# Episodes of War and Peace in an Estimated Open Economy Model

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E31, E32, E62, F41, H56, H63

Working Paper

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February 10, 2017

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# 1 Introduction

How can a dynamic general equilibrium model account for the macroeconomic effects of war episodes like world wars? This paper proposes an approach based on the estimation of a medium-scale model on a rather large set of macroeconomic time series for France, Germany, the UK and the U.S. The model has usual features (capital accumulation, sticky prices) but allows for a set of flexibilities that make possible its estimation on historical time series that include war episodes.

The question at hand is clearly overwhelming. Events like world war destroy human lives and infrastructures, produce massive resources reallocation both from the private to the public sector but also within sectors, disrupt financial markets, generate goods rationing, lead to changes in borders and very large wealth transfers among belligerents. They also induce profound changes in the labor market and lead governments to adopt very different policy measures than during peaceful times. Let us state very clearly from the beginning that the attempt proposed in this paper is anything but pretending to be exhaustive. However, we believe that a model featuring enough flexibility can give some general insights of how to account for the macroeconomic effects of war episodes.

The model is a significant extension of the Smets and Wouters (2005) model. First, we allow for trade in some components of demand (private consumption and investment). Second, we consider incompleteness in international financial markets to account for potential wealth transfers (see Auray and Eyquem (2014) for a full discussion). Third, we include a full set of policy instruments: the money growth rate, public spending, public investment, public debt and distortionary taxes on labor and capital.

The structure of the model is flexible in the sense that some parameters of the model can switch to specific (estimated) values when a war episode occurs: the depreciation rate of capital is allowed to rise (to capture war related capital destruction), the possibility of a military draft reducing the labor available to private sector companies is opened, a default on public debt may occur, and households preferences towards the public good can be altered. We also allow war episodes to exert specific effects on exogenous shocks and policy instruments. These war spillovers provide an additional degree of flexibility to the model that may capture all the features that are not explicitly taken into account by our model.

Obviously, this model can be criticized as it does not take into account explicitly all the dimensions along which war episodes affect the economy: goods rationing, financial markets disruptions, changes in national borders, changes in the monetary standard[1], diseases, population displacement, to name just a few. However, it makes a significant step forward in this task, and features enough flexibility to capture business cycle dynamics during normal times as well as during war episodes. In addition, we explicitly place our approach in the line of the wedge approach proposed by Chari, Kehoe and McGrattan (2007), according to which "shocks" may not necessarily reflect structural shocks but may capture features of the economy that are not modeled explicitly.

We have four different datasets for France (1898-2006), Germany (1880-2008), UK (1870-2005) and the U.S. (1871-2010). For each country a separate model is estimated on a country-specific dataset that features a dummy for world war years and a series of macroeconomic quantities or prices. Datasets mix data from Barro and Ursùa (2011) and data from Piketty and Zucman (2014). Models are estimated using Bayesian methods.[2] For each country, we obtain a set of point estimates for parameters for each country and a set of smoothed shocks that perfectly account for the data since models are exactly identified. Our main results derive from the exploitation of the estimations.

Based on our model, we investigate the effects of war shocks on the dynamics of the four countries. In the U.S., war episodes are overwhelmingly driven by the subsequent massive increase in public spending. Other channels (draft, capital depreciation, default) and other spillovers play only minor roles in the dynamics after a war shock. To some extent, the dynamics for the UK is similar to that of the U.S. since the government spending spillover is very large too. For the UK however, other important features have significant effects: war episodes reduce productivity and hurt investment efficiency, and provoke a disruption in external trade, captured by a fall in world demand. France and Germany feature very different adjustment patterns. In these countries, GDP falls by 40% and consumption falls more than GDP. This suggests that other channels like the depreciation rate of capital matter more than in the U.S. or in the UK. In addition, in these countries, the public

[1]From fixed exchange rates before WWI, to suspension during WWI, to resumption afterward, to floating rates before WWII, to capital controls during WWII, Bretton Woods after WWII and its suspension after 1973.

[2]From a methodological point of view, our approach is not a strictly speaking a Markov-Switching Bayesian estimation because the state (the war dummy) is perfectly observed but it is very close to works resorting to this kind of methods (see Lubik and Matthes (2015) for instance for a recent contribution). The idea is to capture some non-linearity in the data generating process due to war episodes and war-specific behavior of the economies that are studied in the paper. Canova, Ferroni and Matthes (2016) also show that the decision rules and resulting IRFs can be dramatically impacted by the time-varying nature of some parameters of DGSEs, and therefore that considering potentially time-varying or state-dependent parameters can improve the quality of the fit of estimated models.

spending spillover is muted but productivity and investment spillovers are negative and significant. Both contribute to lower investment and GDP. For France, the trade spillover is also negative and very large.

Our main conclusion is thus that the approach proposed by Braun and McGrattan (1993) and McGrattan and Ohanian (2010), according to which a neoclassical model fed with a large public spending shock explains most of the dynamics of the economy, is valid but only for the U.S. and the UK.[3] For countries like France and Germany, the macroeconomic effects of war episodes can not be reduced to a massive rise in public spending. The statistical significance of productivity, investment or trade spillovers echoes a series of work suggesting that these are important transmission channels. In particular, Francis and Ramey (2006) disentangle the extent to which macroeconomic fluctuations were due to technological *vs.* non-technological shocks in the U.S. history, and highlight the importance of technological shocks, especially before WWII. Besides, Auray, Eyquem and Jouneau-Sion (2014) show that capital depreciation shocks *à la* Ambler and Paque (1994) crucially contribute to the macroeconomic dynamics induced by major war episodes.[4] Another part of the literature also highlights the importance of external trade and finance to account for the dynamics of economies during wars. Devereux and Smith (2007) analyze the Franco-Prussian 1871 war indemnity through the lens of the transfer problem, invoking the 1929 Keynes-Ohlin controversy. More generally, war episodes most often induce large disruptions in trade, that contribute to the dynamics of key domestic macroeconomic variables (see Anderton and Carter (2001) or more recently Glick and Taylor (2010)), a channel that our model is fully able to take into account.[5]

Using our estimation results, we also investigate the question of state-dependent public spending multipliers. Given the large number of papers using war episodes to identify the effects of discretionary public spending shocks (the "narrative approach", see Ramey and Shapiro (1997), Ramey (2011b), Ramey (2011a) and more recently Ben Zeev and Pappa

[3]The seminal contribution of Braun and McGrattan (1993), as well as McGrattan and Ohanian (2010) show that the standard neoclassical business cycle model fed with exogenous shocks on government spending, investment and taxes can properly account for the effects of WWII in the U.S. or in the UK. An additional contribution is Ohanian (1997), who shows the great importance of financing schemes in the effects of war episodes on output and welfare.

[4]See also Furlanetto and Seneca (2014) regarding the importance of capital depreciation shocks over the business cycle in normal times.

[5]Focusing on a different issue, Martin, Mayer and Thoenig (2008) identify the impact of international trade on the occurrence of conflicts. To sum up, data show that the sign and the magnitude of the relationship between trade openness and armed conflicts depend on the specific characteristics of trade flows and agreements but that major conflicts reduce international trade flows.

(2015)), it seems crucial to know whether the resulting multipliers are the same during war episodes and during normal times. We find that the impact and short-term multipliers are not significantly different for GDP (they are for investment and consumption) in the U.S. and in the UK. For France and Germany, we find that impact and short-run multipliers are significantly larger during war episodes than during normal times, but that long-run multipliers tend to converge. Once again these two patterns suggest that results derived for the U.S. or the UK should not be generalized. Finally, we also quantify the welfare losses from war episodes and contrast those to the welfare losses from fluctuations. We find that war episodes generate large welfare losses relative to other shocks, especially for Germany and France.

The paper is organized as follows. Section 2 describes our open-economy model. Section 3 presents the datasets and the estimation strategy. Section 4 reports our estimates for the U.S., characterizes the effects of war episodes and derives the state-dependent public spending multipliers. Section 5 compares our results for the UK, France and Germany to those derived for the U.S. Section 6 presents an analysis of the welfare losses from business cycles, as well as a quantification of the welfare losses attached to large war episodes. Section 7 concludes.

# 2 The model

We consider a small open economy model with a government in charge of fiscal and monetary policy. The model is based on a standard DGSE but is extended along many dimensions. First, it considers an open economy with trade in consumption and investment goods, home bias, and an incomplete international financial market. Second, we introduce money in the utility function and monetary policy is not conducted through a Taylor-type rule, but is affected by exogenous money growth rate shocks. In addition, seignorage revenues are transferred to the government. Both assumptions are consistent with a non-trivial role for monetary policy and for a potential financing of public spending through seignorage revenues. Third, the government levies distortionary taxes on labor and capital income. Both tax rates are assumed to follow exogenous processes reflecting discretionary decisions made by the government. The government spends on domestic consumption goods, invests in domestic public capital goods, issues government bonds, levies taxes and has access to seignorage revenues when issuing money. Finally, we introduce a dummy for war episodes that gives rise to a larger depreciation rate of public and private capital stocks, opens the possibility of a military draft, triggers a default on sovereign debt, and shifts household preferences regarding the public good.

## 2.1 Equilibrium conditions

### 2.1.1 Households

We consider a unit continuum of households indexed in $j$ that maximize their lifetime welfare

$$\mathcal{W}_t = E_t \left\{ \sum_{s=t}^{\infty} \beta^{s-t} \left( \frac{\widetilde{c}_s(j)^{1-\sigma_c}}{1-\sigma_c} + \chi_m \frac{(m_s(j)/p_s)^{1-\sigma_m}}{1-\sigma_m} - \chi_n \frac{n_s(j)^{1+\psi}}{1+\psi} \right) \right\} \tag{1}$$

In the welfare index, total consumption $\widetilde{c}_s(j)$ is a bundle of individual consumption of the private good $c_t(j)$ and the total consumption of public good $g_t$

$$\widetilde{c}_t(j) = \left( \varphi c_t(j)^{\frac{\nu_t - 1}{\nu_t}} + (1-\varphi) g_t^{\frac{\nu_t - 1}{\nu_t}} \right)^{\frac{\nu_t - 1}{\nu_t}}, \; \nu_t > 0 \tag{2}$$

When $\nu_t > 1$, private and public goods are substitutes while $\nu_t < 1$ implies complementarity.[6] We introduce the possibility that this parameter takes different values whether countries experience a war episode or not, that is

$$\nu_t = (1-\Delta_t)\, \nu_{norm} + \Delta_t \nu_{war} \tag{3}$$

where $\Delta_t = \{0, 1\}$ is a variable that equals one during war episodes and zero in normal times. As will be clear over the presentation of the economy, this variable triggers several channels through which war may affect the economy. Regarding other variables of the welfare index, $m_t(j)/p_t$ is the level of real money balances, and $n_t(j)$ is the total amount of labor supply, expressed in hours. Parameters $\sigma_c$ and $\sigma_m$ are the degrees of risk-aversion with respect to total consumption and real money balances, and $\psi$ is the inverse of the Frisch elasticity of labor supply.

The budget constraint of agent $j$ is

$$\begin{aligned} e_t f_t(j) + b_t(j) + m_t(j) + p_t \left( c_t(j) + i_t(j) + ac_t^f(j) \right) &= e_t r^* f_{t-1}(j) + r_{t-1} \left(1 - \Delta_t p^b\right) b_{t-1}(j) \\ &+ m_{t-1}(j) + \left( \left(1-\tau_t^k\right) r_t^k z_t(j) - p_t ac_t^z(j) + p_t \tau_t^k \delta_t \right) k_{t-1}(j) \\ &+ (1-\tau_t^n)\, w_t(j)\, n_t(j) + \Pi_t(j) + tax_t(j) \end{aligned} \tag{4}$$

[6]See Bouakez and Rebei (2007) and references therein for a discussion of the empirical relevance of this assumption.

In this equation, $e_t$ is the nominal exchange rate, $f_t(j)$ denotes the nominal value of foreign bonds returning a constant risk-free rate $r^*$ between period $t$ and $t+1$ and $b_t(j)$ denotes the nominal value of government bonds returning a nominal rate $r_t$ between period $t$ and $t+1$. Government bonds can be subject to partial default with hair-cut size $p^b$ in the event of a war episode. Further, $p_t$ is the consumption price level, $i_t(j)$ is the investment in physical capital, $\tau_t^n$ is the labor income tax rate, $w_t(j)$ is the nominal wage rate paid to type-$j$ labor, $\tau_t^k$ the tax rate on capital income, that comes with a tax deduction on depreciated capital, $r_t^k$ is the gross nominal return on the capital stock, $z_t(j)$ is the utilization rate of private capital, $\delta_t$ the time-varying depreciation rate of capital. Variable $tax_t$ is a lump-sum transfer that is rebated to the households. Capital depreciation is an additional channel through which war episodes can affect the dynamics of the economy as we assume

$$\delta_t = \delta\left(1 + \Delta_t p^\delta\right) \tag{5}$$

As in Auray et al. (2014), the idea is to capture war capital destruction through higher capital depreciation, where $p^\delta$ captures the size of war-related capital destruction. Finally, $ac_t^f(j) = (\phi_f/2)\left(e_t f_t(j)/p_t - ef(j)/p\right)^2$ is an adjustment cost on real net foreign assets, $ac_t^z(j) = (\phi_z/2)\left(z_t(j) - 1\right)^2$ is a utilization rate adjustment cost and $\Pi_t(j)$ denotes the profits from monopolistic firms paid to household $j$. An additional constraint to this optimization problem is the law of capital accumulation

$$k_t(j) = (1-\delta_t)\, k_{t-1}(j) + \zeta_t \left(1 - \frac{\phi_i}{2}\left(\frac{i_t(j)}{i_{t-1}(j)} - 1\right)^2\right) i_t(j) \tag{6}$$

The latter is subject to investment adjustment costs and to investment shocks $\zeta_t$. These shocks evolve according to an autoregressive process, augmented with a specific effect of war episodes. In a Chari et al. (2007) wedge approach, it aims at capturing all the potential channels through which war may affect capital accumulation that are not modeled explicitly in our economy. Formally the law of motion of investment shocks is:

$$\zeta_t = (1-\rho_\zeta) + \rho_\zeta \zeta_{t-1} + \phi_\zeta \Delta_t + \varepsilon_t^\zeta \tag{7}$$

Households maximize the welfare function subject to the budget constraints with respect to consumption, government and foreign bonds, as well as the quantity of money.

