Immigration and the Macroeconomy: a VAR Perspective. VERY PRELIMINARY*

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Abstract

We propose a new VAR identification scheme that enables us to disentangle immigrations shocks from alternative labor market shocks. Identification is achieved by imposing sign restrictions on Norwegian data over the period 1985-2015. The use of a quarterly series for job related immigration is crucial to achieve identification. Notably, immigration is an endogenous variable in the model and can respond to the state of the economy. We find that domestic labor supply shocks and immigration shocks are well identified and are the dominant drivers of immigration dynamics. An exogenous immigration shock lowers unemployment (even among native workers), has a positive effect on prices and on public finances in the medium run and has little impact on house prices and productivity.

Keywords: labor supply shocks, wage mark-up shocks, identification, VAR, labor force participation

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1 Introduction

During the past decades immigration flows have increased significantly in most developed economies. While a large literature has studied in detail the effects of immigration flows on employment and wages using mostly disaggregate data, the impact of immigration on standard macroeconomic variables has not been investigated systematically in a unified framework. This paper aims at filling this gap.

Our goal is to include a net immigration variable into a Structural Vector Autoregression (SVAR), which is the most used empirical model for macroeconomic analysis. Notably, in our set-up immigration is not driven only by an immigration shock but responds also to a series of macroeconomic disturbances that drive the business cycle. Following the seminal contributions by Canova and De Nicolo' (2002), Faust (1998), Fry and Pagan (2011), Peersman (2005) and Uhlig (2005), our identification strategy is based on imposing a limited number of sign restrictions on a few selected variables to disentangle immigration shocks from alternative sources of business cycle fluctuations. Our main contribution is to investigate the impact of immigration shocks on a number of variables that we leave unrestricted in the estimation such as unemployment, a measure of the state of public finances, house prices, prices and exchange rates and a measure of productivity. Furthermore, we are able to quantify the relative importance of immigration shocks for macroeconomic dynamics and evaluate how important is the endogenous response of immigration to the other shocks identified in our system.

We conduct our analysis using Norwegian data as Norway is one of the few countries for which a quarterly net immigration series is available from the early 80s. This series, plotted in Figure 1, is provided by Statistics Norway and has been used by Gjelsvik, Nymoen and Sparrman (2015) to analyze the impact of immigration on the wage formation system. The series includes the net flow of workers immigrating to Norway from EU/EFTA countries, North America, Australia, New Zealand and Eastern Europe in percent of the population aged 15-74 The case of Norway is particularly interesting as immigration was a marginal phenomenon in the 90s **(ADD)** whereas it became massive in the aftermath of the EU extension to Eastern European countries. In addition, Norway is an interesting

laboratory to disentangle the immigration shock from two alternative labor market shocks. The first is a domestic labor supply shock that turns out to be particularly important, as participation is cyclical and volatile in Norway. The second is a wage bargaining shock that may have a structural interpretation in Norway given the centralized nature of the wage negotiation system where the wage norm is determined in the sector exposed by international competition (wage leader) and is then used to determine wage increases in the other sectors of the economy (wage followers).

Our key assumption to identify the three labor market shocks (and the immigration shock in particular) is that they imply a negative co-movement between output and real wages. This assumption finds theoretical support in theoretical models (cf. Galí, Smets and Wouters, 2011, and Foroni, Furlanetto and Lepetit, 2015) and empirical support on studies investigating the impact of immigration on micro-data for Norway (cf. Bratsberg and Raaum, 2012, and Bratsberg, Raaum, Røed, and Schøne, 2014). To identify the wage bargaining shock we use data on the participation rate, following Foroni, Furlanetto and Lepetit (2016), whereas to disentangle domestic labor supply shocks from immigration shocks we rely on a restriction on the ratio of immigrants over participants that is naturally pro-cyclical in response to an expansionary immigration shock and countercyclical in response to an expansionary domestic labor supply shock. In addition to the three shocks originating in the labor market, our baseline set-up includes a business cycle shock that move output and real wages in the same direction and that is supposed to capture shocks that do not originate in the labor market (like demand shocks and productivity shocks).

This set-up allows us to quantify the importance of immigration shocks for business cycle fluctuations and to discuss the endogenous response of immigration to alternative shocks. Notably, we estimate several versions of our baseline model introducing one alternative unrestricted variable in each experiment. This strategy enables us to investigate the macroeconomic effects of immigration shocks on variables like unemployment, public finances, house prices, prices, exchange rates and productivity. The analysis of the drivers of immigration and the effects of immigration shocks on macroeconomic variables constitutes the key contribution of this paper.

In terms of impulse responses, several results emerge from our analysis. First, an exogenous increase in immigration lowers the unemployment rate and even the unemployment rate for natives. Second, a positive immigration shock increases public spending in the medium run but the response of fiscal revenues follows the same path and the net effect on public finances is even positive. Third, the immigration shock has no effect on house prices that are driven mainly by domestic labor supply factors that generate a negative conditional correlation between house prices and immigration. Thus, if anything immigration has a mitigating effect on the housing boom that Norway, as many other countries, has experienced in recent years. Fourth, an expansionary immigration shock has no effect on domestic prices but increases CPI in the medium run through an exchange rate depreciation. Fifth, productivity does not respond to immigration shocks.

In terms of variance decompositions, our main result is that immigration shocks are non-negligible (although not major) drivers of the Norwegian business cycle, explaining on average around 15-20 percent of output fluctuations, while immigration itself is driven mainly by domestic labor supply shocks (together of course with immigration shocks). Immigration responds very little to the state of the business cycle in Norway whereas it responds to factors that are specific to the Norwegian labor market: when participation from natives is low (i.e. in response to a negative domestic labor supply shocks), immigration responds significantly.

