro variables) and the sample is short there is some variation in the IRFs across the specifications. However, the systematic impact of the policy shock is clear and broadly matches the aggregate results shown in Figure 3 in the paper (that come from a BVAR with quarterly data only).

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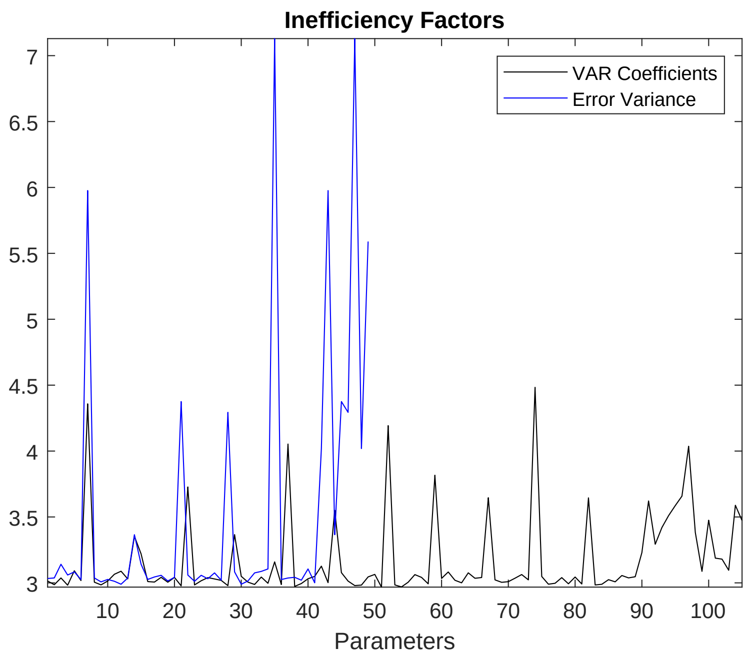


