How Different are Supply Shocks under the Zero Lower Bound and Normal Times? Empirical Investigation of the New-Keynesian Model and Paradoxes

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Abstract

After the Financial Crisis, developed economies reached a situation under which nominal interest rates are constrained by the Zero Lower Bound (ZLB). In this situation, New Keynesian models predict peculiar effects of supply shocks: positive shocks to technology, labor participation or energy supply could potentially have contractionary effects: the 'Paradox of Toil'. This is due to the fact that all of these shocks have in common to reduce inflation or expected inflation, which in a world of constant nominal rates mean higher real rates.

In this paper, we first assess how domestic and foreign shocks can affect output and prices in a New Keynesian model in and out of the ZLB, and show that they all exhibit a version of the paradox. In the remainder of the paper, we test these predictions using four different types of supply shocks and do not find robust empirical evidence of the paradox.

JEL Codes: E0, F3, F4, G1
Keywords: Liquidity Trap, Zero Lower Bound, New Keynesian Economy, Open Economy, Secular Stagnation, Nonlinear solving, Paradox of Toil.

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Contents

1 Introduction

Following the Great Recession, real interest rates fell and monetary policy was quickly constrained by the situation in which it cannot decrease the nominal interest rate below the guaranteed return of cash, which is zero. This situation is called the "Zero Lower Bound" or the "Effective Lower Bound". In this particular economic environment where monetary policy is highly accommodating but also constrained, major economies have been struggling to recover from the crisis. Even though, some may manage to exit from the ZLB by raising the nominal rate, which occurred in the US recently, the possibility that the nominal rates can cut to zero can still yield results similar to that under the ZLB.

In 2013, Lawrence Summers suggested that developed economies entered the age of secular stagnation, a concept first employed by Hansen (1939) during the Great Depression to describe an economy with a permanent insufficient demand. In modern economic history, only Japan has been experiencing a durable economic stagnation characterised by low growth rate and low inflation, called the "Japanese Lost Decades" after the burst of the financial and the real-estate boom in 1990. However, since the onset of the 2007 financial crisis, most advanced economies experienced a very severe economic contraction followed by an economic environment that is similar to that of the Japanese case. But if output is constrained by insufficient demand, anything that affects demand directly affects output. Thus, a positive supply shock, by being deflationary, can shoot up real rates and thus, decrease demand and output: the 'Paradox of Toil'. If it is true, it could have major implication for policy, since anything resembling a positive supply shock, such as labour market flexibility, deregulation of product markets or innovation inducing measures, could have negative instead of positive effects.

This research project is composed of three sections – theoretical evidence with an open-economy model, empirical investigation of the effects and reconciliation or adaptation of the theoretical framework to be compatible with the empirical observation.

The first aims at assessing the theoretical conditions under which such a paradox occurs. In a small open economy New Keynesian (NK) model, we show that domestic and foreign supply shocks both have negative effects on output and prices, as predicted by traditional closed-economy NK models. As a matter of fact, when the nominal interest rate is fixed, a decrease in inflation is equivalent to an increase in real rates. Since consumption and investment are negatively related to the real rates, a positive supply shock, which can be either domestic or foreign, decreases inflation and thus, has negative effects.

The second part of this research project deals with empirical investigation. Supply shocks are traditionally identified via sign restrictions. It reflects the fact that the demand shocks make prices and production move in the same way (higher output with higher inflation since the economy is demand-driven) whereas supply shocks make them move in the opposite way. However, this sign-restriction Structural Vector Auto-Regression (S-VAR) models often developed in existing academic literature cannot be applied here since we remain agnostic on the sign of the effect of supply shocks. we study the effect of three supply shocks: utilisation-adjusted TFP shock, energy (oil and gas) price shock and trade supply shock. Applied the specific case of Euro Area countries, we find no robust evidence of the existence of the Paradox of Toil. This result is crucial since it implies that contrary to the traditional New-Keynesian economic theory, the Zero Lower Bound or more broadly, an economic environment with constrained monetary policy does not radically change traditional economic predictions.

2 Related literature

This research combines various topics. The first section that deals with macroeconomic modelling issues and incorporates elements from open-economy New-Keynesian models, the Zero Lower Bound literature and the non-linear solving techniques. The second section exposes empirical strategies to identify shocks and assess their impacts. we consider three types of supply shocks: utilisation-adjusted total factor productivity, energy (oil and gas) shock and international trade shock. Finally, to reconcile theory and the empirical observation, we get inspiration from the state-of-the-art literature on the economic modelling. we describe in more details those literature below.

Open-economy New-Keynesian models: With both trade liberalisation and the advent of the global value chain, the open-economy models seem to reflect better the reality and more useful in analysing economic policies and its implications. Indeed, the effect of policies and the agents' behaviour can be quite different between an open economy and a closed economy. Among the open-economy models, one can consider either a small open-economy model (SOE) or a multi-economy model (a number of countries of similar size). In this paper, to compare the effect of supply shocks in ZLB and in normal times, we opt for a small-open economy model following Gali and Monacelli (2005) and Eyquem and Kamber (2014). (*In the second place, we may build a two-economy model with Euro area and the rest of world following Christiano et al. (2005) or Smets and Wouters (2007)*)

Supply-side policies: In the wake of the global financial crisis, there has been a thriving literature around the effect of supply side policies and structural reforms. Eggertsson *et al.* (2014) develop a model in which structural reforms described as a decline in monopolistic rents (markups) or in wage leads to a negative effect on the economy. The downside effect is even larger if those reforms are temporary. Cacciatore *et al.* (2017) consider three types of structural reforms (one on the product market and two others on the labour market) and find that they can be expansionary. The effects of these reforms mainly stem from the New-Keynesian framework.