The literature on immigration in the context of standard macroeconomic models is surprisingly scant, perhaps due to the absence of reliable quarterly series for net immigration over a sufficiently long period for many countries. As far as we know, Mandelman and Zlate (2012) is the only recently published paper presenting a fully specified dynamic stochastic general equilibrium (DSGE) model with immigration. In that paper, however, the focus in on remittances for emerging market economies. In the VAR literature, Kiguchi and Mountford (2013) provide an analysis on US annual data using the penalty function approach and identifying two shocks. They find that a shock to the working population (that could be due to immigration but also to domestic factors) lead to a temporary reduction in GDP and consumption per capita. D'Albis, Boubtane and

Coulibaly (2015) use monthly data for France over the sample period 1994-2008 in a VAR identified with a recursive scheme. They find that immigration responds significantly to France's macroeconomic perspectives and at the same time immigration itself increases GDP per capita, particularly in the case of family immigration. The closest papers to our analysis are a series of recent and interesting analysis on New Zealand data. Mc Donald (2013) studies the effect of an immigration shock on house prices in a VAR identified with a recursive scheme. He finds that an immigration shock has a strong positive effect on house prices and construction activity, thus boosting aggregate demand even more than aggregate supply. Armstrong and McDonald (2016) extend the previous set-up to include a second immigration shock associated to fluctuations in Australian unemployment. They find that higher net immigration due to a higher Australian unemployment rate leads to a higher unemployment rate in New Zealand, whereas higher net immigration for other reasons reduces unemployment in New Zealand. Our contribution to this previous literature is the separate identification of an immigration shock from alternative shocks originating in the labor market and the analysis in the same context of the macroeconomic effects of immigration on five variables that have been considered only in isolation.

While we could find only a few DSGE and VAR studies on the macroeconomic effects of immigration, the literature using more disaggregate data is extremely rich (for a survey cf. Kerr and Kerr, 2011). Selected issues of interest are the assimilation of immigrants into the host-country labor market in terms of wages and employment, the identification of displacement effects on native workers in terms of wages and employment, the impact of immigration on public finances (cf. Borjas, 1999, Preston, 2014, Storesletten, 2000, among many others), on house prices (cf. Saiz, 2003, Ottaviano and Peri, 2006, and Sá, 2014, among others), on prices and the composition of demand (cf. Lach, 2007, Cortes, 2008, and Frattini, 2008, among others) and on productivity (cf. Peri, 2011). While we impose as an identification assumption that an immigration boom has a dampening effect on wages (in keeping with the micro-evidence for Norway), our set-up can shed light on all the macroeconomic issues listed above in the context of an aggregate time-series approach that is complementary to analysis based on more disaggregate data and with a

microeconomic focus.

The paper is structured as follows. Section 2 presents the VAR model and describes the identification strategy. In Section 3 we present our results for the baseline case with unemployment introduced as an unrestricted variable in the system. Section 4 presents several extensions to discuss the effects of immigration shocks on public finances, house prices, prices and exchange rates and productivity. Finally, Section 5 concludes.

2 The VAR model and the identification strategy

We start from the standard reduced-form VAR representation:

$$y_t = C_B + \sum_{i=1}^{P} B_i y_{t-i} + u_t, \tag{1}$$

where y_t is a $N \times 1$ vector containing our N endogenous variables, C_B is a $N \times 1$ vector of constants, B_i for $i = 1, ..., P$ are $N \times N$ parameter matrices, with P the maximum number of lags we include in the model (5 in our specific case), and u_t is the $N \times 1$ one-step ahead prediction error with $u_t \sim N(0, \Sigma)$, where Σ is the $N \times N$ variance-covariance matrix.

Given the large number of parameters to be estimated, we use Bayesian methods. Moreover, the models are specified and estimated with variables in levels. This is a nice feature of the Bayesian approach, which can be applied regardless of the presence of nonstationarity (cf. Sims, Stock, and Watson, 1990, for more details on this point). We specify diffuse priors so that the information in the likelihood is dominant. These priors lead to a Normal-Wishart posterior with mean and variance parameters corresponding to OLS estimates. To obtain identification via sign restrictions, we follow the procedure described in Rubio-Ramirez, Waggoner and Zha (2010). Additional details about the estimation procedure and the identification are provided in Appendix A.

In order to map the economically meaningful structural shocks from the reduced form estimated shocks, we need to impose restrictions on the variance covariance matrix we estimated. In detail, the prediction error u_t can be written as a linear combination of

structural innovations ϵ_t

$$u_t = A\epsilon_t$$

with $\epsilon_t \sim N(0, I_N)$, where I_N is an $(N \times N)$ identity matrix and where A is a non-singular parameter matrix. The variance-covariance matrix has thus the following structure $\Sigma = AA'$. Our goal is to identify A from the symmetric matrix Σ, and to do that we need to impose restrictions. Those restrictions are imposed only on impact, in keeping with the recommendation of Canova and Paustian (2011), and are summarized in Table 1:

	Business Cycle	Wage bargaining	Labor Supply	Immigration
GDP	+	+	+	+
Real Wages	+	-	-	-
Participation Rate	+	-	+	+
Immigrants/Participants	NA	NA	-	+
Unemployment Rate	NA	NA	NA	NA

Our baseline set-up includes four identified shocks: one general business cycle shock and three shocks originating in the labor markets.

The business cycle shock is defined as a shock that moves output, real wages and the participation rate in the same direction. Its interpretation as a generic business cycle shock relies on the fact that both real wages and the participation rate are pro-cyclical in Norway (and more pro-cyclical than in other countries like the US). It is supposed to capture shocks to labor demand like productivity shocks and demand shocks. Therefore, at this stage the business cycle mixes demand and supply shocks, as for computational convenience we do not use data on prices to disentangle the two components.[1]

[1] In Appendix C we further disentangle the business cycle shock into two components: a productivity shock that moves output and prices in opposite directions and a domestic shock that moves output and prices in the same direction. Since all our main results are confirmed in that extended set-up for which the estimation is significantly more computationally intensive, we prefer to rely on a baseline model that is much faster to estimate. Furthermore, we are interested in studying the response of prices to an immigration shock in a set-up where the price varaible is left unrestricted (cf. Section 4).