Figure 6: Inefficiency factors

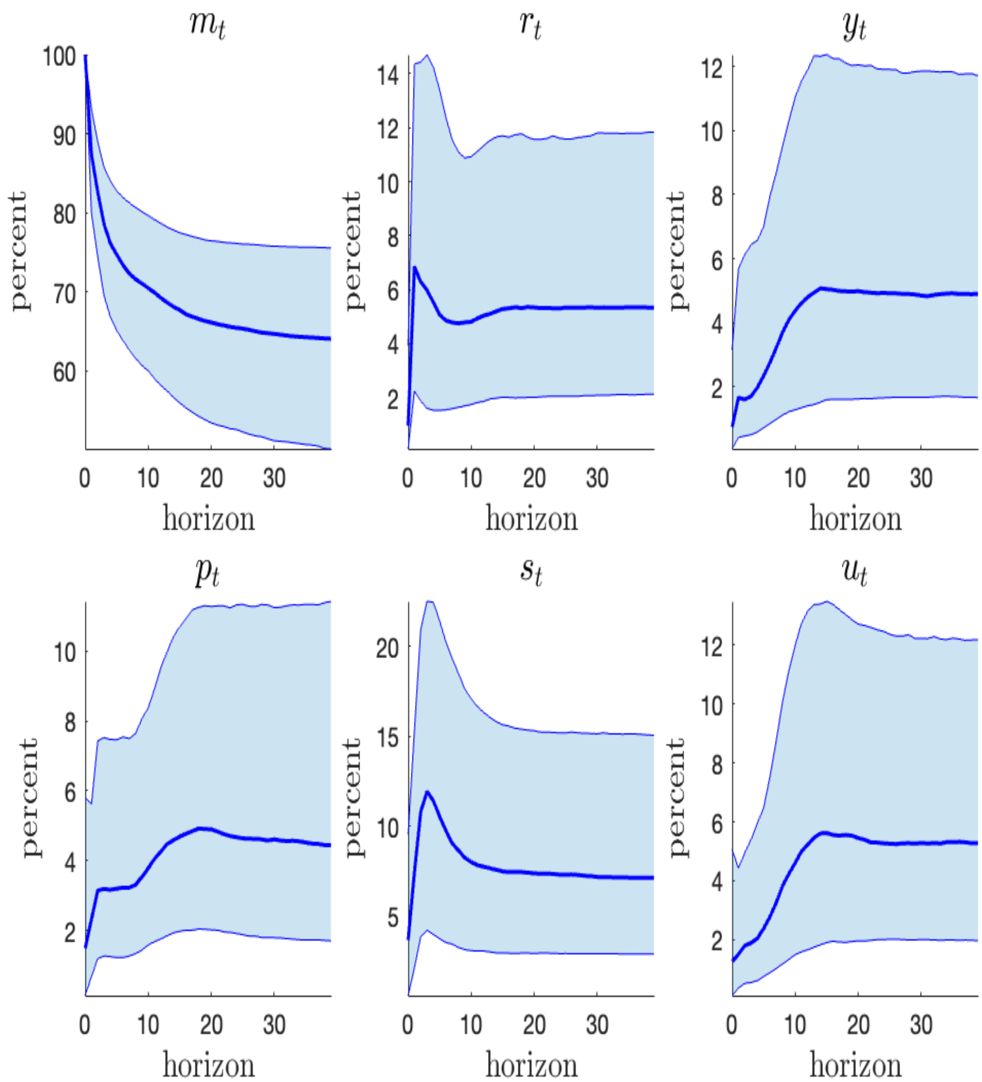


Figure 7: Contribution of the the monetary policy shock to the Forecast error variance of the main macroeconomic variables

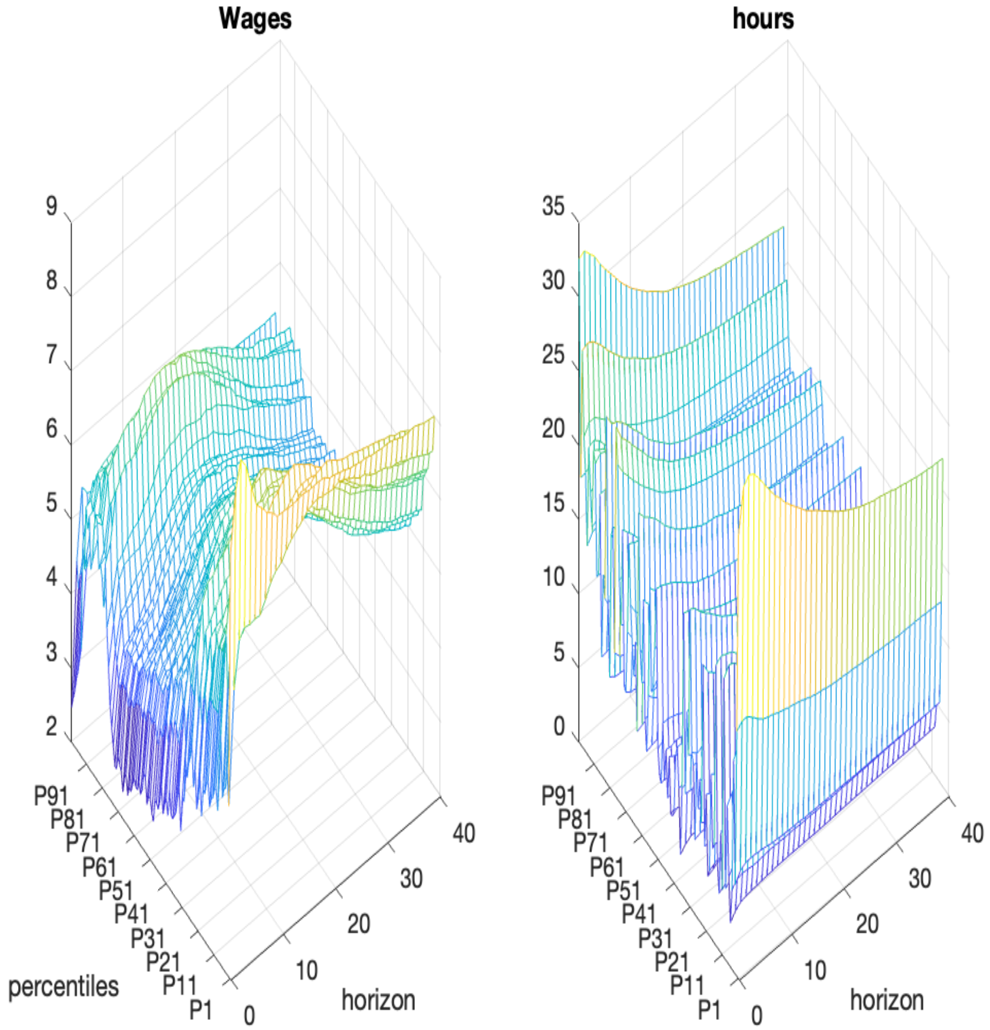


Figure 8: Contribution of the the monetary policy shock to the Forecast error variance of hours and wages at different horizons