Zero Lower Bound: The Zero Lower Bound (ZLB) is a peculiar environment in which many traditional theoretical economic mechanisms do not hold or need to be revisited. For instance, Eggertsson (2011) finds that a cut in labour tax rate leads to a fall in the employment level (a property he calls "paradox of toil"). Christiano *et al.* (2005) and Woodford (2011) find that the size of the government multiplier is much larger during the ZLB than the normal times. Indeed, in a situation of liquidity trap, fiscal policies do have potentially much larger and stronger effect than monetary policies, which are much weaker. Also, the forward guidance policy *i.e.* a commitment of the central bank to keep the interest rate low in the future without taking any current action can boost current consumption and output since agents expect lower future interest rates. Wieland (2016) builds a New-Keynesian framework and finds that a negative supply shock can be expansionary. However, he concludes that such mechanisms are not verified empirically. One of the objectives of our paper is to provide empirical evidence of the paradox within the Eurozone countries.

Occasionally binding constraint: Simulating the ZLB is anything but obvious since it introduces a non-linearity. Indeed, New-Keynesian DSGE model is traditionally solved through a small perturbation method by log-linearising. However, the ZLB constraint introduces a non-linearity to the problem. Guerrieri and Iacoviello (2014) present a piecewise technique to solve the occasionally binding constraint model in a piecewise way. They solve the problem segment by segment on which problem becomes linear.

Identification of shocks: Our empirical assessment is carried out in two steps: First, supply shocks are identified by an econometric or a structural VAR model (depending on the type of shock). Second, the extracted shock profiles are used to quantify their effects on economic activity.

- Garin *et al.* (2016), following Basu *et al.* (2006) and Fernald (2012), compute a quarterly measure of the TFPs adjusted of the factor heterogeneity and utilisation for US business sector, and show that supply shocks have more expansionary effects at the ZLB.

- Wieland (2016) uses a methodology developed by Kilian (2009) to identify oil supply shocks, and under the assumption of a small open economy, uses this exogenous shock profile to look at the effect on output. He also considers the exogenous supply shock that is the Fukushima accident in Japan. The author does not find empirical evidence supporting the paradox. We apply his methodology to look at the effect of oil and gas supply shocks on the Euro Area.

- Autor *et al.* (2016) use the rise of trade with China as an exogenous supply shock to local domestic markets. Indeed, high productivity growth in the emerging countries can be regarded as a supply shock in the importing developed countries.

3 Theoretical framework

Here, based on the Gali and Monacelli (2005) and Eyquem and Kamber (2014), a New Keynesian small open economy model is sketched. The aim of this section is to check whether the paradox holds even in an open-economy model. Indeed, for a closed-economy, the effect of negative supply shocks is well-documented. One of the key building blocks of our model is the transmission channel of foreign supply shocks to the domestic product cost, thus, affecting the domestic supply side.

3.1 Households

A representative household maximises her utility over consumption and labour. The preference shock Λ_t affects households and brings the economy to the ZLB situation.

$$\mathbb{E}\left\{\sum_{t=0}^{\infty}\beta^t\Lambda_t U(C_t,N_t)\right\} \tag{1}$$

- N_t denotes hours of labour

- Λ_t denotes preference shock

- C_t denotes the composite consumption index. It combines consumption of domestic goods and foreign goods with elasticity of substitution η. The degree of openness is measured by α.

$$C_t = \left[(1-\alpha)^{\frac{1}{\eta}} C_{H,t}^{\frac{\eta-1}{\eta}} + (\alpha)^{\frac{1}{\eta}} C_{F,t}^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}$$

subject to the budget constraint:

$$l_{t,t+1}B_{t+1} + P_tC_t = B_t + \chi_t + W_tN_t + T_t$$

First-Order-Conditions are:

$$\frac{U_{N,t}}{U_{C,t}} = -\frac{W_t}{P_t} \tag{2}$$

$$\beta R_t \mathbb{E}_t \left\{ \left(\frac{\Lambda_{t+1}}{\Lambda_t} \right) \left(\frac{U_{C,t+1}}{U_{C,t}} \right) \left(\frac{P_t}{P_{t+1}} \right) \right\} = 1 \tag{3}$$

Equation 2 translates household's intratemporal arbitrage between consumption and labour and equation 3 intertemporal arbitrage of consumption.

Aggregate price P_t is given by:

$$P_t = \left[(1-\alpha) P_{H,t}^{1-\eta} + \alpha P_{F,t}^{1-\eta} \right]^{\frac{1}{1-\eta}}$$

Varieties j are aggregated as follows:

$$C_{H,t} = \left\{ \int C_{H,t}(j)^{\frac{\theta-1}{\theta}} dj \right\}^{\frac{\theta}{\theta-1}}$$

Optimal demands for goods are given as:

$$\begin{cases} C_{H,t} & = (1-\alpha) \left(\frac{P_{H,t}}{P_t} \right)^{-\eta} C_t \\ C_{F,t} & = \alpha \left(\frac{P_{F,t}}{P_t} \right)^{-\eta} C_t \end{cases}$$

$$\begin{cases} C_{H,t}(j) & = \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\theta} C_{H,t} \\ C_{F,t}(j) & = \left(\frac{P_{F,t}(j)}{P_{F,t}} \right)^{-\theta} C_{F,t} \end{cases}$$

Given the international environment, trade-related variables are given by:

- Terms of trade: $S_t = \frac{P_{F,t}}{P_{H,t}}$
- Real exchange rate: $\mathcal{Q}_t = \frac{\mathcal{E}_t P_t^*}{P_t}$
- International risk sharing: $\Lambda_t^{\frac{1}{\sigma}} C_t = \vartheta_i (\Lambda_t^*)^{\frac{1}{\sigma}} C_t^* \mathcal{Q}_t^{\frac{1}{\sigma}}$
- Uncovered interest rate parity: $R_t = R_t^* \frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}$

Assuming that the preference shock takes place only in the domestic country, $\Lambda_t^* = 1$ and symmetric initial state, $\vartheta = 1$.

$$\Lambda_t^{\frac{1}{\sigma}} C_t = \vartheta C_t^* \mathcal{Q}_t^{\frac{1}{\sigma}}$$

3.2 Firms

3.2.1 Intermediate goods

Intermediate goods are produced using a linear production technology:

$$X_t = A_t N_t^d$$

where A_t is the productivity of labour.