The three remaining shocks originate in the labor markets. The first is a wage bargaining shock defined as a shock that generate a countercyclical dynamics in real wages and in the participation rate. These restrictions find strong theoretical support in a New Keynesian model with search and matching frictions and endogenous labor force participation, as described in Foroni, Furlanetto and Lepetit (2016), but also in the model of unemployment proposed by Galí, Smets and Wouters (2011). Notice that, as already mentioned in the Introduction, Norway is the ideal laboratory to study wage bargaining shocks given its highly centralized system of wage negotiation. In addition, we consider two labor supply shocks, one domestic and one driven by exogenous immigration flows. Both shocks are supposed to increase the participation rate in keeping with the fact that most immigrants included in our series come to Norway and start working immediately. To separately identify those two shocks, we include the immigration rate as a separate variable in the system and we impose a restriction on the ratio of the immigration rate over the participation rate. Somewhat intuitively, we assume that on impact (and only on impact) an expansionary domestic labor supply shock lowers the ratio of immigrants over participants whereas an exogenous increase in immigration increases the same ratio. Note that we are just assuming that the relative impact of an immigration shock is larger over the pool of immigrants than on the pool of participants, thus ruling out extreme shifts in the participation pattern of native citizens. Along the same lines, the response of immigration to an expansionary domestic labor supply shock is allowed to be positive or negative. If positive, however, we impose that the immigration response has to be lower than the participation response. The separate identification of domestic labor supply shocks and immigration shocks, arguably the most important drivers of the participation rate, is a key contribution of this paper.

In our baseline estimation exercise we include five series: GDP for Mainland Norway (thus excluding petroleum activities and ocean transport activities, as it is standard in all macroeconomic analysis for Norway), the series for real wages ADD, the participation rate ADD, the immigration rate and the unemployment rate DISCUSS. A detailed description of the dataset is presented in Appendix B. The sample period is SAY.

We include a fifth shock to match the number of shocks with the number of observables. This is a residual that does not satisfy the restrictions imposed on the other five identified shocks. Although this shock is supposed to capture only the residual dynamics in the system, it has an economic interpretation: it is a shock that moves output and participation (and wages) in different directions. In this way, the system is fully identified.

3 Results

In this Section we present the results for our estimated baseline VAR model. In Figures 2 and 3 we plot impulse responses to immigration and domestic labor supply, respectively. An expansionary immigration shock has persistent effects on GDP, real wages, the participation rate and the immigration rate, despite being all these variables restricted only on the impact response. While the expansionary effect on GDP is sizeable, the maximum effect is achieved well before the peak in the immigration response. Notably, unemployment declines on impact and more so after few quarters. This partly reflects the mechanical response due to an increase in participation but the size of the response is nonetheless remarkable. An expansionary labor supply shock delivers similar (but more persistent) dynamics with the important exception of the immigration rate that declines substantially in response to the shock. The different response of the immigration rate in response to the two shocks highlights how our identification scheme is successful at disentangling those two labor market shocks. The immigration rate is very responsive to the domestic labor supply shock but substantially less responsive to the business cycle shock and with the unexpected sign (cf. Figure 4).[2] The wage bargaining shock is set apart from the domestic labor supply shock on the basis of the participation response which is negative on impact and essentially flat afterwards (cf. Figure 5). A decline in the bargaining power of workers lowers unemployment in keeping with the predictions of standard New Keynesian models.

In Figure 6 we plot the variance decomposition across different horizons as derived

[2] This countercyclical response of immigration disappears when we disentangle the business cycle shock into a demand and a productivity component (cf. Appendix C).

from our model. The immigration rate is driven mainly by the immigration shock and by the domestic labor supply shock while the participation rate is driven also by the business cycle shock that explain on average 40 percent of its fluctuations. The main result that emerges from our analysis is that domestic labor supply shocks are important drivers of the Norwegian business cycle and also the main drivers of the immigration rate. A key corollary of this result is that the immigration rate features an important endogenous component that, however, responds much more to the labor supply factors than to the state of the economy (as captured by the business cycle shock). In an economy with very low unemployment rate, immigration surges when domestic labor supply factors have an adverse impact on participation. What are those labor supply factors? DEMOGRAPHIC, DISABILITY, SCHOOLING Note that an important role for labor supply factors in economic fluctuations is consistent with previous VAR evidence on US data as shown in Shapiro and Watson (1988), Chang and Schorfheide (2003) and Foroni, Furlanetto and Lepetit (2015).

In our baseline model we impose restrictions only on impact. This assumption may be problematic in the case of variables that exhibit a high degree of stickiness, as it may be the case for our measure of wages. Therefore, we check whether our main results are confirmed in a version of the model where all the restrictions on wages are imposed at horizon four (and only at horizon four). In Figure 7 (panel A) we plot the response of unemployment to an immigration shock, the response of the immigration rate to a domestic labor supply shock and the variance decomposition of the immigration rate. The results emerging from the baseline model are broadly confirmed in this alternative set-up.

A decline in unemployment in response to an exogenous increase in immigration seems to be in contrast with important displacement effects on natives. Nevertheless, it is interesting to re-estimate our model using a measure of unemployment for native Norwegians that is available since DATE rather the total unemployment rate. Notwithstanding the difference in the sample period, we remark that the decline in unemployment for natives is almost identical to the decline in total unemployment in our baseline model. Notably,

in this case the unemployment response to a domestic labor supply shock is basically nil, thus indicating that fluctuations in unemployment driven by domestic labor supply shocks are mainly driven by non-natives. In this set-up unemployment for natives is driven essentially only by wage bargaining shocks (that are related to fluctuations in unemployment benefits, as shown in Foroni, Furlanetto and Lepetit, 2015) and by immigration shocks. Once again, we reiterate that our immigration variable capture mainly job-related immigration and thus our results should not be extended to the impact of an increase in immigration driven by a flow of refugees. Nevertheless, it is interesting to see how positive are the spillovers of an immigration wave on unemployment for natives.