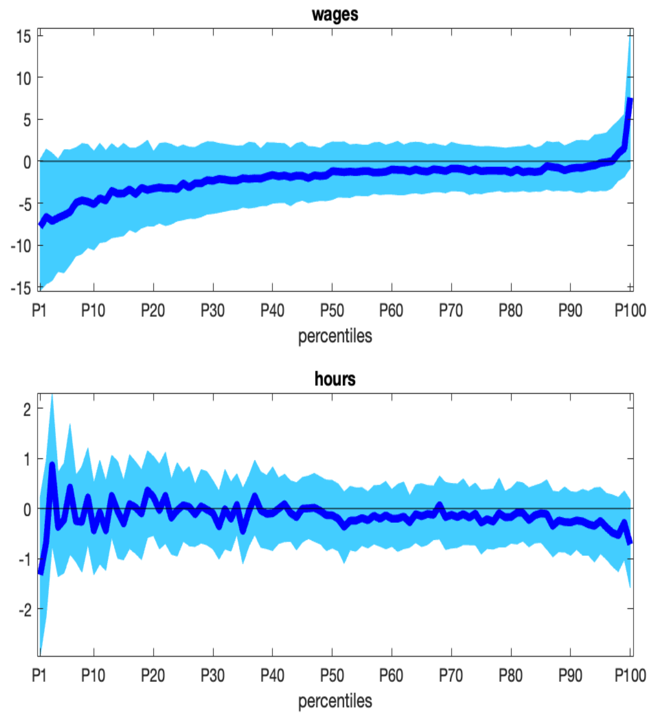


Figure 9: Identification via sign restrictions

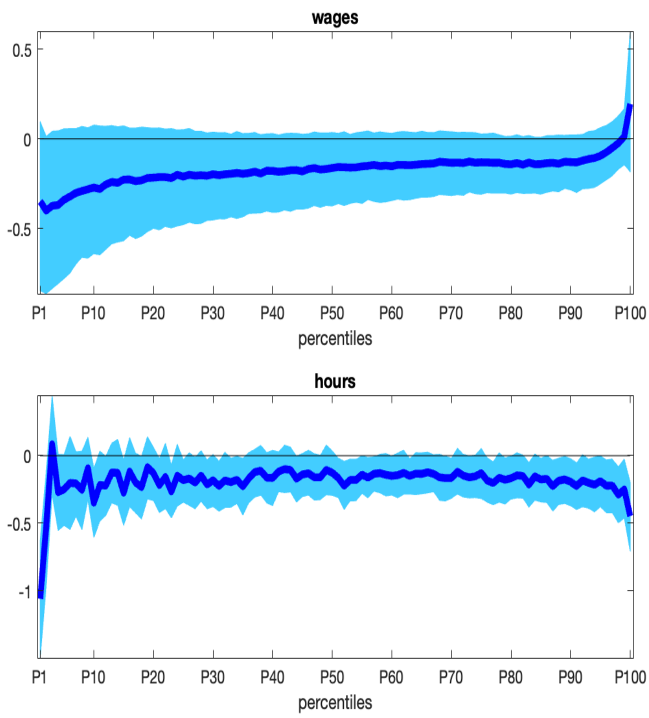


Figure 10: Using additional exogenous variables