First-order conditions imply

$$\beta E_t \left( \frac{u_{c,t+1}(j)}{u_{c,t}(j)} \frac{r_t \left(1 - \Delta_{t+1} p^b\right)}{\pi_{t+1}} \right) = 1 \quad (8)$$

$$\beta E_t \left( \frac{u_{c,t+1}(j)}{u_{c,t}(j)} \frac{e_{t+1} r^*}{e_{t+1} \pi_{t+1} \left(1 + \phi_f \left(f_t^r(j) - f^r\right)\right)} \right) = 1 \quad (9)$$

$$u_{m,t}(j) - u_{c,t}(j) E_t \left( \frac{r_t \left(1 - \Delta_{t+1} p^b\right) - 1}{r_t \left(1 - \Delta_{t+1} p^b\right)} \right) = 0 \quad (10)$$

where $\pi_t = p_t / p_{t-1}$ is the CPI inflation rate, $u_{c,t}(j)$ is the marginal utility of consumption, $u_{m,t}(j)$ the marginal utility of real money balances, and $f_t^r(j) = e_t f_t(j) / p_t$ the real value of net foreign assets. The different types of labor offered by households are imperfectly substitutable, making them monopolistic wage-setters. Labor demands are

$$n_t(j, \omega) = \left( \frac{w_t(j)}{w_t} \right)^{-\theta^w} n_t(\omega) \quad (11)$$

where $\theta^w$ is the elasticity of substitution between types of labor. Those demands are taken into account by households along with the constraints when optimizing. Further, we assume sticky wages whereby wage-setters face an individual probability $1 - \eta^w$ to be allowed to re-optimize and a probability $\eta^w$ to keep their previous-period nominal wage unchanged. The corresponding optimal nominal wage $\mathsf{w}_t(j)$ is thus

$$\sum_{i=0}^{\infty} (\beta \eta^w)^i E_t \left( n_{t+i}(j) \left( \frac{\theta^w}{\theta^w - 1} \frac{u_{n,t+i}(j)}{u_{c,t+i}(j)} + (1 - \tau_t^n) \frac{\mathsf{w}_t(j)}{p_{t+i}} \right) \right) = 0 \quad (12)$$

where $u_{n,t}(j)$ is the marginal disutility of hours worked. The dynamics of nominal wages are

$$w_t^{1-\theta^w} = \eta^w (w_{t-1})^{1-\theta^w} + (1 - \eta^w) \mathsf{w}_t(j)^{1-\theta^w} \quad (13)$$

From now on we assume perfect risk-sharing among households and drop the $j$ indices. Defining $q_t p_t \lambda_t$ as the Lagrange multiplier associated with the capital accumulation constraint, first-order conditions with respect to the capital stock, investment, and utilization are respectively:

$$
\begin{aligned}
\beta E_t\left(\frac{u_{c,t+1}}{u_{c,t}}\left(q_{t+1}\left(1-\delta_{t+1}\right)+\left(1-\tau^k_{t+1}\right)\frac{r^k_{t+1}}{p_{t+1}}+\tau^k_{t+1}\delta_{t+1}\right)\right) &= q_t \quad (14)\\
q_t\zeta_t\left(1-\frac{\phi_i}{2}\gamma_t^2-\phi_i\gamma_t\left(1+\gamma_t\right)\right)+\beta E_t\left(\frac{u_{c,t+1}}{u_{c,t}}q_{t+1}\zeta_{t+1}\phi_i\gamma_{t+1}\left(1+\gamma_{t+1}\right)^2\right) &= 1 \quad (15)\\
\left(1-\tau^k_t\right)r^k_t-\phi_z\left(z_t-1\right) &= 0 \quad (16)
\end{aligned}
$$

where $\gamma_t = (i_t/i_{t-1})-1$ is the growth rate of private investment. Consumption and capital goods are made of domestic ($d$) and foreign ($f$) goods. Adjustment costs are also paid in units of that composite good. The latter is defined as:

$$
x_t=\left((1-\alpha)^{\frac{1}{\mu}}x_{d,t}^{\frac{\mu-1}{\mu}}+\alpha^{\frac{1}{\mu}}x_{f,t}^{\frac{\mu-1}{\mu}}\right)^{\frac{\mu}{\mu-1}},\; x=\left\{c,i,ac^f,ac^z,ac^i\right\} \tag{17}
$$

where $1-\alpha$ is the degree of home bias and $\mu$ the elasticity of substitution between domestic and foreign goods. The corresponding price index is

$$
p_t=\left((1-\alpha)\,p_{d,t}^{1-\mu}+\alpha\left(e_t p_{f,t}\right)^{1-\mu}\right)^{\frac{1}{1-\mu}} \tag{18}
$$

where $p_{d,t}$ and $p_{f,t}$ respectively denote the prices of domestic and foreign goods, expressed in units of local currency, and where $e_t$ is the nominal exchange rate. Optimal expenditure on each good implies

$$
\begin{aligned}
x_{d,t} &= (1-\alpha)\left(\frac{p_{d,t}}{p_t}\right)^{-\mu}x_t=(1-\alpha)\left(1-\alpha+\alpha s_t^{1-\mu}\right)^{\frac{\mu}{1-\mu}}x_t && (19)\\
x_{f,t} &= \alpha\left(\frac{e_t p_{f,t}}{p_t}\right)^{-\mu}x_t=\alpha\left((1-\alpha)\,s_t^{\mu-1}+\alpha\right)^{\frac{\mu}{1-\mu}}x_t && (20)
\end{aligned}
$$

for $x=\left\{c,i,ac^f,ac^z,ac^i\right\}$ where $s_t = e_t p_{f,t}/p_{d,t}$ stands for terms of trade.

### 2.1.2 Firms

There is a continuum of final good producers indexed in $\omega$, with the following production function

$$
y_t(\omega)=a_t k_t^s(\omega)^{\iota}\left(\left(1-\Delta_t p^{\ell}\right)\ell_t(\omega)\right)^{1-\iota} \tag{21}
$$

where $k_t^s$ is a measure of capital services used in production and $\left(1-\Delta_t p^{\ell}\right)\ell_t$ is the amount of labor that firms use to produce. Total labor $\ell_t$ is affected by a military draft that lowers the amount of labor used by private firms during war episodes. Finally, $a_t$ is a productivity measure following an autoregressive process. Again, we introduce the possibility that war episodes have indirect effects on productivity through channels that are not explicitly specified in the model:

$$a_t = (1 - \rho_a) + \rho_a a_{t-1} + \phi_a \Delta_t + \varepsilon_t^a \tag{22}$$

Cost minimization implies

$$k_t^s(\omega) = \frac{\iota}{1-\iota} \frac{w_t}{r_t^k} \ell_t(\omega) \tag{23}$$

which can be used to derive an expression of the nominal marginal cost

$$mc_t(\omega) = mc_t = \frac{\left(r_t^k\right)^{\iota} (w_t)^{1-\iota} \left((1-\iota)\left(1-\Delta_t p^{\ell}\right)+\iota\right)}{a_t \iota^{\iota} (1-\iota)^{(1-\iota)} \left(1-\Delta_t p^{\ell}\right)^{1-\iota}} \tag{24}$$

The adjustment of production prices is also subject to Calvo contracts. Re-setters face the following problem

$$\max_{\mathsf{p}_{d,t}(\omega)} \sum_{i=0}^{\infty} (\beta\eta^p)^i E_t \left( \frac{u_{c,t+i}}{u_{c,t}} \frac{p_t}{p_{t+i}} \left(\mathsf{p}_{d,t}(\omega)\, y_{t+i}(\omega) - mc_{t+i} y_{t+i}(\omega)\right)\right) \tag{25}$$

taking into account the demand addressed to firm $\omega$

$$y_{d,t}(\omega) = \left(\frac{p_{d,t}(\omega)}{p_{d,t}}\right)^{-\theta^p} y_{d,t} \tag{26}$$

The optimal pricing condition is thus

$$\sum_{i=0}^{\infty} (\beta\eta^p)^i E_t \left( \frac{u_{c,t+i}}{p_{t+i}} y_{t+i}(\omega) \left(\mathsf{p}_{d,t}(\omega) - \frac{\theta^p}{\theta^p - 1} mc_{t+i}\right)\right) = 0 \tag{27}$$

while the dynamics of prices are given by

$$p_{d,t}^{1-\theta^p} = \eta^p \left(p_{d,t-1}\right)^{1-\theta^p} + (1-\eta^p)\, \mathsf{p}_{d,t}(\omega)^{1-\theta^p} \tag{28}$$

## 2.2 Monetary policy, government and aggregation

The government is in charge of both monetary policy, public spending and fiscal policy. Its budget constraint is

$$
\begin{aligned}
b_t + m_t + \tau_t^n w_t n_t - \Delta_t p^\ell w_t \ell_t + \tau_t^k \left(r_t^k z_t - p_t \delta_t\right) k_{t-1} + tax_t \\
= r_{t-1}\left(1 - \Delta_t p^b\right) b_{t-1} + m_{t-1} + p_{d,t}\left(g_t + i_t^g\right)
\end{aligned} \tag{29}
$$

The total revenues from labor income taxation are lowered during war times since governments have to pay drafted people.[7] Remember also that we have introduced the possibility of defaulting on public debt during war times, $p^b$ being the size of haircut. We assume that fiscal solvency is enforced in the medium run by tax rules and a government spending rule. These rules imply that policy instruments react to the deviations of real public debt to its steady state value. In addition, we consider war-specific reactions of taxes and spending. Finally, policy instruments are also affected by AR(1) exogenous shocks:

$$g_t = g + d_{\tau_n}\left(br_{t-1} - br\right) + \phi_g \Delta_t + s_t^g \tag{30}$$

$$\tau_t^n = \tau^n + d_{\tau^n}\left(br_{t-1} - br\right) + \phi_{\tau^n} \Delta_t + s_t^{\tau^n} \tag{31}$$

$$\tau_t^k = \tau^k + d_{\tau^k}\left(br_{t-1} - br\right) + \phi_{\tau^k} \Delta_t + s_t^{\tau^k} \tag{32}$$

where

$$s_t^g = \rho_g s_{t-1}^g + \varepsilon_t^g \tag{33}$$

$$s_t^{\tau_n} = \rho_{\tau_n} s_{t-1}^{\tau_n} + \varepsilon_t^{\tau_n} \tag{34}$$

$$s_t^{\tau_k} = \rho_{\tau_k} s_{t-1}^{\tau_k} + \varepsilon_t^{\tau_k} \tag{35}$$

Finally, we consider that money supply grows at a rate $\mu_t^m = m_t/m_{t-1}$ that follows an AR(1) process augmented with a potential war-specific component:

$$\mu_t^m = (1 - \rho_m) + \rho_m \mu_{t-1}^m + \phi_\mu \Delta_t + \varepsilon_t^m \tag{36}$$

Further, as in Auray et al. (2014), the government adjusts the amount of public in-

[7] Here we follow the assumption made by Siu (2008) in its baseline model according to which wages paid to the military equal market wages.

vestment to secure a given constant level of public unproductive capital $k^g$:

$$i_t^g = \delta_t k^g \tag{37}$$

where, remember, capital depreciation $\delta_t$ is time-varying and is supposed to increase during war episodes. We expect this channel to produce a rise in public investment during war episodes.

An equilibrium of the model is as a path of endogenous variables that, conditional on the dynamics of exogenous variables, ($i$) satisfies households and firms first-order conditions, and ($ii$) clears markets. Equilibrium in the labor market implies

$$\ell_t = \int_0^1 \ell_t(\omega)\, d\omega = \int_0^1 \int_0^1 n_t(j,\omega)\, dj d\omega = \Upsilon_t^w n_t \tag{38}$$

where $\Upsilon_t^w = \int_0^1 (w_t(j)/w_t)^{-\theta^w} dj$ is the dispersion of wages. Equilibrium in the capital market gives

$$k_t^s = \int_0^1 k_t^s(\omega)\, d\omega = z_t k_{t-1} \tag{39}$$

and equilibrium in goods markets implies

$$y_t = (1-\alpha)\left(\frac{p_{d,t}}{p_t}\right)^{-\mu} y_t^d + \alpha\left(\frac{p_{d,t}}{p_t^*}\right)^{-\mu} y_t^* + g_t + i_t + i_t^g \tag{40}$$

where $y_t^d = c_t + i_t + \phi_f (f_t^r - f^r)^2/2 + \left(\phi_z (z_t-1)^2/2\right) k_{t-1}$ and $y_t^*$ is the foreign counterpart of $y_t^d$. It is subject to autoregressive shocks, and augmented with a war-specific component:

$$y_t^* = (1-\rho_{y^*})\, y^* + \rho_{y^*} y_{t-1}^* + \phi_{y^*}\Delta_t + \varepsilon_t^{y^*} \tag{41}$$

Finally, the aggregate production function is

$$\Upsilon_t^p y_t = a_t (z_t k_{t-1})^{\iota} \left(\Upsilon_t^w \left(1-\Delta_t p^{\ell}\right) n_t\right)^{1-\iota} \tag{42}$$

where $\Upsilon_t^p = \int_0^1 (p_{d,t}(\omega)/p_{d,t})^{-\theta^p} d\omega$ is the dispersion of producer prices. This small open economy model is closed by the net foreign asset equation, obtained by consolidating households, firms and government budget constraints

$$f_t^r = \left(\frac{e_t}{e_{t-1}}\right)\frac{r^* f_{t-1}^r}{\pi_t} + nx_t \tag{43}$$

where $nx_t$ represents net exports, defined as

$$nx_t = \frac{p_{d,t}}{p_t}\left(y_t - g_t - i_t^g\right) - c_t - i_t - \frac{\phi_f}{2}\left(f_t^r - f^r\right)^2 - \frac{\phi_z}{2}\left(z_t - 1\right)^2 k_{t-1} \tag{44}$$

## 2.3 Discussion

We build the above model to capture the dynamics of developed economies over a very long course of history. As such, it is necessarily incomplete. Of course, the dynamics during war episodes is characterized by centralization and state-regulated production of goods, goods rationing, financial markets breakdown, wealth transfers among belligerents, changes in national borders, etc... No macroeconomic model can account for all the specificities of the four countries under investigation. We thus see our model as a way to discipline the data rather than an actual attempt to model all the aspects of wars, even though the introduction of war-specific parameters or switches in parameters are probably steps into the right direction. Similarly, none of the considered countries is strictly a small open economy. Here again, capturing accurately trade relations during war times would require country-specific assumptions. Above all, the effort of modeling war-specific dynamics would probably fail to capture "regular" business cycle moments from the data. Our approach here can therefore be brought in relation with the proposal of Chari et al. (2007), who argue that models can be used to uncover the dynamics of wedges: exogenous shocks capture all the dynamics from the data that are not modeled explicitly. This is why our structural shocks (policy shocks, productivity and investment shocks, trade shocks) are augmented with war-specific components. Subject to the above caveats, we argue that the above model is flexible enough to capture the largest part of relevant macroeconomic dynamics both during war times and during normal times.

# 3 Estimation

We estimate our model using Bayesian methods, adopting the standard approach of An and Schorfheide (2007). This implies obtaining the posterior distribution of our estimated parameters based on the linear approximation of the model's solution around the steady state using the Kalman filter. A major advantage of the approach is that it allows for the extraction of the dynamics of shocks, as well as the historical paths of endogenous variables. We will therefore have a complete quantitative evaluation of the model with respect to the data.

*Steady state*. We analyze the linearized dynamics of the model around a symmetric steady-state without inflation, implying zero net foreign assets.[8] Our goal is to identify the sources of macroeconomic fluctuations with a specific interest in war episodes, focusing on France, Germany, the UK and the U.S. The model is flexible enough to allow for cross-country differences and remains relatively agnostic on the behavior of the government. Aside from the fiscal rules, policy instruments are allowed to feature a war-specific reaction, with no sign restrictions imposed on those spillovers from war episodes when estimating them.