4 The impact of immigration on public finances, house prices, prices, exchange rates and productivity

In the previous section we have discussed employment immigrant assimilation and employment displacement effects through the lenses of our macroeconomic model. In this section we offer a macro-perspective on some topics that have emerged in the more recent literature on immigration and that have so far been analyzed only in the context of microeconomic studies. In particular, we investigate the link between immigration and public finances, house prices, prices and exchange rates, and productivity. In each experiment we include a different unrestricted variable as last variable in the system at the place of unemployment. The general results emphasized in the previous section are confirmed in these alternative experiments. Therefore, the goal of the section is to discuss the response of the variables that are left unrestricted in the system.

Immigration and public finances. The burden that immigrants may place on public finances is often one of the popular arguments used to oppose to immigration. Social security programs in host countries (and in Norway in particular) are more generous than in immigrants' originating countries. Borjas (1999) discusses the "welfare magnet effects" that may attract a large pool of immigrants to countries with generous welfare systems. On the other hand immigrants may also be net contributors to public finances, especially

if young and highly educated. Storesletten (2000) finds that a reform of immigration policies alone could resolve the fiscal problems associated with the aging of the baby boom generation. In particular, he investigates feasible policies in the context of a calibrated general equilibrium overlapping generations model and suggests the admission to the US of 1.6 million 40-44 year-old high skilled immigrants annually.

We can investigate the impact of an immigration shock on public finances by including a measure of net fiscal revenues as an unrestricted variable in our system. In Figure NUM we plot the response of public finances to an exogenous increase in immigration. We remark that the response of public finances in hardly significant and if anything, on the positive side. Notice, however, that when we consider a measure of public spending in isolation, we see that an exogenous increase in immigration leads to an increase in public spending in the medium run. The two impulse responses can be reconciled only with a positive effect on tax revenues in the medium run. Thus, our result confirms previous findings emerging from the microeconomic literature: the net fiscal impact of an exogenous increase immigration is relatively small but the effects on both public spending and tax revenues are not negligible, possibly in keeping with the effects discussed in Borjas (1999) and Storesletten (2000). Results are different in the case of an increase in immigration driven endogenously by a negative domestic labor supply shock: in this case the shock generate a negative conditional correlation between immigration and the state of public finances. In this case, however, it is reasonable to think that the worsening in public finances is driven by the decline in participation from natives and immigration may even mitigate the negative consequences of the shock.

Immigration and house prices. Immigration booms are often associated to housing booms. McDonald (2013) finds that net migration changes imply large positive effects on house prices in a VAR identified with a recursive structure on New Zealand data. Other papers have shown that immigration has a positive impact on *average* house prices using disaggregate data from metropolitan area (cf. Saiz, 2003, Ottaviano and Peri, 2006).[3] Our

[3]Notice that recent research has highlighted a negative impact of immigration on house prices *within* metropolitan areas in the US and in the UK due to the mobility response of the native population (cf. Saiz and Wachter, 2011, and Sá, 2014).

VAR is the ideal laboratory to analyze the link between immigration and house prices at the *aggregate* level by introducing house prices as an unrestricted variable in the model.

As we can see in Figure NUM, according to our model immigration shocks have no impact on house prices that are instead driven mainly by domestic labor supply shocks. Those shocks generate a negative conditional correlation between house prices and immigration but, as in the case of public finance, it is conceivable that the surge in immigration may mitigate the decline in house prices in response to a negative domestic labor supply shock. House prices respond strongly to the business cycle shock, and to some extent to domestic labor supply shocks whereas immigration shocks are almost irrelevant for house price dynamics, as it can be seen in the variance decomposition prsented in Figure NUM. More generally, we can conclude that immigration does not seem to play a big role in driving the recent housing boom in Norway. One possible explanation relates to the fact a large share of immigrants is composed by Polish and Lithuanian workers active in the construction sector. While many of these workers are unlikely to buy a house (at least in the short-run), their contribution to the supply of new houses may be substantial.

Immigration, prices and the exchange rate. The effect of an immigration shock on prices is not obvious. On the hand, the wage mitigating effects of the increase in labor supply may put downward pressure on marginal costs and thus on prices, depending on the degree of price rigidity. On the other hand, the size (but also the composition) of aggregate demand for consumer goods changes with a larger population. If supply adjusts with a delay, we may expect an increase in prices. Lach (2007) explores the effects of the massive inflow of Russian Jewish immigrants into Israel during the 1990s and finds that prices of goods decrease. He attributes this result to the higher price elasticity and lower search costs of the new immigrants compared to the existing population. Cortes (2008) considers the effects on non-tradable goods and services (unlike Lach, 2007) in the US and finds a negative effect, in particular for services intensive in low-skilled labor. Frattini (2008) finds small effects on UK prices: immigration decreases the growth rate of prices for services and non-traded goods whereas it tends to increase prices of tradeable goods.

We introduce a measure of CPI prices as an unrestricted variable in our system and we

find no effect on the impact of the shock. Nevertheless, CPI prices tend to increase in the medium run. Notably, this effect seems to be driven by a depreciation of the exchange rate whereas a measure of domestic prices does not react at all to an immigration shock. While these effects are relatively small, in keeping with Frattini (2008), we uncover a new channel (the exchange rate channel) that, as far as we know, has not been discussed in the previous literature. The effect on the exchange rate is quantitatively important as immigration shocks explain around 25% of exchange rate fluctuations in Norway. Investigating the link between labor supply and the exchange rate in theoretical models seems to be an interesting avenue for future research.