3.2.2 Final goods

Final goods are produced from intermediate goods, produced in home or foreign economies:

$$Y_t(j) = \left[(1-\gamma)^{\frac{1}{\phi}} X_{H,t}(j)^{\frac{\phi-1}{\phi}} + \gamma^{\frac{1}{\phi}} X_{F,t}(j)^{\frac{\phi-1}{\phi}}\right]^{\frac{\phi}{\phi-1}}$$

- γ the home bias in the production of consumption goods
- ϕ the elasticity of substitution between intermediate goods produced in different countries

Nominal marginal cost is given by:

$$MC_t = \left\{(1-\gamma)\left(\frac{W_t}{A_t}\right)^{1-\phi} + \gamma\left(\frac{\mathcal{E}_t W_t^*}{A_t^*}\right)^{1-\phi}\right\}^{\frac{1}{1-\phi}}$$

Optimal demands for domestic intermediate goods are derived:

$$X_{H,t}(j) = \gamma\left(\frac{W_t/A_t}{MC_t}\right)^{-\phi} Y_t(j)$$

3.2.3 Pricing

Calvo pricing with probability ψ of changing the price, we obtain:

$$\overline{P_{H,t}}(j) = \mathcal{M}\frac{\sum_{v=0}^{\infty}(\psi\beta)^v \mathbb{E}_t\{\xi_{t+v} Y_{t+v}(j) MC_{t+v}\}}{\sum_{v=0}^{\infty}(\psi\beta)^v \mathbb{E}_t\{\xi_{t+v} Y_{t+v}(j)\}}$$

where $\mathcal{M} = \frac{\theta}{(\theta-1)(1-\tau)}$ is the steady-state markup (characterising the distortion of the first best allocation yield by monopolistic competition).

Aggregating across firms, the new price is given by:

$$P_{H,t} = \left[(1-\psi)\overline{P_{H,t}}(j)^{1-\theta} + \psi P_{H,t-1}^{1-\theta}\right]^{\frac{1}{1-\theta}}$$

3.3 Equilibrium

Domestic production is either consumed by the domestic economy $C_{H,t}(j)$ or the foreign economy $C_{H,t}^*(j)$:

$$Y_t(j) = C_{H,t}(j) + C_{H,t}^*(j)$$

From the optimal demands:

$$\begin{cases} C_{H,t}(j) & = (1-\alpha)\left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\theta}\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t \\ C_{H,t}(j)^* & = \alpha\left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\theta}\left(\frac{P_{H,t}/\mathcal{E}_t}{P_t^*}\right)^{-\eta} C_t^* \end{cases}$$

Market clearing yields:

$$Y_t = \left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t\left\{(1-\alpha) + \alpha \mathcal{Q}_t^{\eta-\frac{1}{\sigma}} \Lambda_t^{\frac{-1}{\sigma}}\right\}$$

$$Y_t = \left\{(1-\alpha) + \alpha S_t^{1-\mu}\right\}^{\frac{\mu}{1-\mu}} C_t\left\{(1-\alpha) + \alpha \mathcal{Q}_t^{\eta-\frac{1}{\sigma}} \Lambda_t^{\frac{-1}{\sigma}}\right\}$$

3.4 Calibration

Parameter	Value
Discount factor	$\beta = 0.99$
Risk aversion	$\sigma = 1$
Elasticity of labour supply	$1/\hat{\psi} = 1/2$
Total trade openness	$\alpha + \gamma = 0.4$
Intermediate goods trade openness	$\gamma \in [0; 0.4]$
Consumption goods trade openness	Adusted
Elasticity of substitution of intermediate goods	$\phi = 1.5$
Elasticity of substitution of consumption goods	$\eta = 1.5$
Duration of price contracts	$\frac{1}{1-\psi} = 4$
Persistence of monetary policy changes	$\rho_r = 0.7$
Reaction of monetary policy to inflation	$\varphi_\pi = 1.5$
Reaction of monetary policy to output	$\varphi_y = 0.125$
Persistence of productivity shocks	$\rho_a = \rho_{a^*} = 0.9$
Standard deviation of productivity innovations	$\sigma(\xi_a) = \sigma(\xi_{a^*}) = 1\%$
Standard deviation of monetary innovations	$\sigma(\xi_r) = \sigma(\xi_{r^*}) = 0.25\%$

The model is calibrated using parameter values presented in Eyquem and Kamber (2014). Households have log-utility function (*i.e.* $\sigma = 1$) and their elasticity of labour supply, also called the Frisch elasticity, ranges from 0.05 to 0.35 according to the estimation by Canzoneri, Cumby and Diba (2007). Macroeconomic models assume higher value of the Frisch elasticity, thus the choice of value 2. The elasticity of substitution between domestic and foreign goods in the aggregate consumption bundle is set to $\eta = 1.5$ according to the estimation by Backus, Kehoe, and Kydland (1993). In our simulation, trade openness is set as follows: $\alpha = \gamma = 0.2$. The average duration of prices is 4 quarters. The elasticity of nominal interest rate to the inflation rate is $\varphi_\pi = 1.5$ and the elasticity to output is $\varphi_y = 0.125$. Finally, consistent with the estimates of Canzoneri, Cumby, and Diba (2007), standard deviation of productivity innovations is set to 1 and that of monetary innovations to 0.25%.