*Data*. For each country, a version of the model is estimated using a country-specific dataset. Before presenting the results, we describe our datasets. In the model section, we have introduced a dummy variable for war episodes. This variable is treated as an exogenous shock, and the dummy variable is included as an observed variable. The dummy time series is country-specific since the sample is different for each country. The shock can only take two values 0 and 1 and is perfectly observed. Further, given the considerable likelihood of measurement error in the data, we add a measurement error shock on GDP. These two shocks added to the other shocks: productivity, investment, foreign demand, public spending, labor income tax rate and capital income tax rate provide a total number of 8 shocks. Exact identification thus requires 8 time series. We have four separate datasets for France (1898-2006), Germany (1880-2008), UK (1870-2005) and the U.S. (1871-2010). For each country, a first time series is the dummy variable for war periods. Our focus is on world wars so the variable is $\Delta_t = 1$ during WWI and WWII observations (years) and $\Delta_t = 0$ otherwise. For each country, the dataset then includes GDP and consumption per capita in 2006$, investment as a percentage of GDP ($i_t/y_t$), total consumption expenditure (public and private) as a percentage of GDP ($(c_t + g_t)/y_t$), net exports as a percentage of GDP ($nx_t/y_t$), debt to GDP ($b_t^r/y_t$), total tax receipts as a percentage of GDP and the inflation rate ($\pi_t$). GDP and consumption per capita are taken from the dataset of Barro and Ursùa (2011). Other variables are taken mostly from Piketty and Zucman (2014). For the U.S., total tax receipts are taken from Mitchell (1998) before 1947 and FRED after 1947. For Germany, total tax receipts are taken from Flandreau and Zumer (2004) before 1913 and from Piketty and Zucman (2014) from 1950 onwards. The inflation rate is based on the CPI for France and Germany, and on the GDP deflator for the UK and the U.S., a distinction that our open economy model handles easily.[9] Our datasets are made stationary in the following way. Some variables are considered in growth rates.

[8]Details about the steady state are given in Appendix A.

[9]Over the whole sample, it was not possible to obtain a GDP deflator for all four countries.

We take the log-difference of GDP, consumption and inflation. We transform public debt and taxes in levels using ratios and the levels of GDP, and take the log-difference. Other variables, like total consumption expenditure, net exports or investment are expressed relative to GDP. We make these ratios stationary by removing a linear-quadratic trend. Whenever our dataset has missing points, they are handled as follows.[10] Series are first interpolated with a spline before being transformed (taken in log-difference or having their trend removed). Then the interpolated missing observations are removed, to be properly handled as missing observations by the estimation algorithm. We use the Dynare built-in estimation routine, that copes with missing observations treating them as unobserved states and using the Kalman filter to infer their values during estimation. Appendix B reports the time series used to estimate the model.

*Calibrated parameters.* Before estimating the model, we choose to fix the value of some of the parameters, either to preserve the model's steady state or because of weak identification from the data. The time unit is the year. The steady-state discount factor is $\beta = 0.96$, producing an average 4.17% real interest rate. The risk-aversion parameters on (total) consumption and real money balances are respectively $\sigma_c = 1.5$ and $\sigma_m = 1.5$. The steady-state capital depreciation rate is $\delta = 10\%$, the adjustment cost on utilization is $\phi_z = 0.15$ and the capital share is $\iota = 0.36$. The import share is $\alpha = 0.15$ and the adjustment cost on foreign assets is $\phi_f = 0.025$, as in Ghironi and Melitz (2005). The value of the labor disutility parameter $\chi_n$ is adjusted to normalize hours of work to one, which makes our choice for the calibrated value of the wage mark-up ($1/(\theta^w - 1) = 20\%$) basically inessential (see Appendix A for details). Due to identification issues, the Frisch labor supply elasticity $1/\psi$ is calibrated to 2/3, a rather consensual value. Finally, the real balances utility parameter is set to $\chi_m = 0.05$, to produce steady-state real balances to GDP between 0.2 and 0.25, in accordance with (unreported) evidence from Piketty and Zucman (2014)'s dataset. Those parameters remain fixed across countries and their values are summarized in Table 1 below.

*Country-specific calibrated parameters.* Remaining calibrated parameters are country specific, to account for differences in the tax systems, the levels of public consumption to GDP ($\kappa$) or public debt to GDP. Our calibrated values are based on data taken from the Piketty and Zucman dataset that are not necessarily used to estimate the model. Using

[10]For Germany, investment and consumption expenditure to GDP have missing points from 1914 to 1924, and from 1939 to 1949. Net exports to GDP have missing points from 1919 to 1924 and from 1939 to 1949. Inflation data in 1922 and 1923 are considered missing. Total tax receipts are missing from 1914 to 1949. For the U.S., tax data are missing from 1918 to 1924.

**Table 1:** Calibrated common parameter values

| | |
|---|---|
| Discount factor | $\beta = 0.96$ |
| Frisch elasticity on labor supply | $1/\psi = 2/3$ |
| Risk-aversion (consumption) | $\sigma_c = 1.5$ |
| Risk-aversion (real money balances) | $\sigma_m = 1.5$ |
| Capital depreciation | $\delta = 0.10$ |
| Utilization adjustment cost | $\phi_z = 0.15$ |
| Capital share | $\iota = 0.36$ |
| Import share | $\alpha = 0.15$ |
| Adjustment cost on foreign assets | $\phi_f = 0.0025$ |
| Real money utility parameter | $\chi_m = 0.05$ |
| Wage mark-up | $1/(\theta^w - 1) = 0.2$ |
| Labor disutility parameter | $\chi_n$ adjusted to get $n = 1$ |

average values of tax rates in France, we set the steady-state tax rates to $\tau^n = 0.3$ and $\tau^k = 0.22$. The average government investment rate, taken from French data is $\kappa^i = 0.0253$. We adjust public consumption to GDP $\kappa = 0.1346$ to match exactly the average level of debt to GDP (75%) over the sample. Last, we set $\theta^p = 6$ to match average net profits (20%). In the absence of empirical evidence for profits in Germany, we set $\theta^p = 6$. German data suggest $\kappa^i = 0.0164$ and $\kappa = 0.1490$. The average level of capital income taxation is $\tau^k = 0.2$. We adjust $\tau^n = 0.2926$ to match the average level of debt to GDP (45%) over the sample. Concerning the UK, our time series average indicate a profit rate of 25%, implying $\theta^p = 5$. Average government investment to GDP over our sample is $\kappa^i = 0.0263$. We assume $\tau^k = 0.2$ and $\tau^n = 0.3$, and adjust $\kappa = 0.1138$ to hit the 97% average debt-to-GDP ratio of our sample. Finally, for the U.S., based on sample averages, we set $\kappa^i = 0.0190$, impose $\kappa = 0.10$ with $\tau^k = 0.35$ and adjust $\tau^n = 0.1678$ to hit the average debt-to-GDP ratio of our sample (55%). Those parameter values are summarized in Table 2 below.

**Table 2:** Calibrated country-specific parameter values

| | France | Germany | UK | U.S. |
|---|---|---|---|---|
| Share of public investment in GDP ($\kappa^i$) | 0.0253 | 0.0164 | 0.0263 | 0.0190 |
| Share of public consumption in GDP ($\kappa$) | 0.1346 | 0.1490 | 0.1138 | 0.1000 |
| Labor income tax rate ($\tau^n$) | 0.3000 | 0.2926 | 0.3000 | 0.1678 |
| Capital income tax rate ($\tau^k$) | 0.2200 | 0.2000 | 0.2000 | 0.3500 |
| Steady-state price mark-up ($1/(\theta^p - 1)$) | 0.2000 | 0.2000 | 0.2500 | 0.2000 |

*Estimated parameters.* Remaining parameters of the model are estimated. Our priors are as follows. The Calvo parameters on prices $\eta^p$ and on wages $\eta^w$ are Betas, with prior means 0.25 and standard deviations 0.1.[11] The Edgeworth complementarity parameters $(\nu_{norm}, \nu_{war})$ are estimated separately but with the same priors. They are Inverse Gammas with prior means 0.5 and standard deviations 0.25. The percentage of public debt defaulted during war episodes $p^b$, the proportion of the workforce that is drafted $p^\ell$ and the percentage increase in the depreciation rate of capital induced by war episodes $p^\delta$ are assumed to be Betas with prior means 0.1 and standard deviations 0.05. Following Smets and Wouters (2003), the investment adjustment cost parameter $\phi_i$ is a Normal with prior mean 5 and standard deviation 0.5. As in the standard international RBC literature (see Backus, Kehoe and Kydland (1993) or more recently Auray, Eyquem and Gomme (2016)), the trade elasticity is a Normal with prior mean 1.5 and a 0.25 standard deviation. Parameters governing the reaction of fiscal instruments to the deviations of public debt $(d_g, d_{\tau_n}, d_{\tau_k})$ are restricted to be positive (to ensure determinacy), and therefore assumed to be Inverse Gammas with prior means 0.25 with a 0.25 standard deviation. We are completely agnostic about the sign of war spillovers on exogenous processes, and assume that $(\phi_a, \phi_g, \phi_\varsigma, \phi_{y^*}, \phi_{\tau_n}, \phi_{\tau_k}, \phi_\mu)$ are Normals with prior means 0 and standard deviations 2. Finally, the persistence of forcing processes (including the measurement error shock on GDP) are Betas with prior means 0.7 and standard deviations 0.2 and the standard deviations of innovations are Inverse Gammas, with prior means 0.1 and infinite standard deviations.

*Estimation results.* Table 5 and Table 6 in Appendix C report the estimated parameters with 90% confidence intervals for each of the four countries, based on 250 000 replications of the MH algorithm where the first 20% were discarded and the scale parameter adjusted to get a 30% acceptance rate. The estimated parameter values will be discussed in the next Section, starting with the case of the U.S. and then contrasting the results for other countries.

# 4 United States: estimation results and implications

## 4.1 Estimation results

Prior and posterior distributions are reported in Appendix D and show that the estimation procedure provides enough information to significantly update prior distributions. Further, most parameters found in other estimated models have reasonable point estimates. For

[11] We did try to estimate different values of the Calvo parameters during war times and during normal times but Calvo parameters during war times were weakly identified.

example Calvo parameters for the U.S. are 0.4 for prices and 0.2 for wages, suggesting adjustment of prices and wages between 5 and 7 quarters, numbers that are consistent with estimates based on quarterly datasets and models. Similar comment are in order for parameters like the investment adjustment cost, the trade elasticity or tax and spending rule parameters.

The unusual part of our estimation lies in the estimation of the Edgeworth complementarity parameter $\nu$, and war-specific parameters like spillovers, the size of war-related depreciation, draft or default on public debt.

Concerning the Edgeworth parameter, our estimation favors a mild complementarity between public and private goods in households utility function, as the estimated values $\nu_{norm}$ and $\nu_{war}$ are close and roughly equal to 0.5 (recall, substitutability is observed when $\nu > 1$). We do not claim that the assumption of Edgeworth complementarity/substitutability captures deep microfounded features of households preferences but we do think that it captures quite accurately the transmission mechanism of public spending shocks to private consumption (see Bouakez and Rebei (2007) for a discussion). The latter may in fact go through financial constraints, subsistence points, goods rationing or precautionary motives, but including each of these effects would require substantial additional modeling efforts and result in an even larger model to estimate. Notice that this parameter is correctly estimated both during war times and normal times, and that, in the case of the U.S., we can not conclude that these estimates are statistically different, as confidence intervals overlap. Based on post-war Canadian data and using ML methods, Bouakez and Rebei (2007) estimate a value of 0.3320 for this parameter. Larger values found by our empirical work reflect a lower complementarity between private and public goods in the U.S. over the period considered.

The estimated value of the size of the war draft ($p_\ell$) for the U.S. is 6%, which is to be confronted with the numbers reported by Siu (2008) (a 6.8% conscription in the U.S. during WWI and a 15.6% conscription during WWII). Alternative sources point to a 11% draft during WWII. Our estimate is therefore conservative at best. According to Young and Musgrave (1980) the net private capital stock fell by 2.2% between 1940 and 1945 in the U.S. (see Table 1.A.1). After taking into account the average growth rate of output over our sample (1.93% annually) must put this number somewhere above 4% while our model delivers a larger number of 9%. However, the observed 4% number is over a 5 years period: in our model a 9% increase in capital depreciation will produce a rise in investment and the capital stock should not fall as much as 9%, unless on impact since it is pre-determined. Concerning sovereign default, one must recognize that the U.S. did not default on their debt during world wars. Our model finds a 12% hair-cut during war episodes. We believe that this feature captures something different: the rise of default risk perceived by the households.[12]

Let us now comment the signs and size of war spillovers. We have allowed exogenous or policy processes to react to a war episode. We believe this should capture (*i*) the effects of war on exogenous processes that are indirect or not formally included in the model (for productivity, investment or trade for instance) and (*ii*) the discretionary decisions made by the government about war finance (public spending, taxes and money growth). Our estimation for the U.S. shows that neither the spillover on productivity or investment is significantly different from zero. However, the trade spillover is significant and positive: a "typical" war episode would raise foreign demand for U.S. goods, that should result in an improvement of the trade balance. Concerning policy spillovers, our estimation concludes that public spending responds positively and significantly, and that this increase in public spending is financed by a war-specific rise in the labor tax, along with a fall in the capital income tax. The money growth spillover is not significantly different from zero. Comparing our results to those reported by McGrattan and Ohanian (2010), the only major qualitative difference would be that the capital income tax did not fall during WWII in the data while our model suggest it would.

We do not comment extensively the characteristics of estimated parameters governing the dynamics of exogenous shocks as most persistence estimates are in line with common values found in the empirical literature.

## 4.2 The macroeconomic effects of a war shock

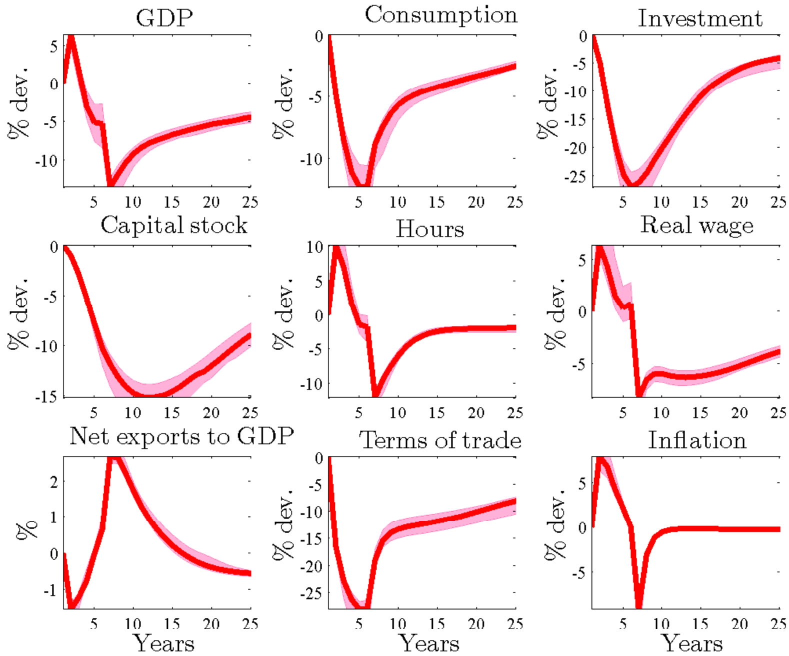
What are the effects of a war shock (*i.e.* a shock on $\Delta_t$) in the U.S. according to our estimated model? Consider the economy to be initially in the steady-state and feed in a 5-year shock on $\Delta_t$. The model is solved using a non-linear method. We draw values for estimated parameters from their posterior distribution and assume that spillovers terms that are not significant in our estimation are simply zero.[13] Based on 120 simulations,

[12]Evidence about the trading of German government bonds in Zurich and Stockholm during the war period is reported by Frey and Waldenström (2004), and shows that war events play a major role in volumes traded. We take this as indirect evidence of our sovereign default channel.