Immigration and productivity. The impact of immigration on productivity has been discussed in Peri (2011) who finds a strong positive association between immigration and total factor productivity in US data. The main channel responsible for this result is the presence of task specialization. Peri and Sparber (2009) show that in states with large inflows of immigrants, natives with lower education tend to specialize in communication-intensive tasks, leaving more manual-intensive task to immigrants. The rebalancing produces task specialization based on comparative advantages and results in efficiency gains.

In our last experiment we introduce a measure of productivity, measured as output per hour, as an unrestricted variable in our VAR. We find a positive effect, that is, however, far from being economically and statistically significant. Immigration shocks turn out to be minor drivers of productivity as shown in Figure NUM.

5 Conclusion

The connection between immigration and the main macroeconomic varaibles is at the heart of a righ and lively literature that studies these issues using detailed disaggregate data. In contrast, the macroeconomic literature is lagging and has yet investigated the impact of immigration on the macroeconomy in a unified framework using aggregate data. This paper is one of the first attemps to include net immigration into the set of standard variables that are used in VAR studies to disentangle the drivers of immigration and the impact of immigration shocks on several variables that have been studied in the

microeconomic literature. While a disaggregate approach can be more informative and detailed in sevral dimension, an aggregate approach is needed to study business cycle fluctuations and possibly also the implications for macroeconomic policies.

We find that an exogenous immigration shock in Norway lowers unemployment (even among native workers), has a positive effect on prices and on public finances in the medium run and has little impact on house prices and productivity. In addition, immigration shocks are non-negligible (although not major) drivers of the Norwegian business cycle, explaining on average around 15-20 percent of output fluctuations, while immigration itself is driven mainly by domestic labor supply shocks (together of course with immigration shocks). Immigration responds very little to the state of the business cycle in Norway whereas it responds significantly to factors that are specific to the Norwegian labor market.

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A Appendix

A.1 Bayesian Estimation of the VAR

We illustrate in this Appendix the econometric procedure we use for the estimation of the different VAR models presented in the paper.

Estimation procedure

The VAR model described in (1) can be rewritten in a compact way as:

$$\mathbf{Y} = \mathbf{XB} + \mathbf{U}, \tag{2}$$

where $\mathbf{Y} = [y_1 \ \dots \ y_T]'$, $\mathbf{B} = [C_B \ B_1 \ \dots \ B_p]'$, $\mathbf{U} = [u_1 ... u_T]'$, and

$$\mathbf{X} = \begin{bmatrix} 1 & y_0' & \dots & y_{-p}' \\ \vdots & \vdots & \vdots & \vdots \\ 1 & y_{T-1}' & \dots & y_{T-p}' \end{bmatrix}.$$

Finally, for convenience, we rewrite (2) into its vectorized form:

$$\mathbf{y} = (I_n \otimes \mathbf{X})\beta + \mathbf{u}, \tag{3}$$

where $\mathbf{y} = vec(\mathbf{Y})$, $\beta = vec(\mathbf{B})$, $\mathbf{u} = vec(\mathbf{U})$, and with $vec()$ denoting columnwise vectorization. The error term $\mathbf{u}$ follows a normal distribution with a zero mean and variance-covariance matrix $\Sigma \otimes I_T$.

The likelihood function in $\mathbf{B}$ and Σ is defined as:

$$L(B, \Sigma) \propto |\Sigma|^{-\frac{T}{2}} \exp\left\{-\frac{1}{2}(\beta - \hat{\beta})'^{-1} \otimes \mathbf{X}'\mathbf{X})(\beta - \hat{\beta})\right\} \exp\left\{-\frac{1}{2} tr(\Sigma^{-1} S)\right\},$$

where $S = ((\mathbf{Y} - \mathbf{X}\hat{\mathbf{B}})'(\mathbf{Y} - \mathbf{X}\hat{\mathbf{B}}))$ and $\hat{\beta} = vec(\hat{\mathbf{B}})$ with $\hat{\mathbf{B}} = (\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}'\mathbf{Y}$. We specify diffuse priors so that the information in the likelihood is dominant and these priors lead to a Normal-Wishart posterior. In more detail, we a diffuse prior for β and Σ that is

proportional to $|\Sigma|^{-(n+1)/2}$. The posterior becomes:

$$p(B,\Sigma|y) \propto |\Sigma|^{-\frac{T+n+1}{2}} \exp\left\{-\frac{1}{2}(\beta-\hat{\beta})'^{-1} \otimes \mathbf{X}'\mathbf{X}](\beta-\hat{\beta})\right\} \exp\left\{-\frac{1}{2}tr(\Sigma^{-1}S)\right\}, \quad (4)$$

where y denotes all available data.

The posterior in (4) is the product of a normal distribution for β conditional on Σ and an inverted Wishart distribution for Σ (see, e.g. Kadiyala and Karlsson, 1997 for the proof). We then draw β conditional on Σ from

$$\beta|\Sigma, y \sim N(\hat{\beta}, \Sigma \otimes (\mathbf{X}'\mathbf{X})^{-1})$$

and Σ from

$$\Sigma|y \sim IW(S,\nu),$$

where $\nu = (T-n) * (p-1)$ and N representing the normal distribution and IW the inverted Wishart distribution.

Identification procedure

In order to map the economically meaningful structural shocks from the reduced form estimated shocks, we need to impose restrictions on the variance covariance matrix we estimated.

In detail, the prediction error u_t can be written as a linear combination of structural innovations ϵ_t

$$u_t = A\epsilon_t$$

with $\epsilon_t \sim N(0, I_N)$, where I_N is an $(N \times N)$ identity matrix and where A is a non-singular parameter matrix. The variance-covariance matrix has thus the following structure $\Sigma = AA'$. Our goal is to identify A from the symmetric matrix Σ, and to do that we need to impose restrictions.