3.5 Simulation

From the previously described theoretical framework, we obtain the following simulations.

Figure 1 represents a deviation from the central scenario in normal times and under the Zero Lower Bound after a temporary increase in productivity (1%). Economy is brought to the ZLB via the preference shock. In other words, for each regiem (normal times or ZLB), two simulations are made: one with and without productivity shock. To bring the economy to the ZLB, we use the preference shock. In normal times, a temporary positive productivity shock increases economic activity. However, under the zero lower bound, a temporary increase in productivity reduces consumption and output and the economy stays longer in the constrained situation. We are also interested in the foreign supply shocks that we simulate with a foreign productivity shock (figure 2). Economy contracts in response to those two shocks and this proves that the paradox of toil theoretically exists for both domestic and foreign shocks.

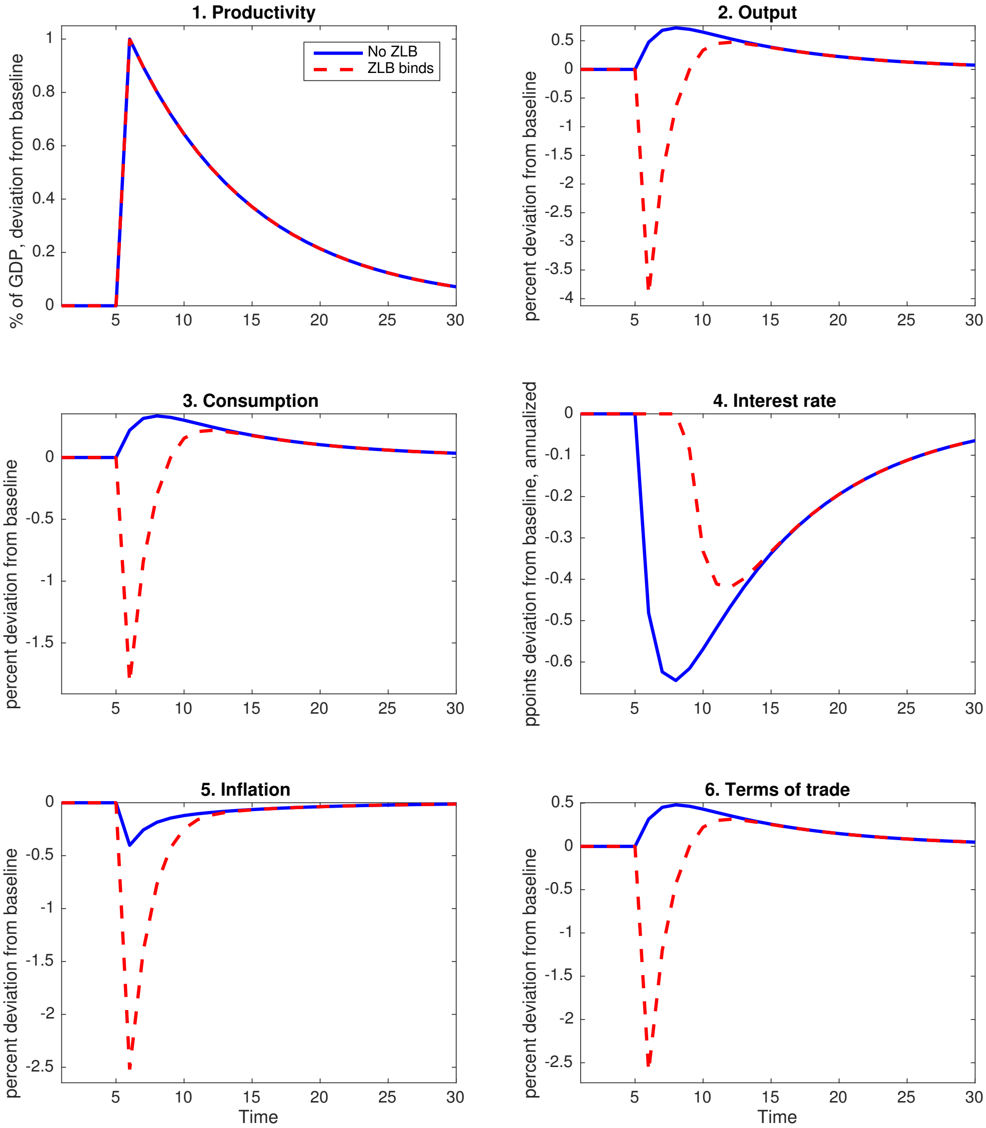


Figure 1: Impulse reponse function for 1% domestic productivity shock

Notes: the preference shock brings the economy to the ZLB and the ZLB is simulated with the OccBin Toolkit of Guerrieri and Iacoviello (2014).

4 Empirical evidence

The key challenge to our empirical study is the identification of supply shocks. Shocks are traditionally identified using the DSGE or Structural VAR models but there are issues with both methods. DSGE models with two monetary regimes are notoriously hard to estimate, and we argue that they impose too many theoretical restrictions for estimations to be general enough. In a SVAR model, following Blanchard and Quah (1993) and Blanchard and Diamond (1990), such shocks are disentangled from other types of shocks using assumptions about their effects on output and prices. However here we are agnostic about such effects because they precisely are what we are trying to measure. Thus, we need to rely on other methods. We study three types of supply shocks: a domestic technology shock, and two foreign shocks - exogenous supply shocks from emerging countries and energy (gas and oil) supply shocks.