[13]This assumption ensures that our simulations do not explode. Since spillovers that are non-significant have widespread distributions around their means, drawing in these distributions can lead to pick very large spillover terms, which can prevent our simulations from converging.

Figures 1 and 2 report the effects of a 5-years war, along with the associated confidence intervals for macro variables and for policy variables respectively.

**Figure 1:** Impulse Response Functions to a 5-year shock on $\Delta_t$ - Macro variables

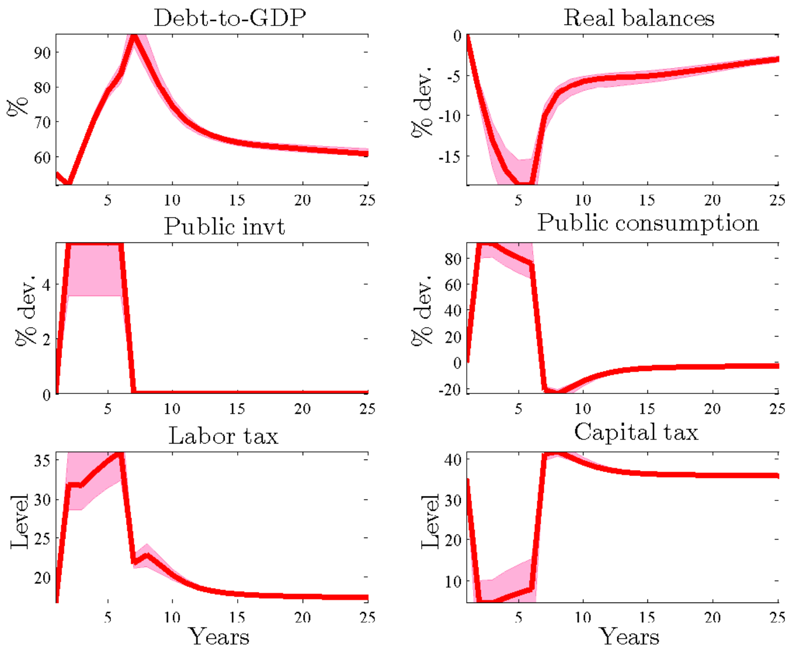



Shaded areas correspond to one standard deviation confidence intervals ($16^{th}$ and $84^{th}$ percentiles) based on 120 simulations.

What are the effects of a world war episode on macroeconomic variables? First, the capital stocks (both private and public) depreciate, which contributes negatively on impact to the dynamics of output but boosts public and private investment with positive impact on output in the subsequent periods. The effect on consumption is clearly negative as savings must increase to finance the rise in investment. Second, a war-related sovereign default occurs, which, all else equal, tends to lower the debt-to-GDP ratio and lowers tax rates through the fiscal rules, with positive expected effects on output dynamics. As shown in the next set of figures, it happens that these two effects play a relatively minor role from a quantitative perspective and are therefore not at the center of the stage. Third, a military draft lowers the bulk of hours worked used in the production process, which tends to put upward pressure on equilibrium wages, lowers output and consumption. This channel has quantitatively limited implications as well, although to a lesser extent than capital depreciation and sovereign default.

Spillover terms play a much bigger role. The war shock is associated with a positive

**Figure 2:** Impulse Response Functions to a 5-year shock on $\Delta_t$ - Policy variables

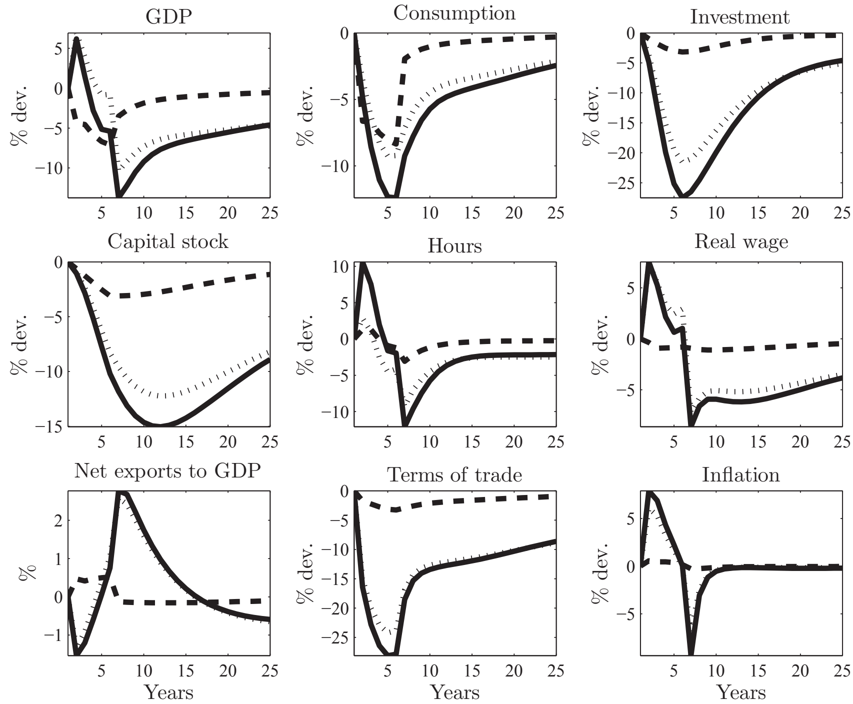



Shaded areas correspond to one standard deviation confidence intervals ($16^{th}$ and $84^{th}$ percentiles) based on 120 simulations.

world demand shock that should lead to an improvement of the trade balance. However, this effect is more than compensated by the public spending spillover. Its importance is overwhelming, as depicted by Figure 3 and 4. The rise of public spending is massive – public expenditure almost double – and drives the positive dynamics of output, the crowding-out effect on investment, the negative (positive) effect on consumption (hours worked), and the terms-of-trade depreciation. It generates a trade deficit in the first periods as well as a massive increase in debt to GDP. Finally, tax spillovers imply a large rise in the labor income tax and a fall in the capital income tax, as was expected given the signs of estimated spillover coefficients (see Table 6). The labor tax tends to cut GDP and consumption while the capital tax should act as a subsidy to investment and should boost output. However, as already mentioned, the overall dynamics of the economy seem almost entirely driven by the rise in public spending.

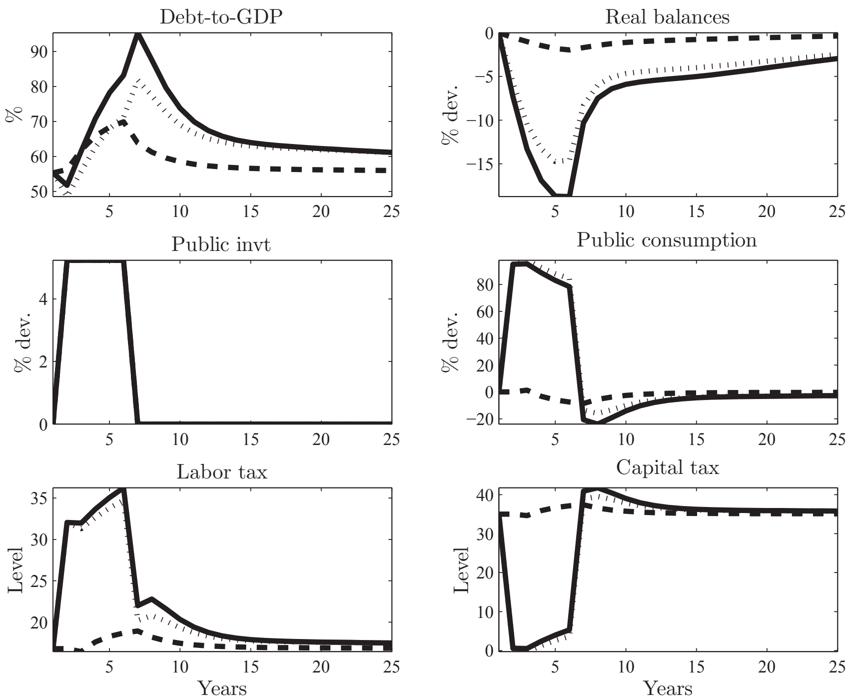
How does our analysis compare with existing papers? Quite well actually, in the sense that most of them find that the dynamics of the U.S. economy during WWII are well captured by a large rise in public spending (see McGrattan and Ohanian (2010)). In particular, the positive joint dynamics of hours worked, pre-tax wages, GDP and the negative dynamics of investment identified in the data by McGrattan and Ohanian (2010)

**Figure 3:** IRFs to a 5-year shock on $\Delta_t$ - Sensitivity - Macro variables




Black: baseline model, dashed: no spillovers, dotted: no draft

**Figure 4:** IRFs to a 5-year shock on $\Delta_t$ - Sensitivity - Policy variables




Black: baseline model, dashed: no spillovers, dotted: no draft are correctly reproduced, at least qualitatively. Similarly, our model predicts a rise in the labor income tax and a rise in public debt, as observed in U.S. data. Most of the additional channels of our model (military draft, sovereign default, capital depreciation) contribute only marginally to the dynamics of the economy and are quantitatively almost negligible compared to the effects of the massive rise in public spending. This is consistent with findings of the literature, according to which the effects of big war episodes such as WWII are captured correctly by a large positive shock on public spending, at least for the U.S.

## 4.3 Public spending output multipliers

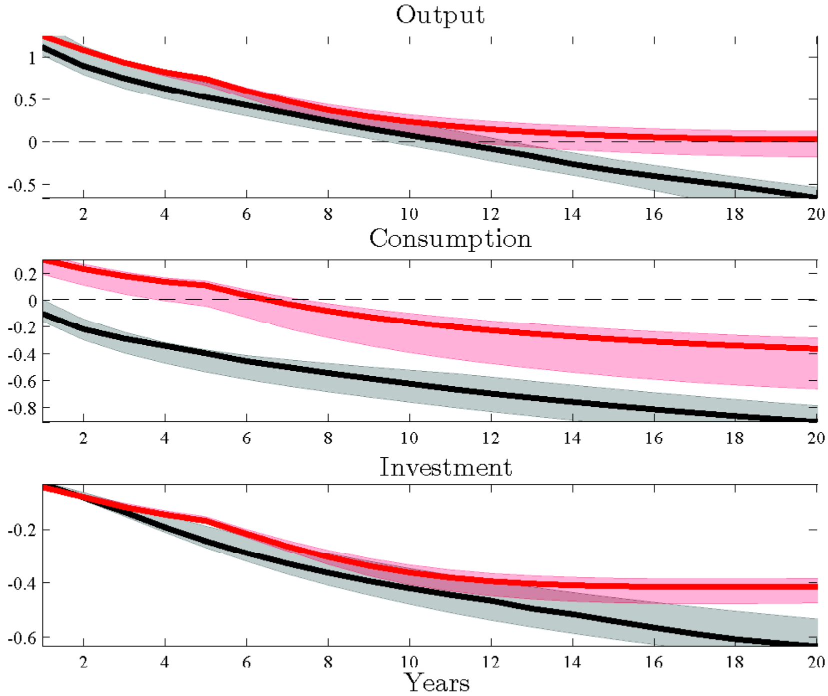
Our previous analysis makes clear that the rise in government spending during war episodes is a robust feature of war periods in the U.S. In this section, we thus make use of our model and Bayesian estimations to compute the values (and confidence intervals) of public spending multipliers. We are interested in the predicted absolute value of multipliers and in determining whether they are significantly different during normal times and during war episodes. Indeed, war episodes have recently been used as natural candidates to identify the effects of exogenous public shocks. However, is this approach informative about the value of multipliers during normal times?

The computation of multipliers is based on non-linear simulations of the model. In all cases, the economy is initially in the steady state. In the case of normal times, we just hit our economy with a 1% public spending shock, and compute present value multipliers at different horizons. In the case of war episodes, we set the war dummy to one for 5 years, the average duration of a war episode, and use the predicted deviations in public spending and GDP to compute the multipliers. In this case, present value multipliers are computed against the dynamics of the U.S. economy without the spending spillover. Figure 5 below reports the value of the present value multipliers, representing the discounted dollar increase in output, consumption or investment that results from a dollar increase in public spending:

$$PVM_{x,T} = \frac{\sum_{j=1}^{T} \beta^j \left(x_{t+j} - x_t\right)}{\sum_{j=1}^{T} \beta^j \left(g_{t+j} - g_t\right)}, \text{ for } x = y, c, i \tag{45}$$

Our results suggest that output present value multipliers (PVMs hereafter) are rather large on impact (larger than 1) and then fall under the combined effects of public spending and tax rules that ensure debt sustainability in the long run (instead of lump-sum taxes

**Figure 5:** Present value multipliers at different horizons




Black: normal times. Red: War episodes. Shaded areas correspond to one standard deviation confidence intervals ($16^{th}$ and $84^{th}$ percentiles) based on 120 replications of our non-linear simulations. Each replication draws a vector of the estimated parameters from the posterior distributions and computes the multipliers.

as in many models). In addition, median estimates of PVMs during war episodes are slightly larger than those computed during normal times. This difference reflects the fact that the Edgeworth complementarity parameter point estimate is slightly lower during war episodes than during normal times. Yet, this difference – as the difference between Edgeworth parameters – is not statistically significant.

Our confidence intervals indeed show that, on impact and until 14 years after a spending shock, the PVMs are not statistically different whether computed during normal times or during war episodes. It suggests that the literature identifying spending shocks through war episodes (like Ramey (2011a) and the subsequent literature) should not produce biased estimates of multipliers based on U.S. data. Let us finally note that consumption PVMs are a bit larger during war episodes, especially below the 5-years horizon. Investment multipliers present similar patterns although they are strictly negative during normal times and during war episodes. These differences result in small and negligible differences in output PVMs because of the response of hours worked and dynamics of terms of trade and the trade balance during normal times.