To obtain identification via sign restrictions, we follow the procedure described in Rubio-Ramirez, Waggoner and Zha (2010). The algorithm has the following steps. First, we compute A as the Cholesky decomposition of our estimated variance covariance ma-

trix. We then compute rotations of this matrix, computing first a matrix Q with a QR decomposition of $X = QR$, where X is drawn from $X \sim N(0, I_N)$. Then, we generate candidate impulse responses from AQ and B_i for $i = 1, ..., P$ and check if the generated impulse responses satisfy the sign restrictions. If the sign restrictions are satisfied, we store our impulse response, if not we draw a new X. We iterate over the same procedure again until we obtain 1000 impulse responses which satisfy our sign restrictions.

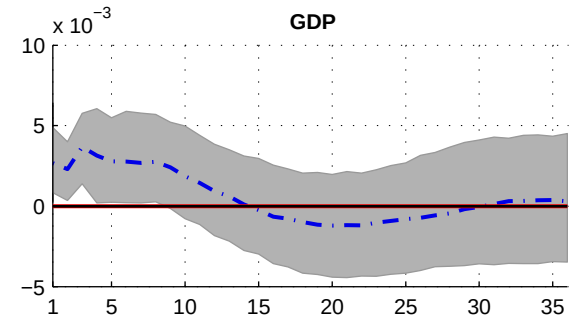
A.2 Data sources

This subsection lists the sources of the data series used in the estimation of the VARx

When the original data is at a monthly frequency, we take quarterly averages of monthly data. Nominal wages are deflated using the implicit price deflator of GDP to obtain real wages.

A.3 Extended model with demand and productivity shocks

To be added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x 10^−3
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5
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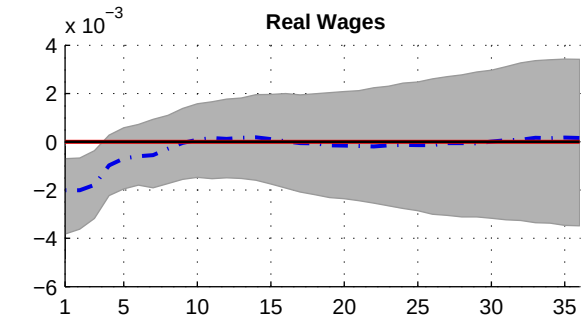
20
25
30
35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x 10^−3
4
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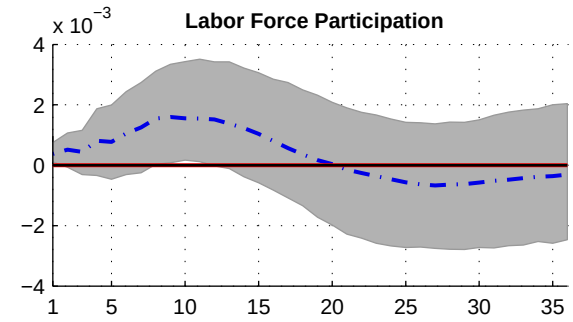
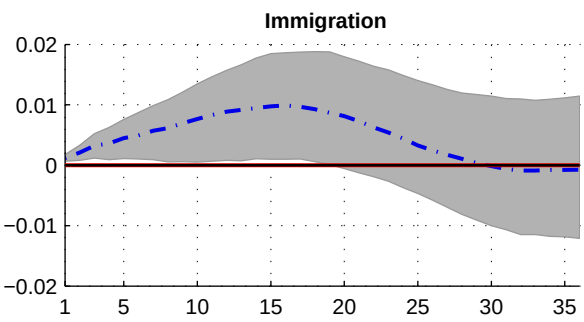
−2
−4
−6
1
5
10
15
20
25
30
35


Labor Force Participation
x 10^−3
4
2
0
−2
−4
1
5
10
15
20
25
30
35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0.01
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−0.01
−0.02
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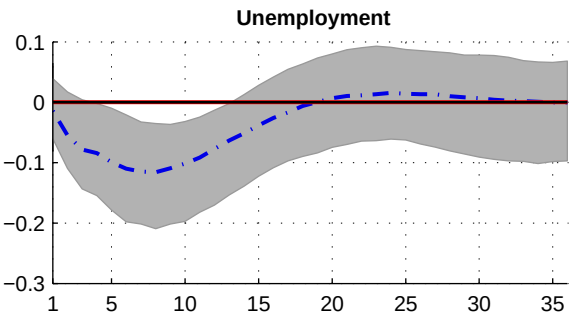
5
10
15
20
25
30
35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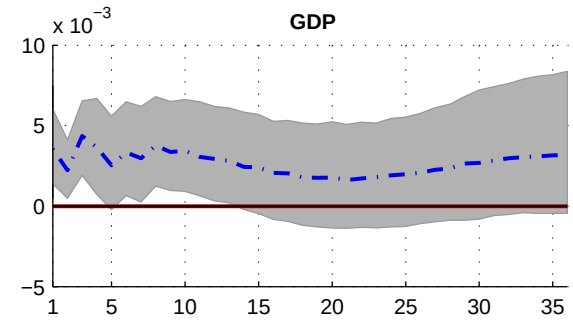
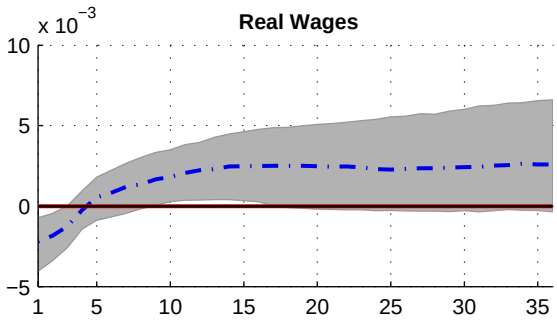
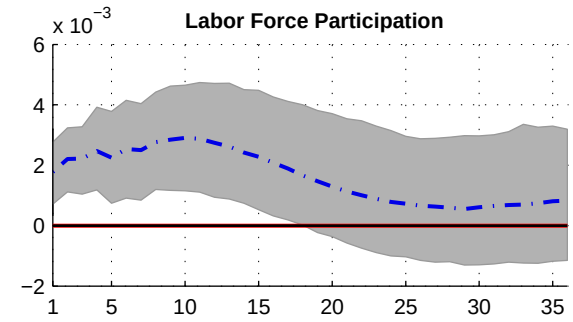
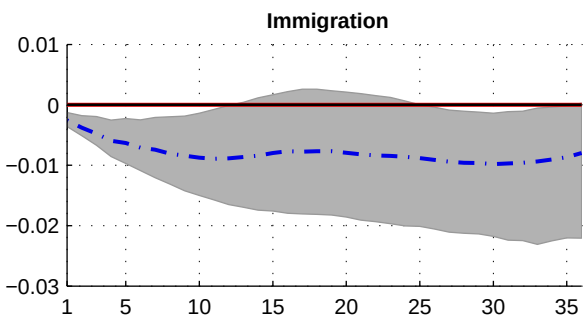
0.1
0
−0.1
−0.2
−0.3
1
5
10
15
20
25
30
35