First, we need to identify supply shocks without making assumptions about their effects on outputs and prices in the domestic economy. Second we estimate Impulse Response Functions

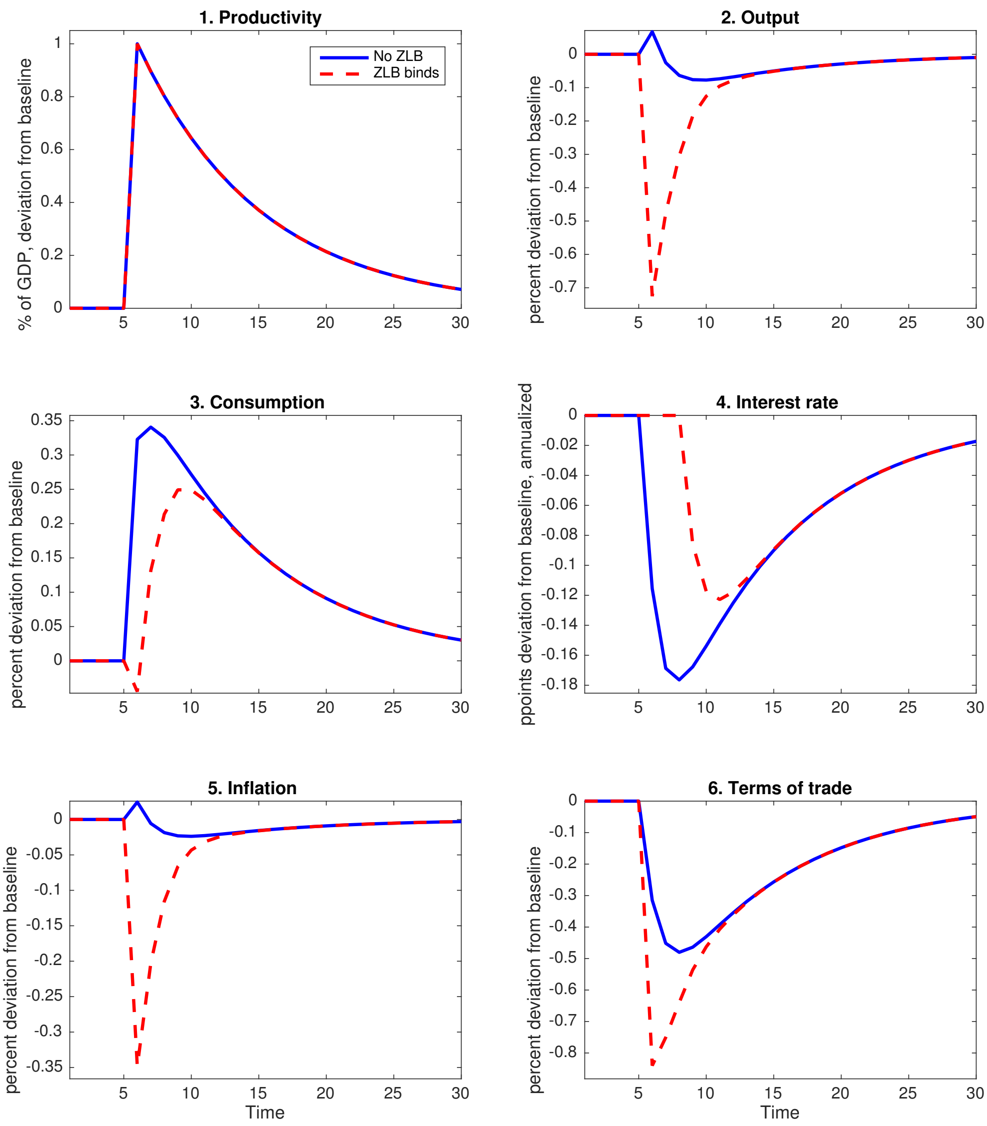


Figure 2: Impulse reponse function for 1% foreign productivity shock

Notes: the preference shock brings the economy to the ZLB and the ZLB is simulated with the OccBin Toolkit of Guerrieri and Iacoviello (2014).

(IRF) of domestic output, hours and prices to the identified shocks using the local projection (LP) method presented in Jorda (2005). Letting y be a dependent variable and z be shocks identified in the first step, the IRF is given by estimating:

$$y_t = \alpha_t + \sum_{h=0}^{p} \beta_h z_{t-p+h} + \varepsilon_{t+h}$$

Where the estimated $\hat{\beta}_{th}$ are the IRF of y to z at horizon h. This flexible representation is more robust than VAR estimation if the underlying data generating process (DGP) does not folow the assumed VAR. We conduct local projections in ZLB and non-ZLB periods, either by estimating separate equations by sub-period or by constraining shock variance with a single equation and dummies on shocks whether they occur during a ZLB or not.

The next section presents our identification strategy and IRFs to a domestic technology shock, then to an oil supply shocks, to a gas supply shock and finally to a world supply shock taking the form of increased trade with emerging markets.