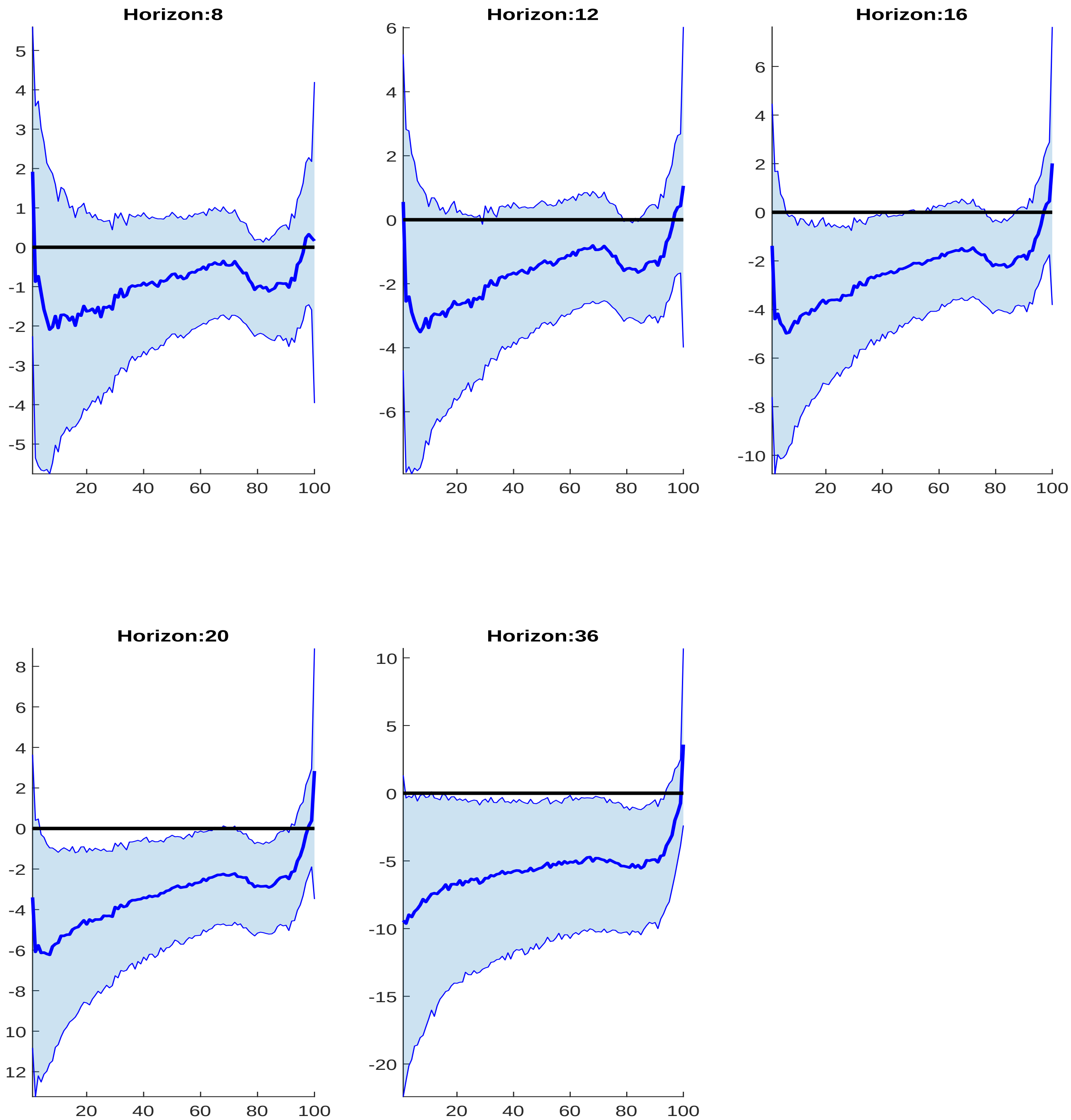


Figure 11: Cumulated response of wages at different horizons

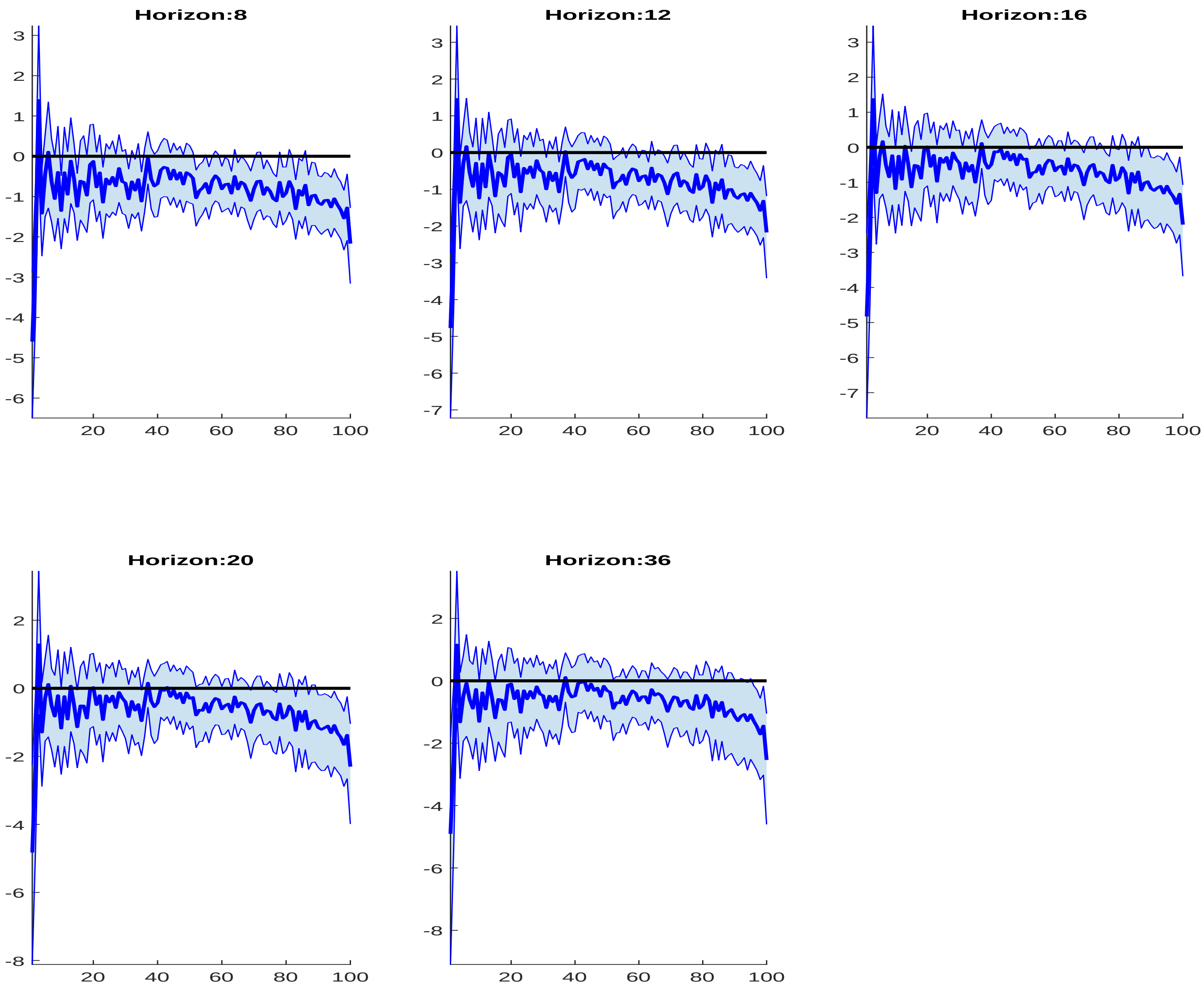


Figure 12: Cumulated response of