GDP
x 10^−3
10
5
0
−5
1
5
10
15
20
25
30
35


Real Wages
x 10^−3
10
5
0
−5
1
5
10
15
20
25
30
35


Labor Force Participation
x 10^−3
6
4
2
0
−2
1
5
10
15
20
25
30
35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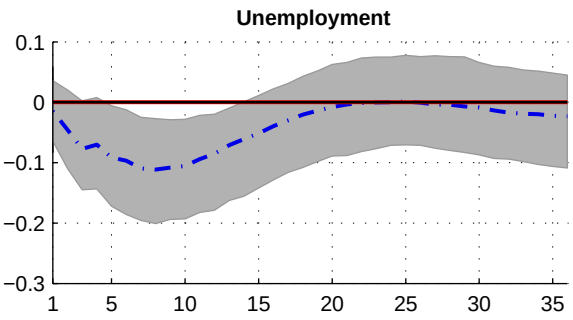
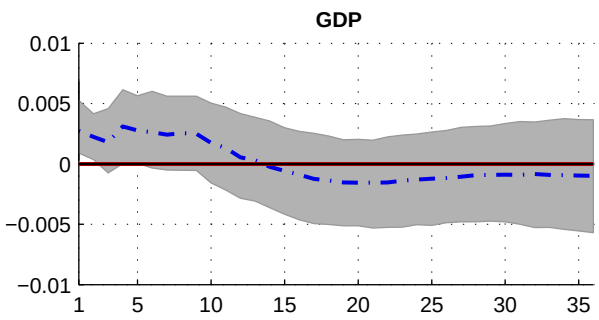
−0.02
−0.03
1
5
10
15
20
25
30
35


Unemployment
0.1
0
−0.1
−0.2
−0.3
1
5
10
15
20
25
30
35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0.005
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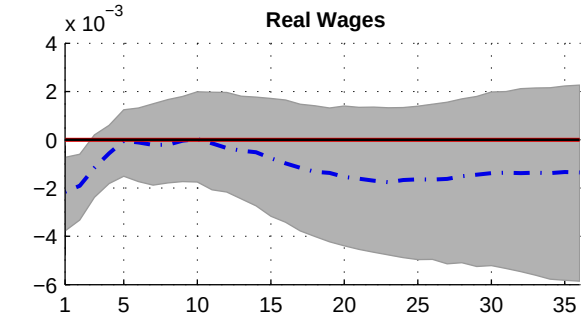
−0.005
−0.01
1
5
10
15
20
25
30
35