4.1 Utilisation-adjusted Total Factor Productivity shock

Total Factor Productivity (TFP) as a Solow residual is easy to construct and is correlated to technology, but in reality encompasses all shocks to outputs that do not affect input growth in the same proportions than output. It is also susceptible to bias if the production function does not exhibit constant return to scale, if markups are variable, if the quality of capital and labor changes over time and over the cycle, and if firms face higher costs to adjust their stock of input than the use of these inputs. In our study, we do not take into account returns to scale and imperfect competition, but we aim to construct Solow residuals that are "purified" from the utilization rates of production factors and from the capital heterogeneity. For instance, assuming that aggregate production follows the production function:

$$Y_t = A_t (w_t K_t)^{\alpha_t} (e_t L_t)^{1-\alpha_t} = A_t u_t K_t^{\alpha_t} L_t^{1-\alpha_t}$$

Where $u_t = w_t^{\alpha_t} e_t^{1-\alpha_t}$ is a measure of factor utilization. Under perfect competition, α_t is the share of capital services to value-added, and the traditional measure of TFP is:

$$\ln TFP_t = \ln Y_t - \alpha_t \ln K_t - (1-\alpha_t) \ln L_t = \ln A_t + \ln u_t$$

Backing-up true technology A_t from the data requires an aggregate measure of utilization u_t. In annual US data, Basu *et al.* (2006) are able to estimate industry-level production functions taking into account non-constant returns to scale and unobserved workweek of capital and labor effort. Assuming, as in Basu *et al.* (2006), that firms adjust both capital and labor use, a good proxy for factor utilization is hours per worker. Their measure of aggregate factor use is thus hours per worker per industry weighted by their estimated coefficients and aggregated using value-added. Industry by industry, they show that adjusted-TFP is less volatile than regular TFP in many industries, consistent with the assumption that utilization is correlated with output, and adjusted-TFP is more weakly correlated with output than traditional TFP, which suggest that it represents an improvement over conventional growth accounting.

However, as presented in Fernald (2012), when constructing a quarterly measure of utilization, one quickly runs into data availability issues. Since we are not able to construct quarterly series on capital services by industry, we cannot yet replicate Basu *et al.* (2006)'s methodology to estimate coefficients of hours per worker that we use to compute utilization per industry. As in Fernald (2012) and Garin *et al.* (2016) for the US, we use industry coefficients from Basu *et al.* (2006) and observed value added industry shares from Eurostat to aggregate hours per worker at the quarterly x industry level. Assuming the same relationship between capacity utilization and hours per worker in Europe and in the US is very debatable, and we aim to relax it in subsequent work.

For the measure of traditional TFP, one needs series on output, capital services, labor services and factor shares. Here are the main sources and implementation strategies:

- Hours and Output: Eurostat provides industry-level quarterly data for EU countries on real and nominal GDP, value added, total hours and number of workers since the 1990s for most EU countries. The latter allows the computation of capacity utilization as well as the total number of hours worked across industries. Data are aggregated at the entire economy level.

- Capital: The EU KLEMS database provides industry-level annual data on real and nominal investment, capital stock and depreciation rates for 10 types of capital: Transport

Equipment, Computer Hardware, Telecommunication Equipment, Other Machinery, Cultivated Assets, Dwellings, Other Buildings and Structures, Computer Software, Research and Development and Other Intellectual Property. Capital stocks are consistent with National Accounts and are not constructed using the perpetual inventory method (PIM). Eurostat provides aggregate quarterly data for real and nominal investment for 5 types of capital: Dwellings, Other Buildings and Structures, Intellectual Property Products, Cultivated Assets and Machinery and Equipment. Classifications are consistent between the two databases, so we construct quarterly series of capital stocks for these 5 types of capital, using quarterly data on investment, implied depreciation rate from EU KLEMS and the end of 1999 capital stock. Growth in these 5 disaggregated types of capital are weighted using estimated user costs to general quarterly capital services.

- Factor shares: EU KLEMS provides an annual decomposition of labor and capital shares. The labor share is computed assuming that self-employed workers earn the same hourly wage as employees, and the capital share is the residual, thus assuming that there is no profit share. We interpolate the shares using cubic splines to obtain quarterly factor shares, and we extrapolate years 2016 and 2017 using a linear trend.

- User cost of capital: Assuming firms are indifferent between renting and buying the capital used in production, each unit of capital of type i is compensated at user-cost:

$$UC_t^i = \left(R_t + \delta^i - \mathbf{E}[\pi_{t+1}^i]\right) P_t^i$$

Where δ^i is the depreciation rate, P_t^i and $\mathbf{E}[\pi_{t+1}^i]$ are investment price and expected inflation, and R_t is the rental rate, which is assumed to clear the condition that the sum of capital compensations equals the capital share:

$$R_t = \frac{\alpha_t Y_t - \sum_i \left(\delta^i - \mathbf{E}[\pi_{t+1}^i]\right) P_t^i K_{t-1}^i}{\sum_i P_t^i K_{t-1}^i}$$

Expected investment price inflation should, under rational expectations, be equal to actual inflation plus white noise error. However, due to the high volatility of actual inflation, this measure leads to implausibly volatile quarter-on-quarter shares of total capital services. Thus, we use a centered 12-quarter moving average. Finally, implied depreciation rates from National Accounts are very volatile and sometimes lead to negative shares. Although we used them to construct quarterly capital stocks that are consistent with annual stocks, we used EU KLEMS rates to calculate user costs (see table 1).

Figure 3 presents the decomposition of GDP growth into technology, utilization and inputs for France. The top panel displays the traditional decomposition, excluding capital services which are not volatile. When total hours and GDP move together, it can be on the extensive or intensive margin. The middle panel shows unobserved factor utilization as proxied by hours per worker at the industry level. It is less volatile than total hours, meaning that the extensive and intensive margin tend to move together. The bottom panel compares traditional TFP with adjusted-TFP. Except in the beginning of the 2000s, when laws on hours per workers were enacted, it is slightly less volatile than traditional TFP.