hours at different horizons

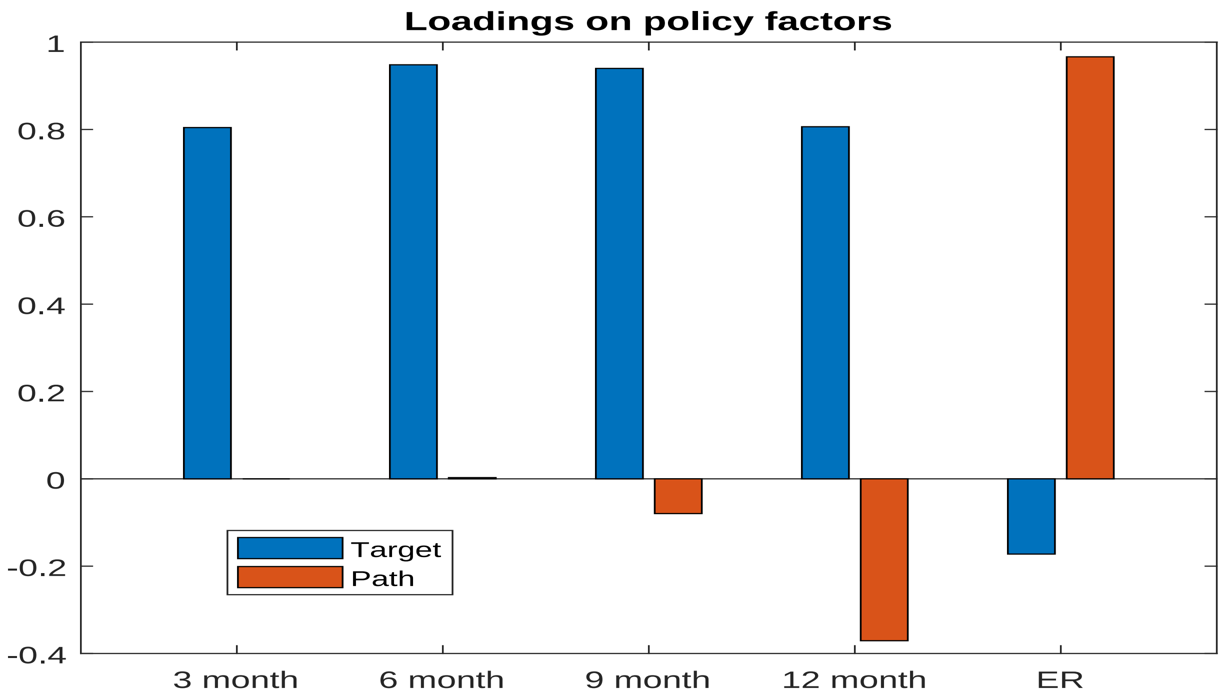


Figure 13: Factor loadings on the target and path factors. The X-axis shows the 4 Pribor future rates and the