Our estimates of multipliers based on U.S. data belong to the upper range of estimated spending output multipliers reported by Ramey (2011a), especially for the impact multipliers. Since fiscal rules allow policy instrument (spending and taxes) to respond to lagged real public debt, the impact multipliers are basically comparable to most estimates of the literature. PVMs however are not directly comparable in the long run since policy instruments adjust to ensure debt sustainability. In addition, the question of state-dependent multipliers has recently been addressed with two different set of conclusions. Auerbach and Gorodnichenko (2012) find that multipliers are larger during slack periods while Owyang, Ramey and Zubairy (2013) find no particular difference for the U.S. but a significant one for Canada. In our model, multipliers differ during war episodes because when the war-dummy is one, Edgeworth parameters may differ and some war-specific effects are triggered (draft, default and capital depreciation), which can result in different transmission mechanisms for shocks on public spending. While this non-linearity seems to matter for the impact response of consumption, it does not produce significantly different output PVMs at short horizons. Our results thus seem to back those Owyang et al. (2013) more than those of Auerbach and Gorodnichenko (2012), based on U.S. data.

# 5 Results for UK, France and Germany

## 5.1 Estimation results

As in the case of the U.S., prior and posterior distributions are reported in Appendix D and show that the estimation procedure provides enough information to significantly update prior distributions. Table 3 below is an extraction of the posterior means of some key parameters for all countries.

**Table 3:** Key parameter estimates

| | Fra. | Ger. | UK | U.S. |
|---|---|---|---|---|
| Structural parameters | | | | |
| Calvo prices ($\eta^p$) | 0.20 | 0.22 | 0.25 | 0.40 |
| Calvo wages ($\eta^w$) | 0.27 | 0.40 | 0.14 | 0.20 |
| Edgeworth comp. ($\nu_{norm}$) | 0.50 | 0.56 | 0.60 | 0.55 |
| Edgeworth comp. ($\nu_{war}$) | 0.35 | 0.48 | 0.46 | 0.51 |
| War draft ($p^\ell$) | 0.08 | 0.08 | 0.11 | 0.06 |
| War default ($p^b$) | 0.08 | 0.10 | 0.06 | 0.12 |
| War capital depreciation ($p^\delta$) | 0.09 | 0.10 | 0.09 | 0.09 |
| War spillovers | | | | |
| Productivity ($\phi_a$) | $-0.05$ | $-0.06$ | $-0.02$ | $n.s.$ |
| Spending ($\phi_g$) | $n.s.$ | $n.s.$ | 0.34 | 0.14 |
| Investment ($\phi_\varsigma$) | $-0.62$ | $-0.46$ | $-0.34$ | $n.s.$ |
| Trade ($\phi_{y^*}$) | $-0.70$ | $n.s.$ | $-0.38$ | 0.16 |
| Labor tax ($\phi_{\tau^n}$) | $-0.18$ | 0.44 | $-0.14$ | 0.13 |
| Capital tax ($\phi_{\tau^n}$) | 0.38 | $-1.75$ | 0.22 | $-0.34$ |
| Money growth ($\phi_\mu$) | $n.s.$ | $n.s.$ | $n.s.$ | $n.s.$ |

Notes: Results are extracted from Table 5 and 6 in Appendix C. "n.s." stands for non-significant at the 90% confidence level.

Table 3 shows that other countries have rather less sticky prices and more sticky wages than in the U.S. Germany seems to feature more overall stickiness than France or the UK. In addition, France, Germany and the UK all feature significantly different estimates for the Edgeworth parameter $\nu$ during normal times and during war times, public and private goods being more strongly complementary during war episodes. This could result in different PVMs patterns compared to the U.S. Draft parameters, sovereign default parameters and depreciation factors are larger than in the U.S., suggesting that these channels could play a more significant role in the dynamics of war episodes. The largest war-specific depreciation factor is estimated at 10% for Germany, the country of our sample that undoubtedly suffered the largest war-related capital destruction.

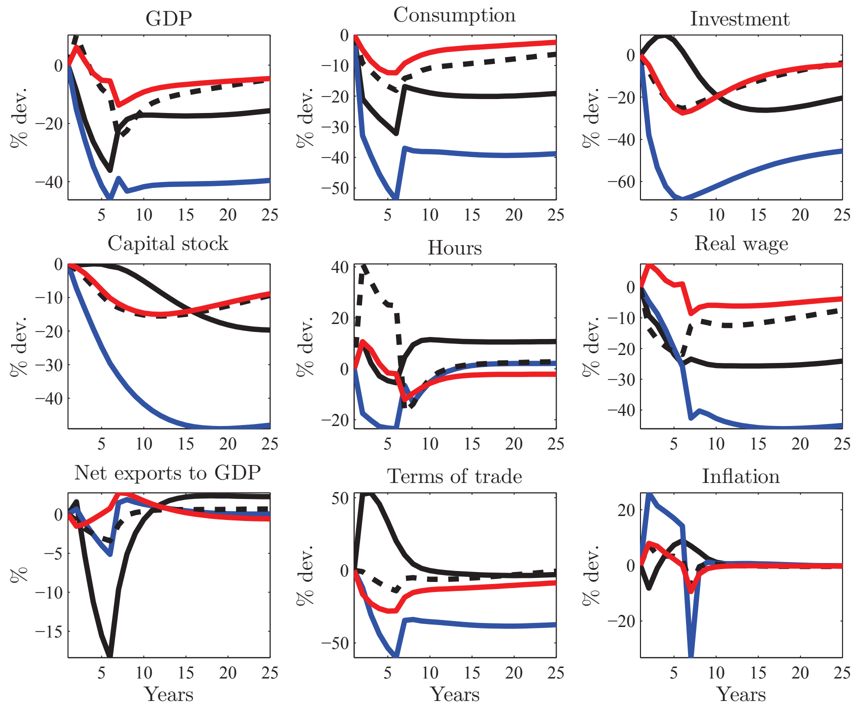
Even more interesting are the differences in war spillovers. As opposed to the U.S. all other countries of our sample experience negative productivity and investment spillovers, and experience negative (France and UK) or non-significant foreign trade spillovers. Only the UK features a positive public spending spillover while this parameter is muted for France and Germany. Finally, France and the UK are characterized by a financing of war efforts through the capital income tax along with a lower labor income tax, while Germany exhibits a financing pattern that is similar to the U.S.: an increase in the labor income tax and a lower capital income tax. In all countries, the spillover on money growth is muted, suggesting that seignorage is not an explicit financing strategy identified by our model and estimation.

We expect these differences to produce quite different dynamics after a war episode, especially for France and Germany. The positive and significant public spending spillover in the UK should make it broadly resemble the U.S.

## 5.2 The macroeconomic effects of a war shock

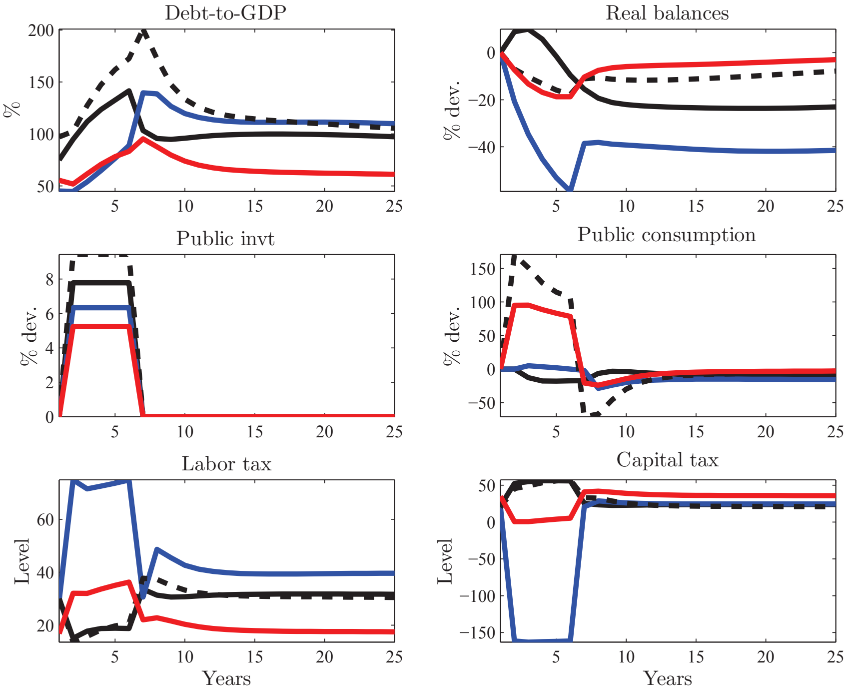
Figure 6 and 7 depict the macroeconomic effects of a war shock in the three countries France, Germany and the UK, as well as the dynamics for the U.S., for a comparison.

**Figure 6:** Impulse Response Functions to a 5-year shock on $\Delta_t$ - Macro variables




Black: France, Blue: Germany, Red: U.S., Dashed: UK

**Figure 7:** Impulse Response Functions to a 5-year shock on $\Delta_t$ - Policy variables




Black: France, Blue: Germany, Red: U.S., Dashed: UK

According to Figure 6 and 7, a war episode in the UK has remarkably similar effects compared to the U.S. GDP rises on impact, consumption and investment fall, driven by the crowding-out effect of the massive rise in public spending. Because the latter is larger than in the U.S., public debt rises much above the levels reached by the U.S. but the global pattern is very much the same. One difference is that the UK shows a different public finance strategy, lowering the labor income tax and raising the capital income tax while the U.S. followed an opposite pattern. However, this different pattern does not seem to feed back so much to key macroeconomic variables. An additional difference is the large trade deficit observed in the UK, driven by the negative trade spillover. The U.S. showed a reduced trade deficit because the trade spillover was positive, mitigating the trade deficit generated by the rise in public spending.

Figure 6 and 7 show a very different pattern for France and Germany. Both countries show similar dynamics, although the magnitude is much larger for Germany. In those countries, a war episode massively lowers GDP – by almost 40% in France and more than 40% in Germany. Consumption falls more than GDP, although public spending does not rise, suggesting that the depreciation of physical capital and the draft play much more prominent roles. France displays a massive trade deficit (almost 20% of GDP) while the

German trade deficit is more reduced and comparable to that found for the UK. Because nominal rigidities are much larger in Germany, inflation rises massively (more than 20%) after reversing when the war shock disappears. France and Germany are characterized by opposite patterns ensuring the sustainability of public debt: France sees a rise in the capital tax and a fall in the labor tax (as the UK) and Germany sees a rise the labor tax and a fall in the capital tax (as the U.S.).

In brief, if the effects of a war episode are rather well captured by a massive rise in public spending for the U.S. and the UK, it is clearly not the case for France and Germany. In those countries, the public spending spillover is not statistically significant, which produces very different dynamics after war episodes. Other channels (military draft, capital destruction) and other negative spillovers (productivity, investment, trade) induce massive negative effects on GDP, consumption and public finance.

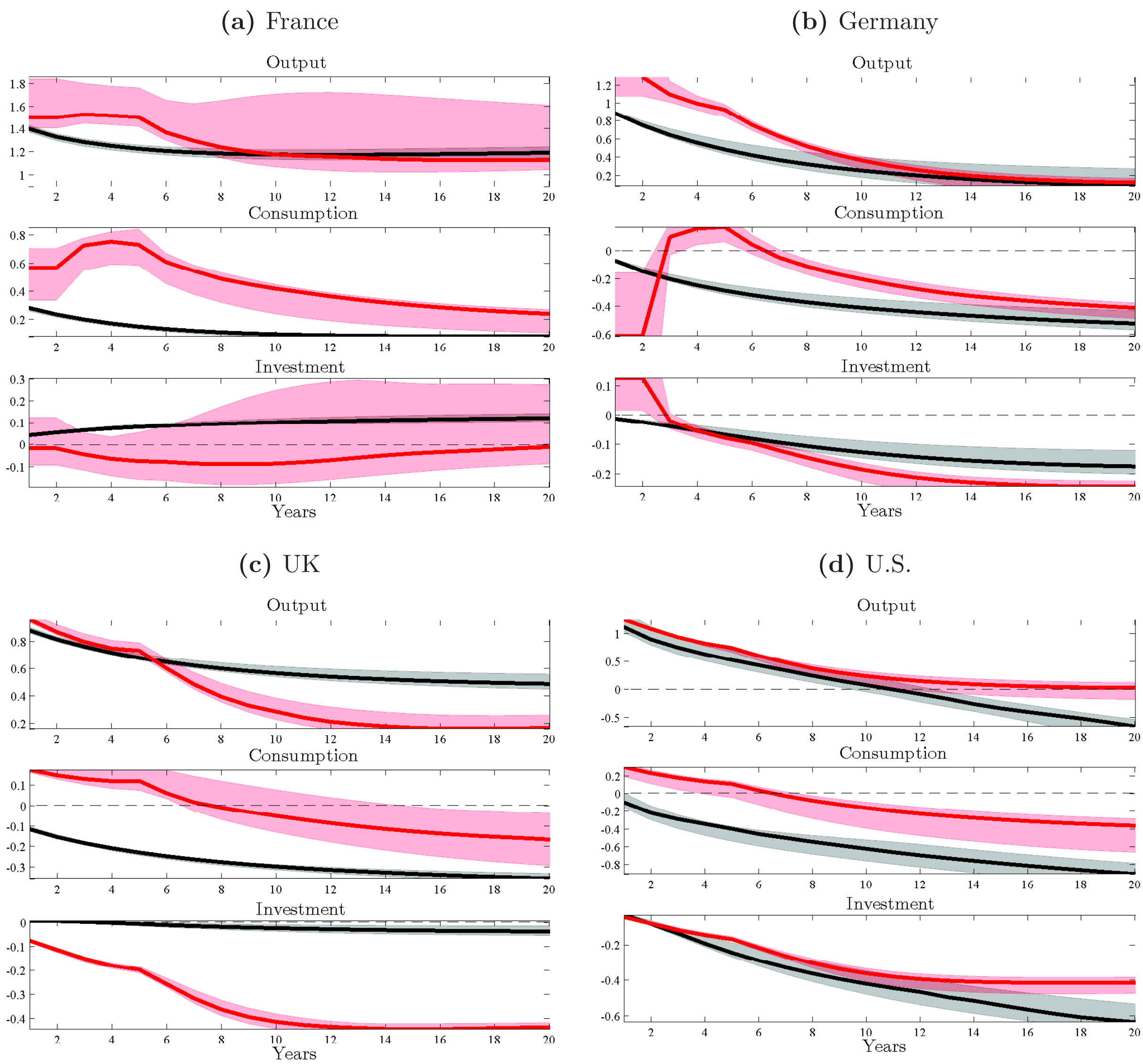
## 5.3 Public spending output multipliers

We now perform the very same computation of public spending multipliers for France, Germany and the UK. Because estimates of the public spending spillover are non-significant for France and Germany, we artificially add a 1% public spending shock to compute the PVMs in the case of wartimes multipliers. Figure 8 reports the public spending multipliers for the four countries along with confidence bands. Again, multipliers are computed conditionally on a war episode or during normal times (i.e. around the steady state).

First, the levels of multipliers differ across countries. France has the largest multipliers (between 1.4 and 1.6 on impact, long-term multipliers above one), followed by the U.S. and Germany (between 1 and 1.3 on impact, long-term multipliers around or slightly above zero), and then the UK features the lowest public spending multipliers (around 0.9 on impact and between 0 and 0.5 in the long run).