Table 2 show correlation coefficients between GDP and the two alternative measures of technology. Correlations with adjusted TFP are lower, as in Garin *et al.* (2016). In it important to note that for Spain and Finland, quarterly data on hours is terribly noisy, and that capital services estimations in Ireland are extremely fragile, as well are the accounting of GDP. We will not use this countries in the second step.
In the second step, we estimate the local projection equations on both sub-periods where y is

Type of Capital	Depreciation Rate (annual)
Equipment (average)	**13.88**
Transport Equipment	18.52
Computer Hardware	31.50
Telecommunication Equipment	11.50
Other Machinery	12.35
Cultivated Assets	**20.14**
Dwellings	**1.14**
Other Buildings and Structures	**3.24**
Intellectual Property Products (average)	**21.98**
Computer Software	31.50
Research and Development	20.00
Other Intellectual Property	12.35

The 10 disaggregated depreciation rates are constant across time and countries. Equipment and Intellectual Property Products depreciation rates are averages of the lower-level rates, using annual real capital stock as weights. They vary across year and countries because weights vary across year and country.

Table 1: Depreciation Rates

GDP correlation with	Regular TFP	Adjusted TFP
Austria	0.89	0.48
Germany	0.85	0.44
Spain	0.17	0.04
Finland	0.69	0.21
France	0.71	0.58
Ireland	0.90	0.84
Italy	0.82	0.45
Netherlands	0.77	0.50

Table 2: GDP growth and TFP correlations

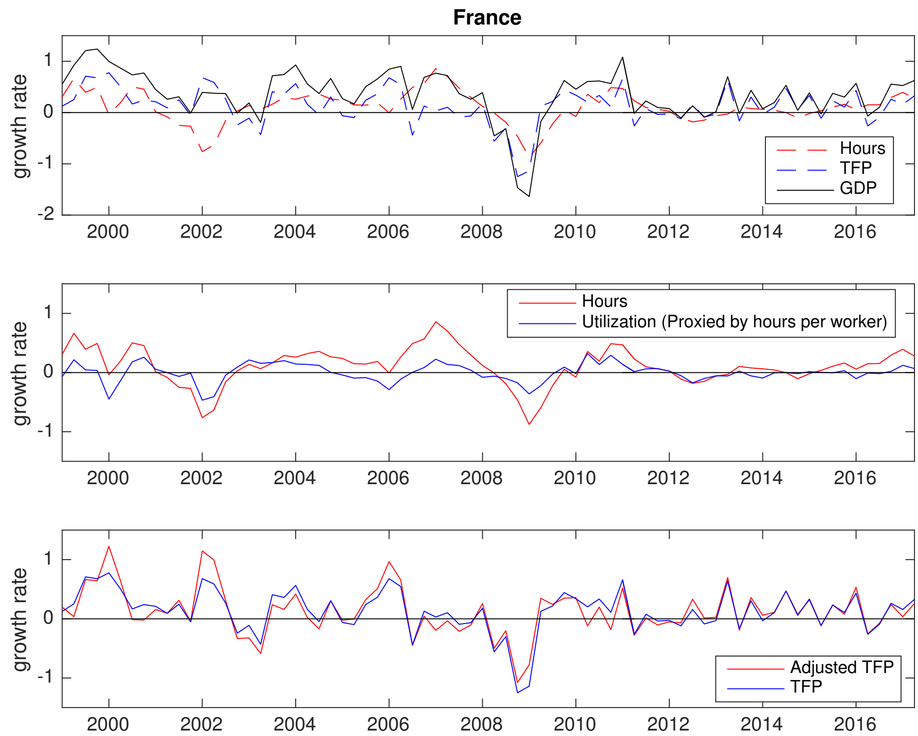


Figure 3: Growth Decomposition, France

GDP growth or Hours growth and z is TFP-adjusted growth.

$$y_t = \alpha_t + \sum_{h=0}^{p} \beta_h z_{t-p+h} + \varepsilon_{t+h}$$

In practice, we include 6 lags, and look at the propagation of a shock over the course of 6 quarters. Figure 4 reports the cumulative results of shocks on GDP growth, that is on GDP log levels. As in Basu *et al.* (2006), outside the ZLB, technology shocks tend to have a contractionary effect on output in the short-run, except in Germany where it is not significant. At the ZLB, the effect does not seem to be significantly different (although it needs to be checked), except in France during the first quarter, where it is significantly lower.

However, figure 5 shows a positive or no response of total hours worked outside the ZLB, and no difference during the ZLB and the non-ZLB periods, except in France where it is less positive during the first quarter, and in Austria where it is more positive after 2 or 3 quarters.

These results are difficult to square with NK models, which do not predict lower output following a technology shock outside the ZLB. Of course, this could mean that our adjusted TFP shock does not correctly identify technology shocks, and further investigation is required.