change in the exchange rate around policy meetings

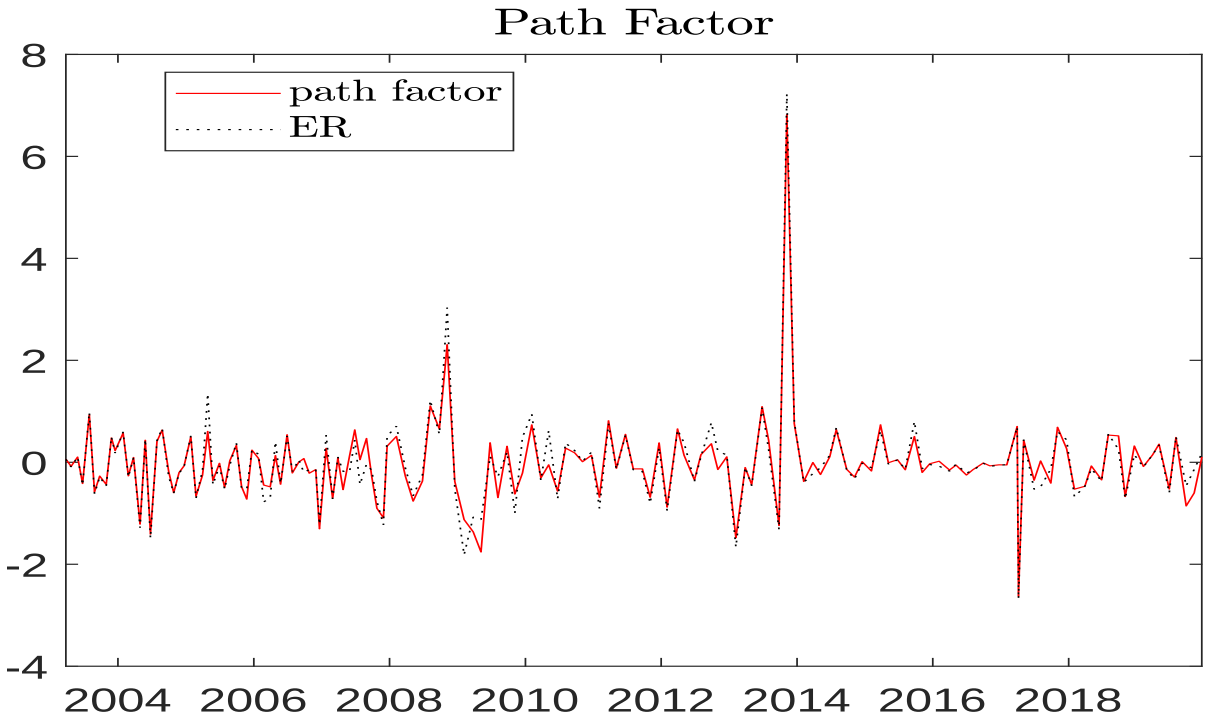


Figure 14: The path factor and the change in the exchange rate around policy meetings