Second, while the UK and the U.S. have broadly similar impact and short-run multipliers during war episodes and during normal times, France and Germany feature larger multipliers during war episodes. These differences are statistically significant and suggest that, for those countries, the values of spending multipliers identified with war episode are not informative about the value of multipliers during normal times. We attribute these differences to the levels and differences of estimated Edgeworth complementarity parameters. In addition, long-term multipliers converge to similar values for France and Germany while they tend to differ for the UK and the U.S.

**Figure 8:** Public spending present value multipliers




Black: normal times. Red: War episodes. Shaded areas correspond to one standard deviation confidence intervals ($16^{th}$ and $84^{th}$ percentiles) based on 120 replications of our non-linear simulations. Each replication draws a vector of the estimated parameters from the posterior distributions reported in Appendix and computes PVMs.

Overall, our conclusion is the following. The U.S and the UK behave relatively similarly during war episodes and exhibit relatively similar state-dependent multipliers. France and Germany behave quite differently during war episodes. For those countries, the effects of war episodes can not be captured by large increases in public spending and alternative channels must be taken into account. As a result, spending multipliers for France and Germany are both larger during war episodes than during normal times because the economy is much more depressed than in countries like the U.S. and the UK. These results suggest that the approach of war episodes found in the literature is very much centered around the U.S. and the UK but does not really fit the context of other countries like France or Germany.

## 6 Welfare losses from war episodes

Finally, we proceed to a welfare analysis. Using the series of smoothed shocks, *i.e.* the series of shocks that perfectly replicate our data (disregarding measurement error shocks though), we simulate the model for each country using estimated parameters. First, we feed the model with all smoothed shocks. Then, we feed the model with all shocks but remove the war dummy. We then compute the welfare losses induced by war episodes, measured as the Hicksian consumption equivalent, *i.e.* the consumption compensation that makes households indifferent between living in a world with war dummies and in a world without them. This approach is also used to measure the welfare costs of other shocks. Finally we also report the total welfare losses from fluctuations, measured as the Hicksian equivalent that makes households indifferent between an economy with fluctuations and an economy where all variables remain constant and equal to their means.[14] The results are reported in Table 4.

**Table 4:** Welfare costs, in percents

| Welfare cost of: | France | Germany | UK | U.S. |
|---|---|---|---|---|
| War episodes | 0.6892 | 0.8752 | 0.1185 | −0.0382 |
| Productivity and investment shocks | −0.6391 | −0.6607 | −0.0196 | −0.0350 |
| Foreign demand shocks | 0.0602 | 0.0074 | 0.0061 | 0.0013 |
| Public spending shocks | −0.1991 | −0.0334 | 0.2768 | −1.5256 |
| Taxes shocks | −0.5378 | 0.0049 | −0.0363 | −0.2480 |
| Money growth shocks | 0.0324 | −0.0245 | 0.0054 | 0.0022 |
| All fluctuations | 0.0153 | 0.0103 | 0.0074 | 0.0586 |

[14] As usual when introducing money in the utility function, the welfare effects of real balances are simply ignored.

Table 4 suggests that war episodes have large negative welfare effects for France and Germany, moderately negative effects for the UK and positive effects in the U.S. These results can be traced to the behavior of key macroeconomic variables during war episodes. France and Germany experience large drops in private consumption that are not compensated by a rise in public spending, and large rises in hours worked, which both generate large welfare losses. Quantitatively speaking, Germany suffers the largest welfare losses, representing 0.88% of permanent consumption. France is not far with 0.69% of permanent consumption.

For the UK and the U.S., the negative effects of war episodes are compensated by a large increase in public spending that supports the economy and brings welfare gains to the households since (*i*) public consumption is a direct argument of the utility function and (*ii*) private consumption is crowded-in when public consumption increases, which attenuates the fall in private consumption. Overall, these effects are large enough in the U.S. to bring welfare gains. For the UK, the welfare losses from war episodes is quantified at 0.12% of permanent consumption. The U.S. show a 0.04% welfare *gain*.

As validity check, we also compute the total welfare losses from fluctuations. Based on the whole sample, the latter are much smaller, because the negative welfare effects of some shocks are almost compensated by the positive effects of other shocks. Overall, the resulting welfare losses from fluctuations are very small, in the order of magnitude typically reported by Lucas (1987) and the subsequent literature, between 0.01% and 0.06% of permanent consumption.

# 7 Conclusion

War episodes induce large shifts in macroeconomic variables provoked by a series of potential related causes: destruction, military draft, changes in national borders, large wealth transfers from a defeated country to a victorious one, interventions of governments that raise public spending, inflate the public and military sector, alter the structure of the labor market and impose financial and goods market restrictions.

This paper proposed an estimated open economy model that would be suited to capture the dynamics of countries like France, Germany, the UK and the U.S. both during normal times and during war episodes. Of course, all the aspects enumerated above could not be fully taken into account but some of them (capital destruction, draft, sovereign default) were, and were shown to be statistically significant. In addition, we shown that the macroeconomic effects of war episodes were not fully accounted for by these only elements, and needed to be completed with other elements. A massive increase in public spending (UK, U.S.), negative productivity and investment shocks (France, Germany and the UK), a negative world demand shock (France and the UK), and variations in the labor and capital income tax rates. While the importance of the public spending shock is overwhelming in the UK and the U.S., other shocks and factors (military draft, capital destruction) seem to matter more for France and Germany.

Finally, our estimation results were used to derive results about the size and state-dependence of public spending output multipliers and about the welfare losses from war episodes. The UK and the U.S. shared a lot of characteristics: state-dependent multipliers were not fundamentally different from those derived in normal times, and the welfare losses from war episode were relatively limited. France and Germany also showed some similarities: wartime multipliers were significantly larger than those obtained in normal times and war episodes imposed much larger welfare losses on those countries.

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# A The steady state

We analyze the linearized dynamics of the model around the closed economy steady-state without inflation, where we also assume $s = 1$. The steady-state of the economy is one where the war dummy is zero, *i.e.* $\Delta = 0$. Further, by definition, $\gamma = 0$, and the dynamics of $q$ gives $q = 1$. The condition on the utilization rate thus gives

$$r^k = \frac{\phi_z (z-1)}{1-\tau^k} \tag{46}$$

which plugged in the investment equation pins down $z$

$$z = \sqrt{1 + \frac{2\left(\beta^{-1} + \delta\left(1-\tau^k\right) - 1\right)}{\phi_z}} \tag{47}$$

as well as $r^k$. Next use the real marginal cost to get the real wage $w$

$$w = \left(\frac{(\theta-1)}{\theta}\iota^{\iota}(1-\iota)^{(1-\iota)}\left(r^k\right)^{-\iota}\right)^{\frac{1}{1-\iota}} \tag{48}$$

Further, we impose $a = n = 1$ and use

$$k = \frac{\iota}{1-\iota}\frac{w}{r^k z} \tag{49}$$

and the aggregate production function

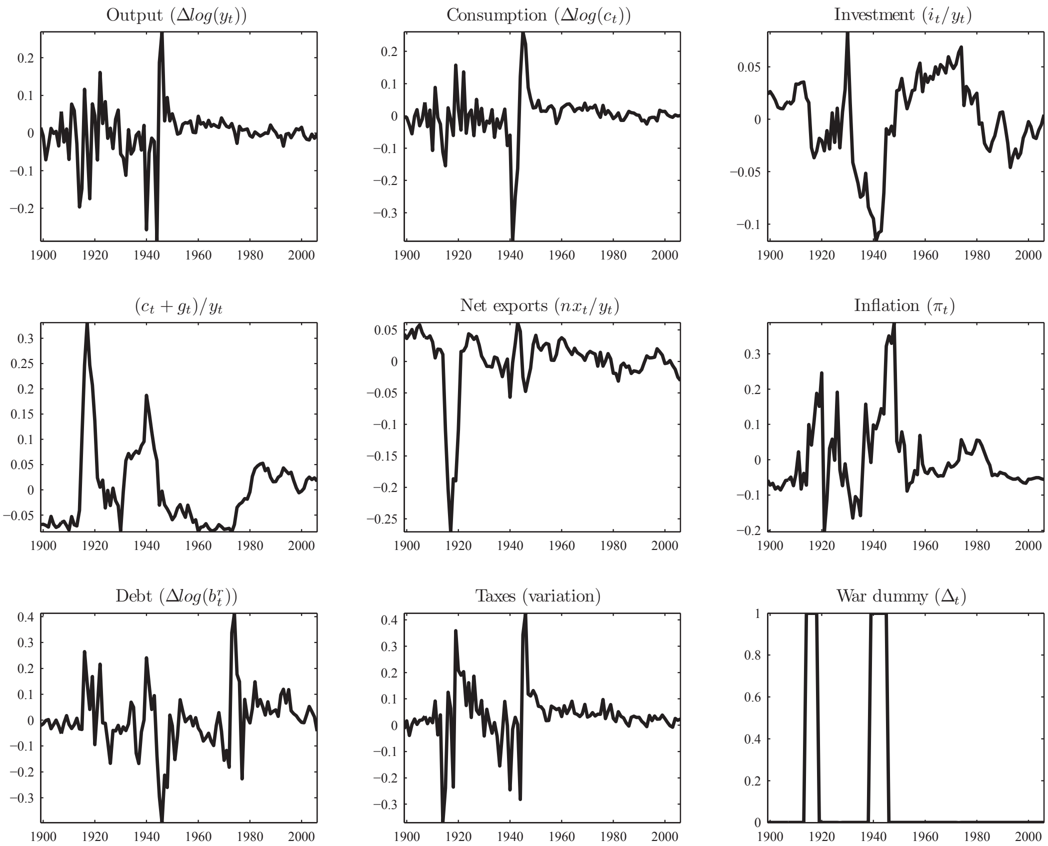
$$y = (zk)^{\iota} \tag{50}$$

to get consumption

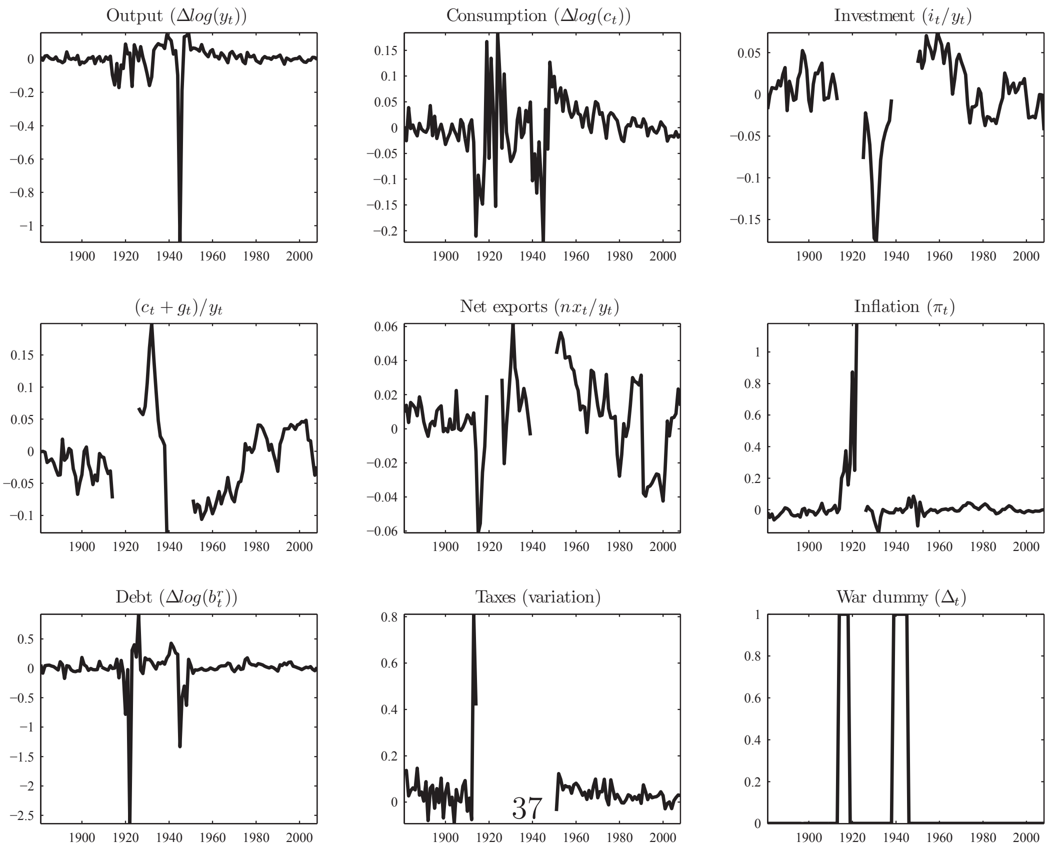
$$c = \left(1-\kappa-\kappa^i\right) y - \delta k - \frac{\phi_z}{2}(z-1)^2 k \tag{51}$$

where $\kappa = g/y$ and $\kappa^i = i^g/y$ are the (imposed) steady-state share of public consumption and investment expenditure in GDP. Finally, the labor supply equation gives the value of $\chi_n$ that normalizes $n$ to one.