Real Wages
x 10^−3
4
2
0
−2
−4
−6
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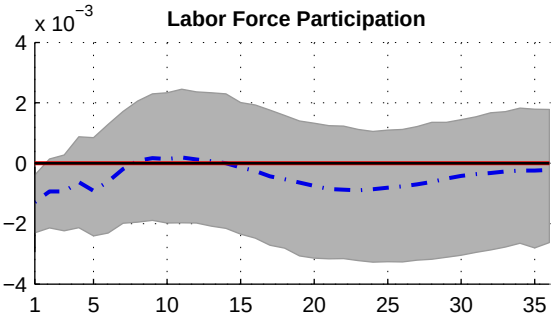
Labor Force Participation
x 10^−3
4
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0
−2
−4
1
5
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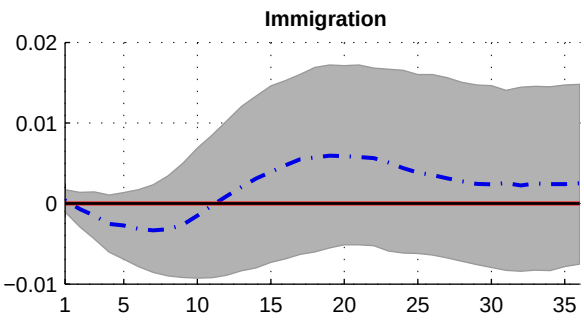
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0.01
0
−0.01
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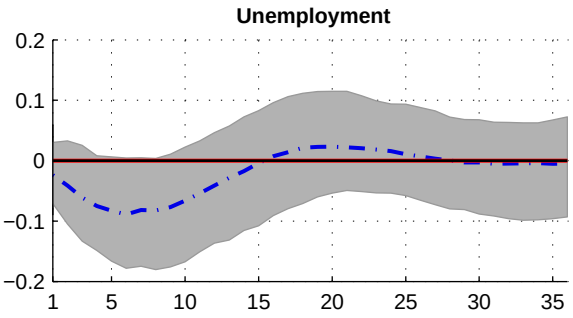
Unemployment
0.2
0.1
0
−0.1
−0.2
1
5
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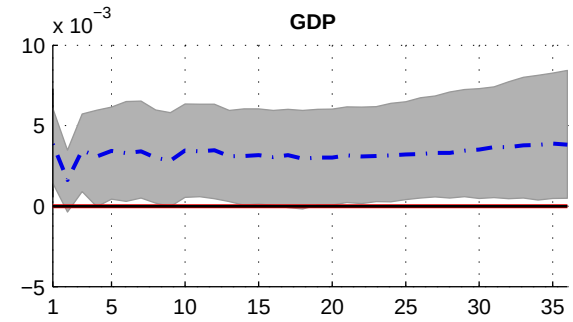
GDP
x 10^−3
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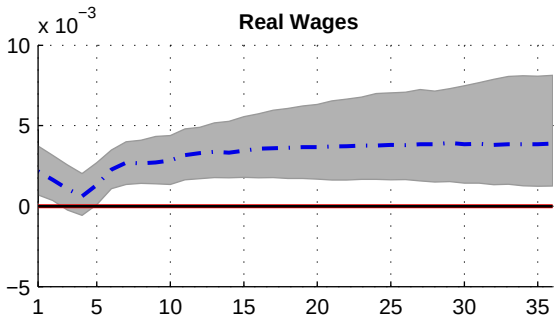
Real Wages
x 10^−3
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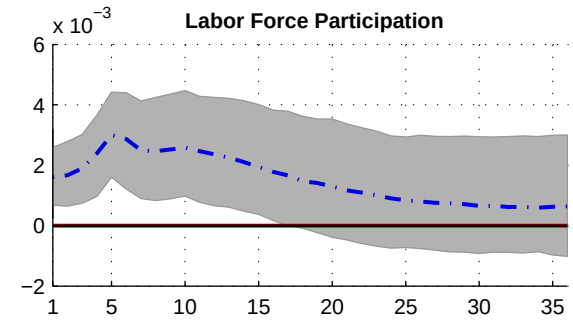
Labor Force Participation
x 10^−3
6
4
2
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−2
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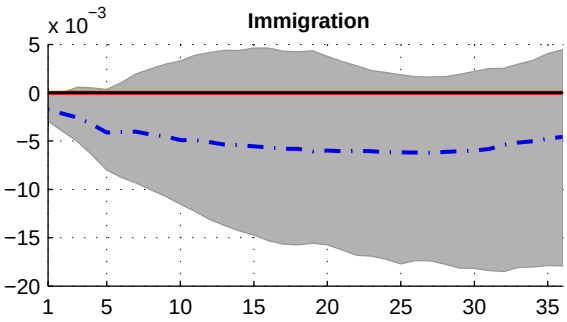
Immigration
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−5
−10
−15
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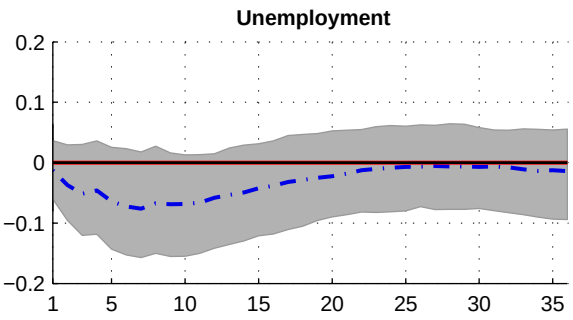
Unemployment
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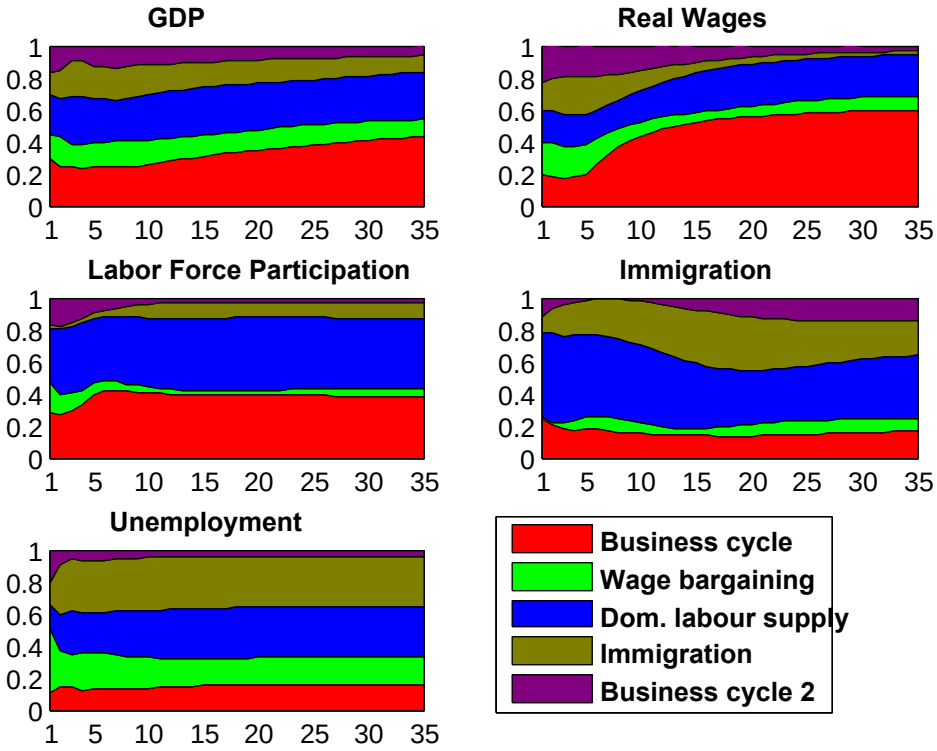
GDP
Real Wages
Labor Force Participation
Immigration
Unemployment
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0.6
0.8
1
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Business cycle
Wage bargaining
Dom. labour supply
Immigration
Business cycle 2