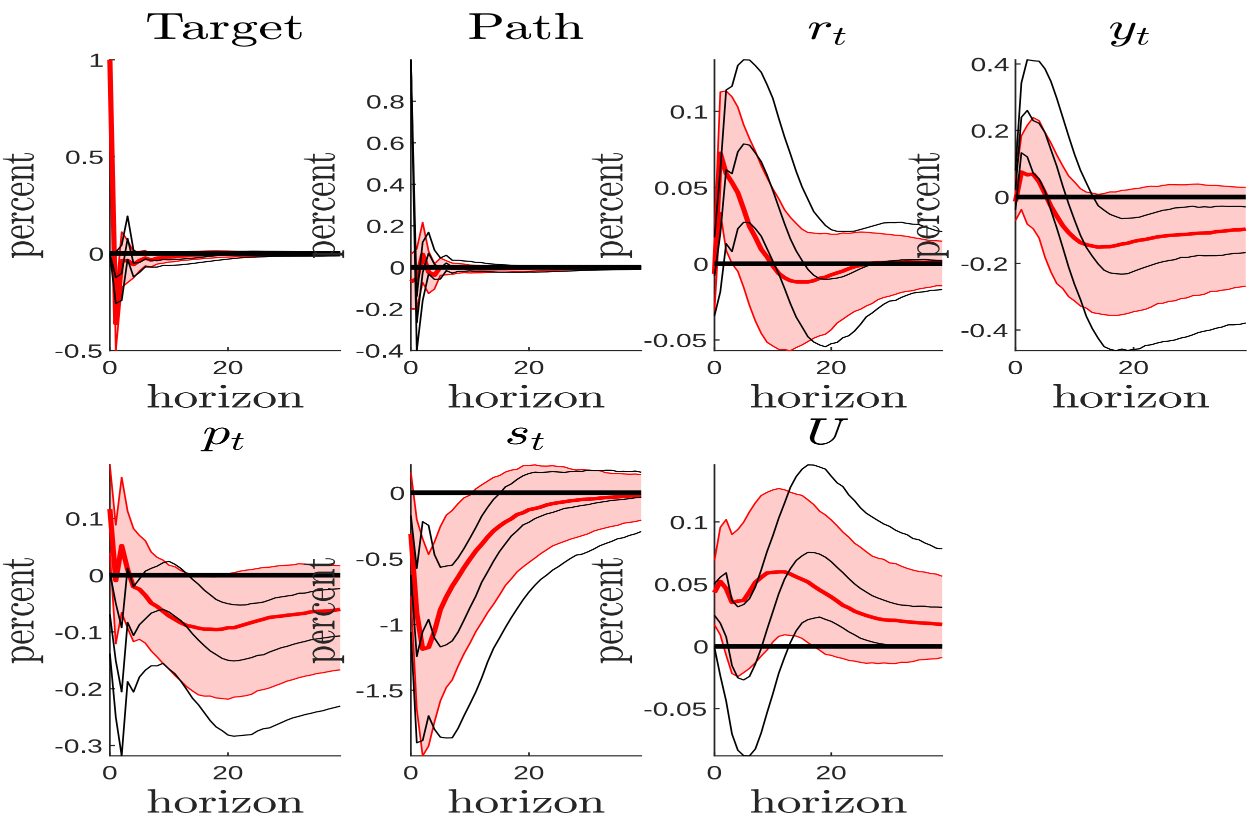
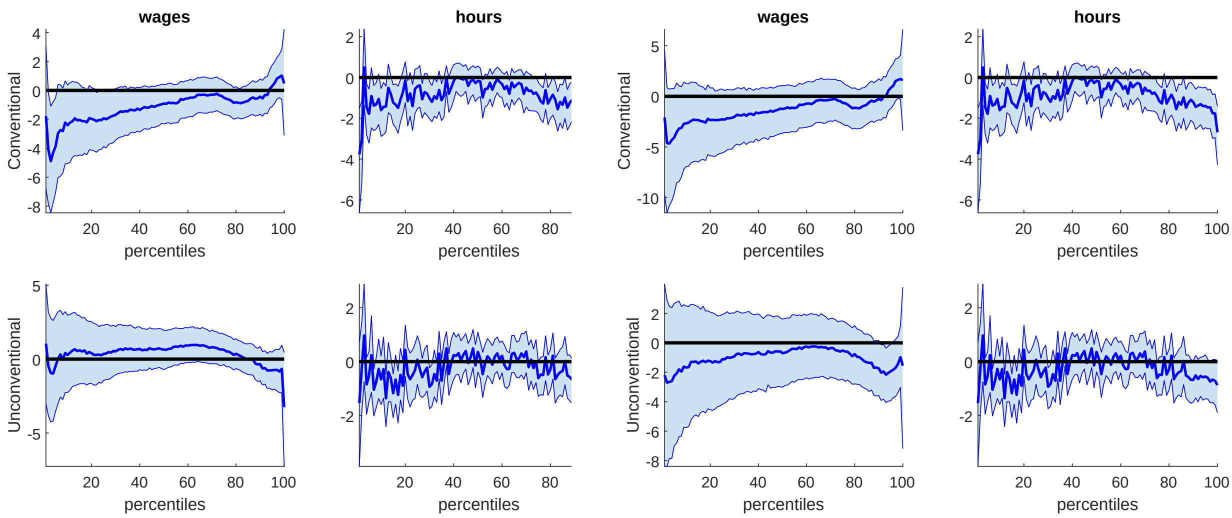