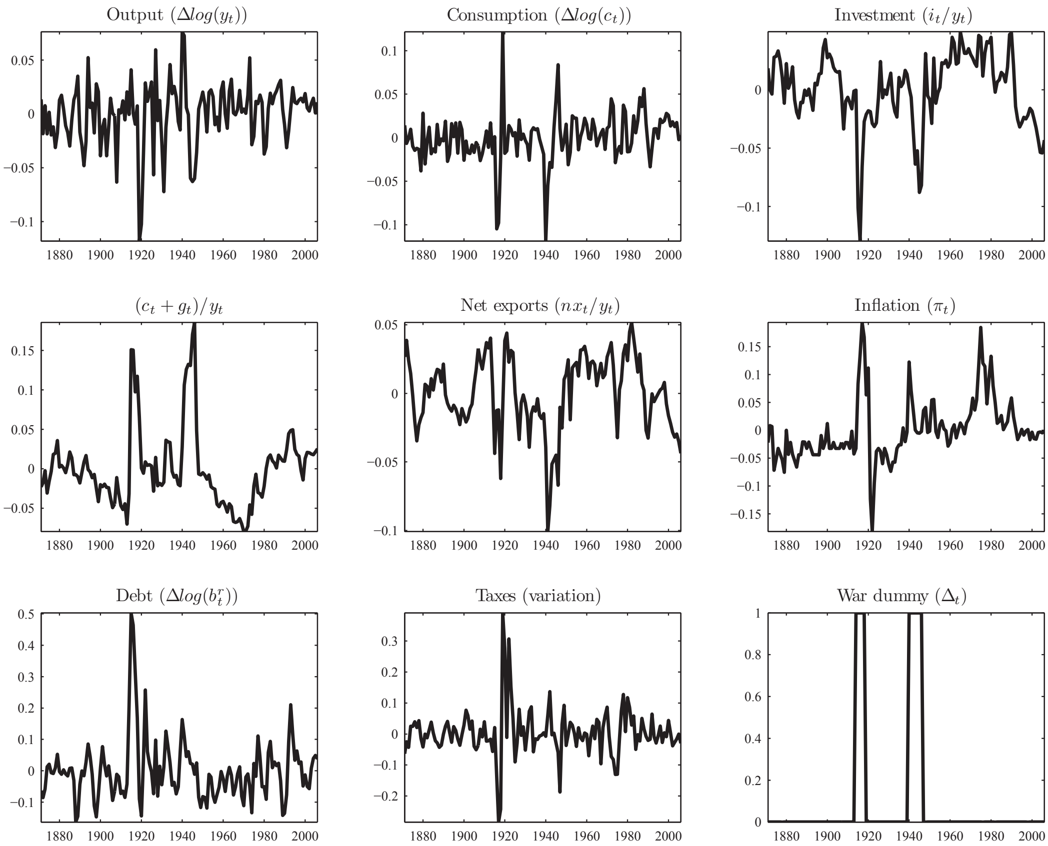
# B Datasets




**(a)** France

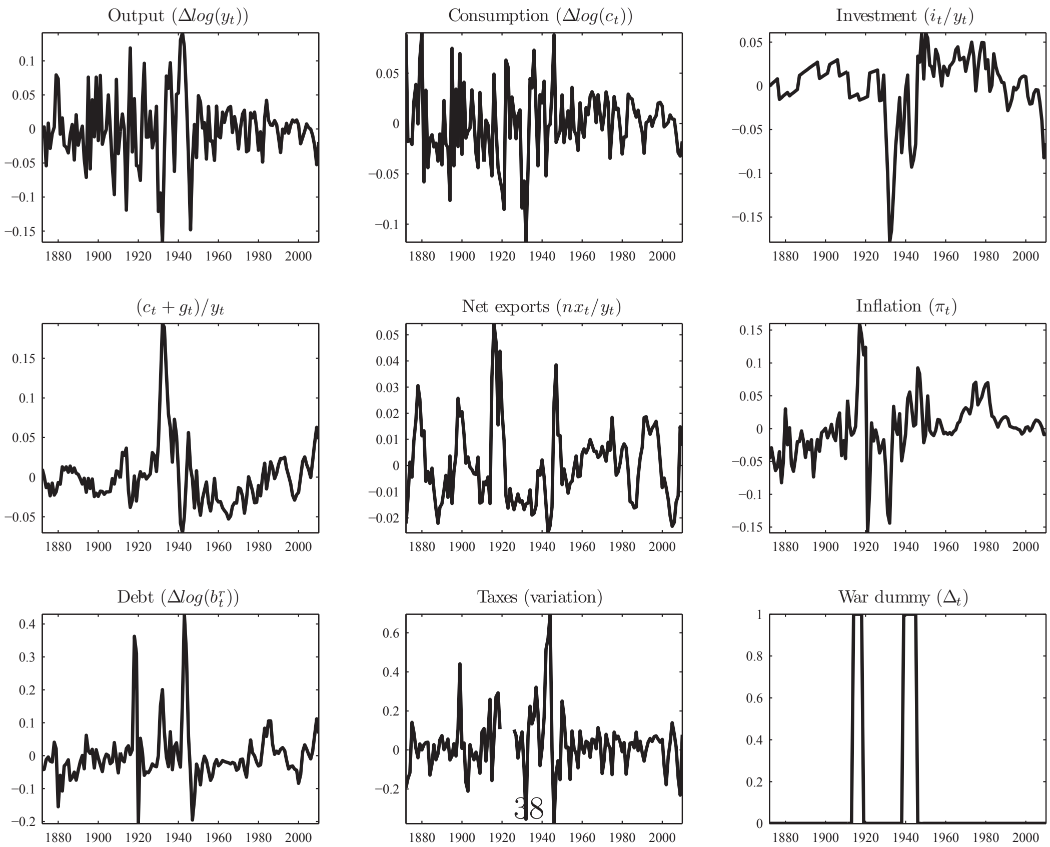



**(b)** Germany



Output ($\Delta log(y_t)$)
Consumption ($\Delta log(c_t)$)
Investment ($i_t/y_t$)
$(c_t + g_t)/y_t$
Net exports ($nx_t/y_t$)
Inflation ($\pi_t$)
Debt ($\Delta log(b_t^r)$)
Taxes (variation)
War dummy ($\Delta_t$)

**(a)** UK



Output ($\Delta log(y_t)$)
Consumption ($\Delta log(c_t)$)
Investment ($i_t/y_t$)
$(c_t + g_t)/y_t$
Net exports ($nx_t/y_t$)
Inflation ($\pi_t$)
Debt ($\Delta log(b_t^r)$)
Taxes (variation)
War dummy ($\Delta_t$)

**(b)** U.S.

# C Estimation results

**Table 5:** Country-specific estimated parameters (France and Germany)

| | Priors | | | Post. (France) | | | Post. (Germany) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Dist. | Mean | Sd. | Mean | Inf | Sup | Mean | Inf | Sup |
| Structural parameters | | | | | | | | | |
| Calvo prices ($\eta^p$) | $B$ | 0.25 | 0.10 | 0.20 | 0.15 | 0.25 | 0.22 | 0.16 | 0.27 |
| Calvo wages ($\eta^w$) | $B$ | 0.25 | 0.10 | 0.27 | 0.14 | 0.39 | 0.40 | 0.33 | 0.47 |
| Edgeworth comp. ($\nu_{norm}$) | $IG$ | 0.50 | 0.25 | 0.50 | 0.47 | 0.53 | 0.56 | 0.52 | 0.60 |
| Edgeworth comp. ($\nu_{war}$) | $IG$ | 0.50 | 0.25 | 0.35 | 0.30 | 0.40 | 0.48 | 0.40 | 0.55 |
| War draft ($p^\ell$) | $B$ | 0.15 | 0.05 | 0.08 | 0.02 | 0.14 | 0.08 | 0.02 | 0.15 |
| War default ($p^b$) | $B$ | 0.15 | 0.05 | 0.08 | 0.03 | 0.13 | 0.10 | 0.02 | 0.16 |
| War capital depreciation ($p^\delta$) | $B$ | 0.15 | 0.05 | 0.09 | 0.02 | 0.15 | 0.10 | 0.02 | 0.17 |
| Investment adj. cost ($\phi_i$) | $N$ | 5.00 | 0.50 | 4.04 | 3.21 | 4.89 | 4.68 | 3.85 | 5.52 |
| Trade elasticity ($\mu$) | $N$ | 1.50 | 0.25 | 1.48 | 1.31 | 1.65 | 1.24 | 1.08 | 1.40 |
| Labor tax rule ($d_{\tau^n}$) | $IG$ | 0.25 | 0.25 | 0.09 | 0.07 | 0.12 | 0.32 | 0.18 | 0.44 |
| Capital tax rule ($d_{\tau^n}$) | $IG$ | 0.25 | 0.25 | 0.13 | 0.08 | 0.18 | 0.15 | 0.08 | 0.22 |
| Spending rule ($d_g$) | $IG$ | 0.25 | 0.25 | 0.15 | 0.09 | 0.21 | 0.10 | 0.07 | 0.13 |
| War spillovers | | | | | | | | | |
| Productivity ($\phi_a$) | $N$ | 0.00 | 2.00 | −0.05 | −0.08 | −0.02 | −0.06 | −0.09 | −0.03 |
| Spending ($\phi_g$) | $N$ | 0.00 | 2.00 | 0.01 | −0.09 | 0.11 | 0.03 | −0.10 | 0.17 |
| Investment ($\phi_\varsigma$) | $N$ | 0.00 | 2.00 | −0.62 | −1.08 | −0.17 | −0.46 | −0.91 | −0.02 |
| Trade ($\phi_{y^*}$) | $N$ | 0.00 | 2.00 | −0.70 | −0.94 | −0.45 | −0.08 | −0.29 | 0.12 |
| Labor tax ($\phi_{\tau^n}$) | $N$ | 0.00 | 2.00 | −0.18 | −0.25 | −0.10 | 0.44 | 0.24 | 0.63 |
| Capital tax ($\phi_{\tau^n}$) | $N$ | 0.00 | 2.00 | 0.38 | 0.18 | 0.59 | −1.75 | −2.49 | −1.00 |
| Money growth ($\phi_\mu$) | $N$ | 0.00 | 2.00 | 0.03 | −0.03 | 0.10 | −0.01 | −0.07 | 0.05 |
| Persistence | | | | | | | | | |
| Productivity ($\rho_a$) | $B$ | 0.70 | 0.20 | 0.98 | 0.97 | 1.00 | 0.99 | 0.97 | 1.00 |
| Public spending ($\rho_g$) | $B$ | 0.70 | 0.20 | 0.99 | 0.98 | 1.00 | 0.97 | 0.95 | 0.99 |
| Investment ($\rho_\zeta$) | $B$ | 0.70 | 0.20 | 0.39 | 0.26 | 0.52 | 0.59 | 0.45 | 0.73 |
| Foreign demand ($\rho_{y^*}$) | $B$ | 0.70 | 0.20 | 0.65 | 0.58 | 0.71 | 0.63 | 0.49 | 0.77 |
| Meas. error ($\rho^y_{err}$) | $B$ | 0.70 | 0.20 | 0.13 | 0.03 | 0.22 | 0.24 | 0.10 | 0.39 |
| Labor tax ($\rho_{\tau^n}$) | $B$ | 0.70 | 0.20 | 1.00 | 1.00 | 1.00 | 0.85 | 0.75 | 0.95 |
| Capital tax ($\rho_{\tau^k}$) | $B$ | 0.70 | 0.20 | 0.88 | 0.82 | 0.94 | 0.53 | 0.34 | 0.71 |
| Money growth ($\rho_m$) | $B$ | 0.70 | 0.20 | 0.14 | 0.03 | 0.24 | 0.38 | 0.05 | 0.68 |
| Standard deviations of shocks | | | | | | | | | |
| Productivity | $IG$ | 0.10 | $Inf$ | 0.06 | 0.05 | 0.07 | 0.04 | 0.03 | 0.05 |
| Public spending | $IG$ | 0.10 | $Inf$ | 0.10 | 0.09 | 0.12 | 0.10 | 0.09 | 0.12 |
| Investment | $IG$ | 0.10 | $Inf$ | 0.78 | 0.59 | 0.96 | 0.54 | 0.41 | 0.66 |
| Foreign demand | $IG$ | 0.10 | $Inf$ | 0.38 | 0.33 | 0.44 | 0.23 | 0.19 | 0.26 |
| Meas. error | $IG$ | 0.10 | $Inf$ | 0.10 | 0.09 | 0.11 | 0.05 | 0.04 | 0.06 |
| Labor tax | $IG$ | 0.10 | $Inf$ | 0.06 | 0.05 | 0.06 | 0.16 | 0.13 | 0.19 |
| Capital tax | $IG$ | 0.10 | $Inf$ | 0.14 | 0.12 | 0.16 | 0.28 | 0.24 | 0.33 |
| Money growth | $IG$ | 0.10 | $Inf$ | 0.13 | 0.11 | 0.16 | 0.11 | 0.05 | 0.17 |
| War | $IG$ | 0.10 | $Inf$ | 0.33 | 0.29 | 0.37 | 0.31 | 0.27 | 0.34 |
| Marginal data density | | | | | | | | | |
| | | | | | 1113.42 | | | 1186.84 | |

Notes: Results based on 250 000 replications of the MH algorithm. Standard deviations are expressed in percents. N, B and IG respectively denote Normal, Beta and Inverse Gamma distributions. Marginal data density is the harmonic mean.

**Table 6:** Country-specific estimated parameters (UK and U.S.)

| | Priors | | | Post. (UK) | | | Post. (U.S.) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Dist. | Mean | Sd. | Mean | Inf | Sup | Mean | Inf | Sup |
| Structural parameters | | | | | | | | | |
| Calvo prices ($\eta^p$) | $B$ | 0.25 | 0.10 | 0.25 | 0.20 | 0.31 | 0.40 | 0.36 | 0.44 |
| Calvo wages ($\eta^w$) | $B$ | 0.25 | 0.10 | 0.14 | 0.05 | 0.22 | 0.20 | 0.11 | 0.30 |
| Edgeworth comp. ($\nu_{norm}$) | $IG$ | 0.50 | 0.25 | 0.60 | 0.59 | 0.62 | 0.55 | 0.53 | 0.57 |
| Edgeworth comp. ($\nu_{war}$) | $IG$ | 0.50 | 0.25 | 0.46 | 0.42 | 0.51 | 0.51 | 0.47 | 0.55 |
| War draft ($p^\ell$) | $B$ | 0.15 | 0.05 | 0.11 | 0.03 | 0.18 | 0.06 | 0.02 | 0.11 |
| War default ($p^b$) | $B$ | 0.15 | 0.05 | 0.06 | 0.02 | 0.10 | 0.12 | 0.06 | 0.18 |
| War capital depreciation ($p^\delta$) | $B$ | 0.15 | 0.05 | 0.09 | 0.02 | 0.15 | 0.09 | 0.02 | 0.16 |
| Investment adj. cost ($\phi_i$) | $N$ | 5.00 | 0.50 | 3.74 | 2.92 | 4.53 | 4.27 | 3.49 | 5.05 |
| Trade elasticity ($\mu$) | $N$ | 1.50 | 0.25 | 1.17 | 1.08 | 1.26 | 1.26 | 1.17 | 1.35 |
| Labor tax rule ($d_{\tau^n}$) | $IG$ | 0.25 | 0.25 | 0.07 | 0.06 | 0.09 | 0.13 | 0.08 | 0.17 |
| Capital tax rule ($d_{\tau^n}$) | $IG$ | 0.25 | 0.25 | 0.11 | 0.08 | 0.15 | 0.17 | 0.08 | 0.25 |
| Spending rule ($d_g$) | $IG$ | 0.25 | 0.25 | 0.11 | 0.07 | 0.15 | 0.10 | 0.07 | 0.13 |
| War spillovers | | | | | | | | | |
| Productivity ($\phi_a$) | $N$ | 0.00 | 2.00 | −0.02 | −0.04 | −0.01 | 0.01 | −0.01 | 0.02 |
| Spending ($\phi_g$) | $N$ | 0.00 | 2.00 | 0.34 | 0.22 | 0.47 | 0.14 | 0.07 | 0.21 |
| Investment ($\phi_\varsigma$) | $N$ | 0.00 | 2.00 | −0.34 | −0.64 | −0.05 | 0.06 | −0.31 | 0.41 |
| Trade ($\phi_{y^*}$) | $N$ | 0.00 | 2.00 | −0.38 | −0.52 | −0.24 | 0.16 | 0.06 | 0.26 |
| Labor tax ($\phi_{\tau^n}$) | $N$ | 0.00 | 2.00 | −0.14 | −0.20 | −0.09 | 0.13 | 0.06 | 0.20 |
| Capital tax ($\phi_{\tau^n}$) | $N$ | 0.00 | 2.00 | 0.22 | 0.08 | 0.36 | −0.34 | −0.54 | −0.14 |
| Money growth ($\phi_\mu$) | $N$ | 0.00 | 2.00 | 0.02 | −0.00 | 0.05 | −0.02 | −0.04 | 0.01 |
| Persistence | | | | | | | | | |
| Productivity ($\rho_a$) | $B$ | 0.70 | 0.20 | 0.95 | 0.92 | 0.99 | 0.97 | 0.95 | 1.00 |
| Public spending ($\rho_g$) | $B$ | 0.70 | 0.20 | 0.97 | 0.95 | 0.99 | 1.00 | 1.00 | 1.00 |
| Investment ($\rho_\varsigma$) | $B$ | 0.70 | 0.20 | 0.51 | 0.40 | 0.62 | 0.55 | 0.43 | 0.67 |
| Foreign demand ($\rho_{y^*}$) | $B$ | 0.70 | 0.20 | 0.60 | 0.53 | 0.68 | 0.86 | 0.81 | 0.92 |
| Meas. error ($\rho^y_{err}$) | $B$ | 0.70 | 0.20 | 0.15 | 0.05 | 0.25 | 0.15 | 0.04 | 0.24 |
| Labor tax ($\rho_{\tau^n}$) | $B$ | 0.70 | 0.20 | 1.00 | 0.99 | 1.00 | 1.00 | 1.00 | 1.00 |
| Capital tax ($\rho_{\tau^k}$) | $B$ | 0.70 | 0.20 | 0.97 | 0.94 | 1.00 | 0.81 | 0.75 | 0.88 |
| Money growth ($\rho_m$) | $B$ | 0.70 | 0.20 | 0.25 | 0.06 | 0.43 | 0.41 | 0.23 | 0.59 |
| Standard deviations of shocks | | | | | | | | | |
| Productivity | $IG$ | 0.10 | $Inf$ | 0.03 | 0.03 | 0.04 | 0.03 | 0.03 | 0.03 |
| Public spending | $IG$ | 0.10 | $Inf$ | 0.12 | 0.11 | 0.14 | 0.07 | 0.06 | 0.08 |
| Investment | $IG$ | 0.10 | $Inf$ | 0.52 | 0.40 | 0.63 | 0.70 | 0.56 | 0.83 |
| Foreign demand | $IG$ | 0.10 | $Inf$ | 0.23 | 0.21 | 0.26 | 0.19 | 0.15 | 0.22 |
| Meas. error | $IG$ | 0.10 | $Inf$ | 0.08 | 0.07 | 0.09 | 0.05 | 0.04 | 0.05 |
| Labor tax | $IG$ | 0.10 | $Inf$ | 0.05 | 0.04 | 0.05 | 0.08 | 0.07 | 0.08 |
| Capital tax | $IG$ | 0.10 | $Inf$ | 0.10 | 0.09 | 0.11 | 0.17 | 0.15 | 0.19 |
| Money growth | $IG$ | 0.10 | $Inf$ | 0.05 | 0.04 | 0.07 | 0.05 | 0.03 | 0.06 |
| War | $IG$ | 0.10 | $Inf$ | 0.30 | 0.27 | 0.32 | 0.29 | 0.26 | 0.32 |
| Marginal data density | | | | | | | | | |
| | | | | | 1883.54 | | | 1870.81 | |