Figure 15: IRF to shocks to target (red) and path factors(black)



(a) 2 year horizon

(b) 5 year horizon

Figure 16: Impulse response of wages and hours to contractionary conventional (target) and unconventional (path) policy shocks

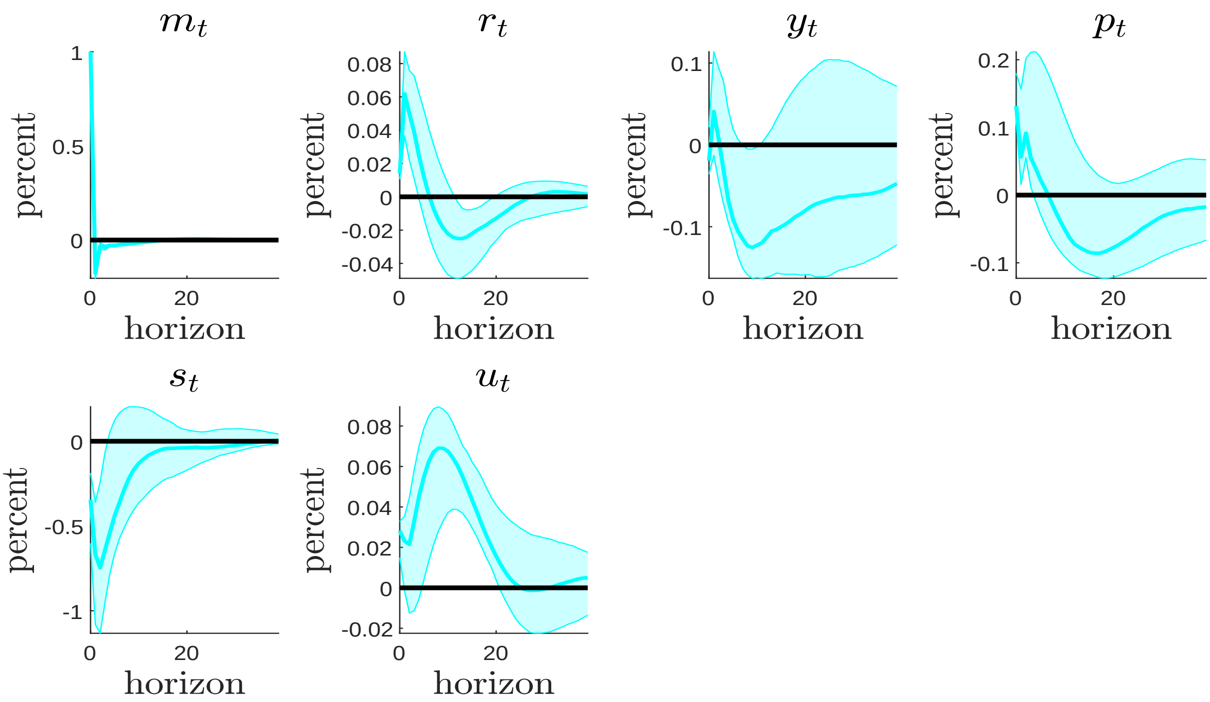


Figure 17: The range of responses of macroeconomic variables from 200 mixed frequency VAR models. The solid line shows the median and the shaded area shows the 90% error band