Notes: Results based on 250 000 replications of the MH algorithm. Standard deviations are expressed in percents. N, B and IG respectively denote Normal, Beta and Inverse Gamma distributions. Marginal data density is the harmonic mean.

# D Prior and posterior distributions

**Figure 9:** Priors and Posteriors - France

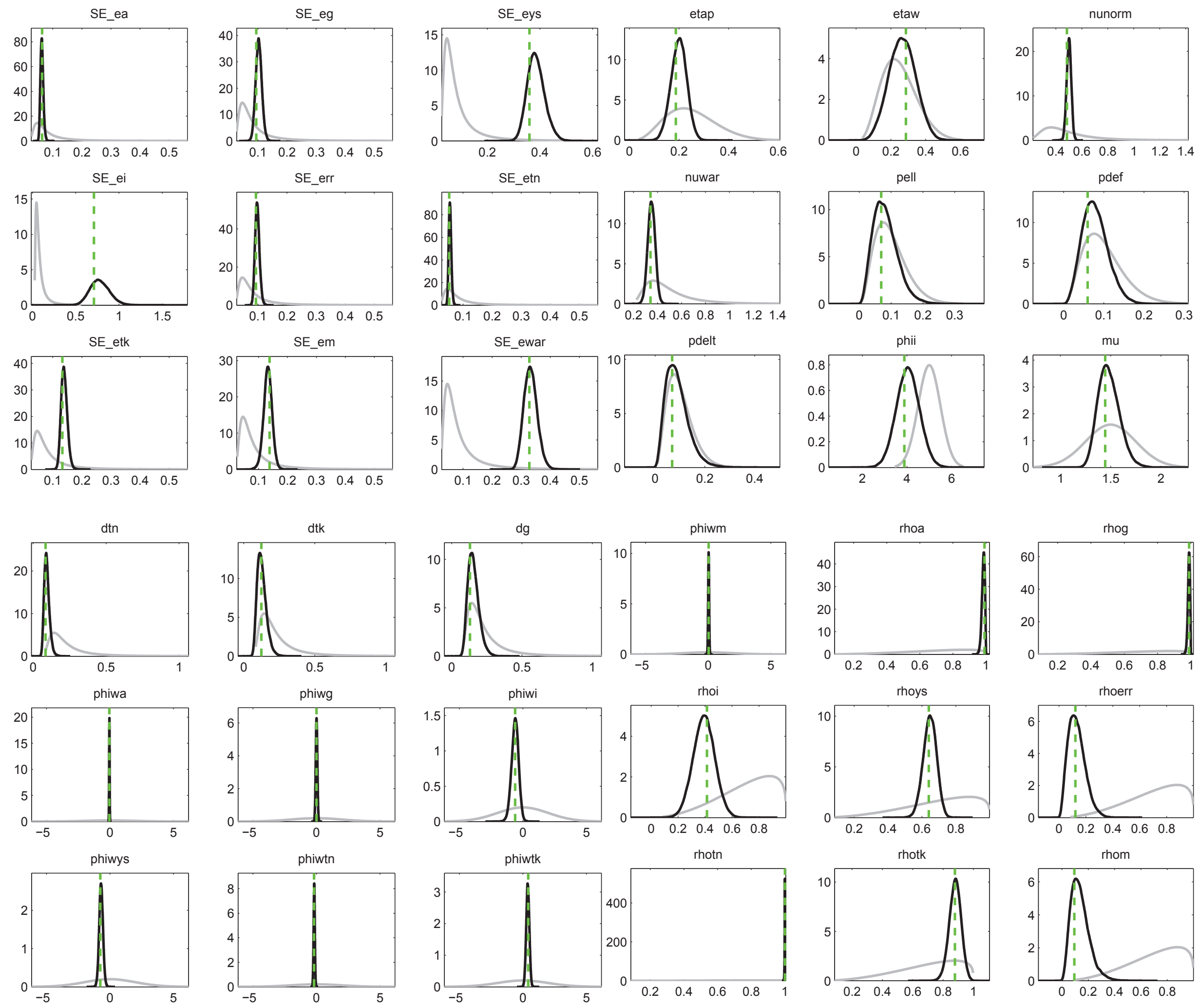


**Figure 10:** Priors and Posteriors - Germany

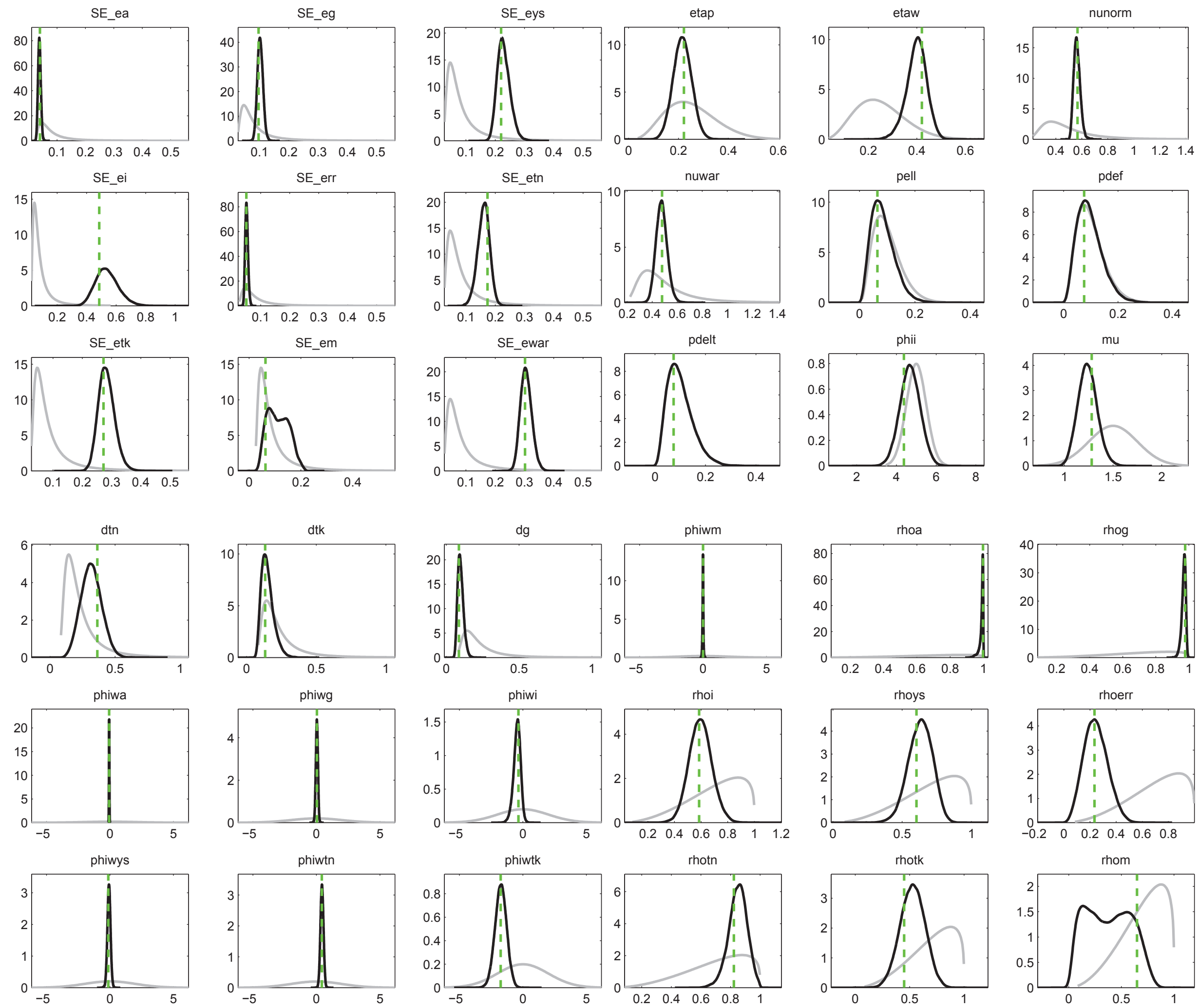


**Figure 11:** Priors and Posteriors - UK

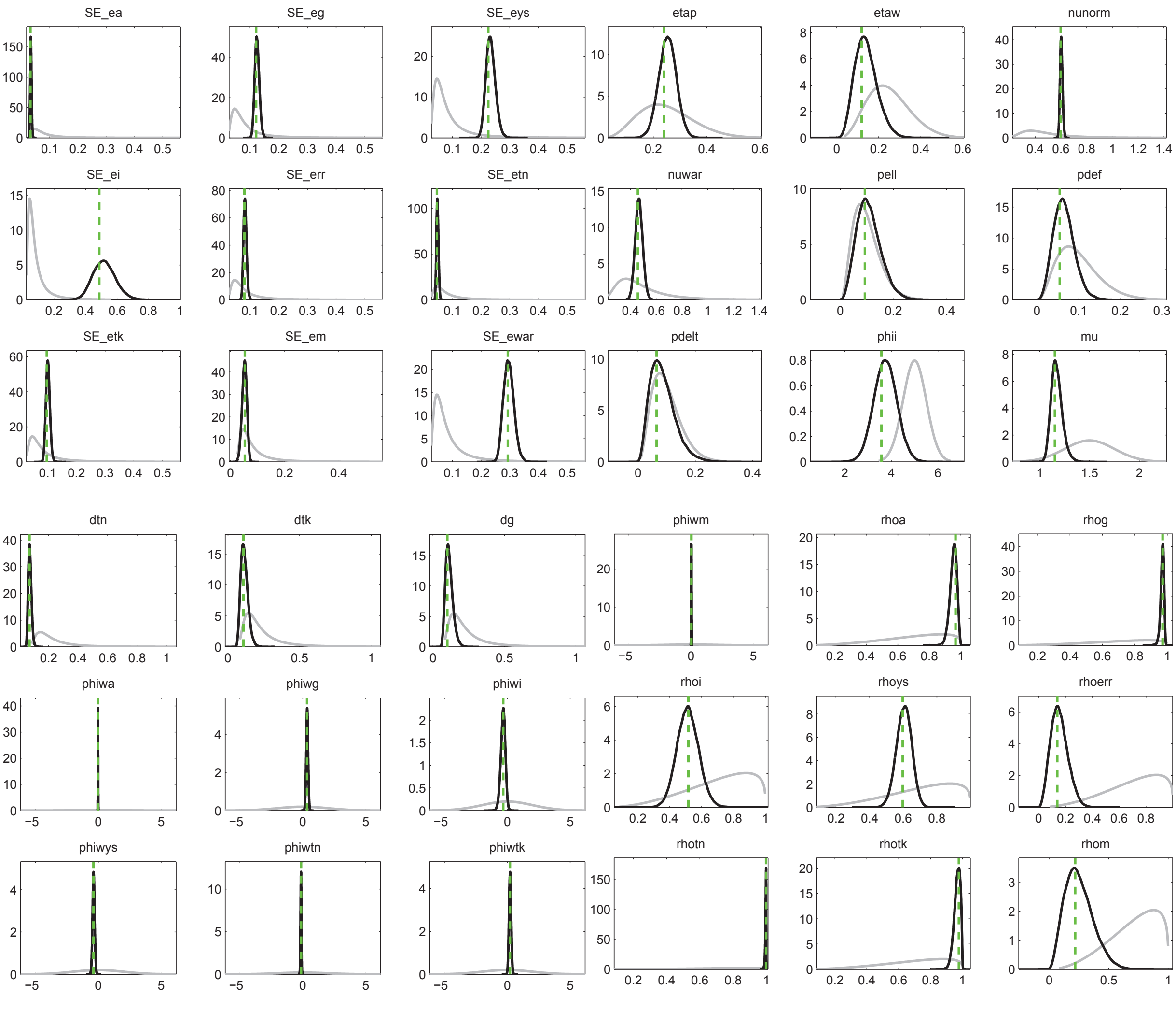


**Figure 12:** Priors and Posteriors - U.S.