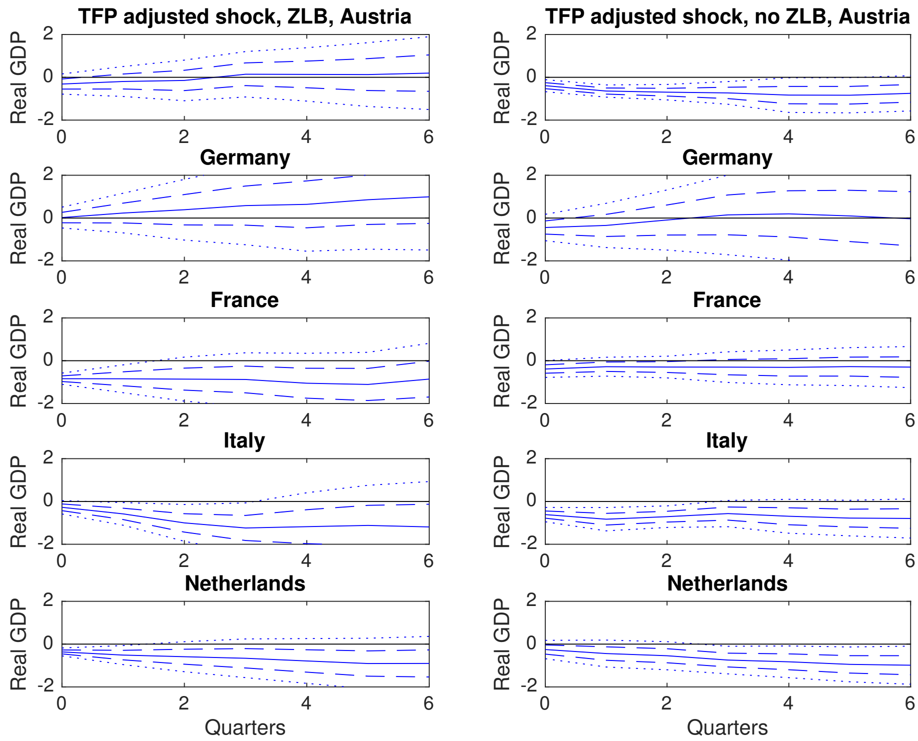


Figure 4: Response of output to a technology shock, ZLB vs no ZLB

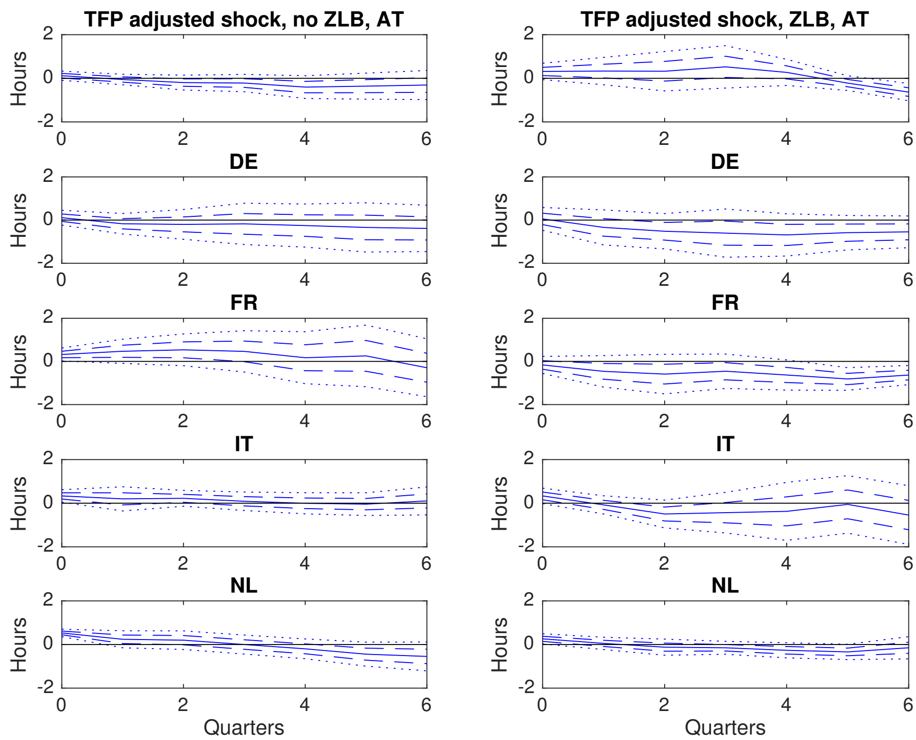


Figure 5: Response of hours to a technology shock, ZLB vs no ZLB

4.2 Oil price shock

Following the identification strategy presented in Kilian (2009), oil price shocks are broken down into oil supply, aggregate demand and precautionary (or oil-market specific) demand shocks. The identification consists of a structural VAR model with three monthly variables: the growth in global crude oil production, a measure of global real economic activity and real oil prices. Global oil production data come from the International Energy Agency (IEA). Global real economic activity is computed by Kilian on the basis of freight and shipping data. Finally, real price of oil is obtained from the IEA with the monthly exchange rate obtained on the OECD database. The data period ranges from January 1974 to July 2017.

The structural form is given by: $A_0 x_t = \alpha_x + \sum_{j=1}^{24} A_j x_{t-j} + \varepsilon_t$
The reduced-form VAR is the following: $x_t = A_0^{-1}\alpha_x + \sum_{j=1}^{24} A_0^{-1} A_j x_{t-j} + \underbrace{A_0^{-1}\varepsilon_t}_{e_t}$

The reduced-form errors e_t.are mutually correlated and thus, they cannot be economically interpreted. Given this, using Cholesky decomposition and recursive ordering assumptions, we can recover the structural i.i.d. errors ε_t.

$$e_t = A_0^{-1}\varepsilon_t$$

$$\begin{pmatrix} e_t^{\Delta prod} \\ e_t^{\Delta rea} \\ e_t^{rpo} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{\Delta oil\ supply} \\ \varepsilon_t^{\Delta aggregate\ demand} \\ \varepsilon_t^{\Delta precautionary\ demand} \end{pmatrix}$$

From the previous VAR structure, we extract oil supply shock, on which the economic activity can be regressed:

$$y_t = \alpha_y + \sum_{j=1}^{12} \beta_{\varepsilon,j} \varepsilon_{t-j}^{\Delta oil\ supply} + \varepsilon_{y,t}$$

where y_t is the dependent variable in first difference, which can be gross domestic product, industrial production level, inflation, unemployment and so forth and op_t the oil price shock. The sample covers the Euro Area countries[1]. Variables of interest, taken on monthly basis, have different time coverages (see table 3)

Figure 6: In the late 1980s, there was a huge negative oil supply disruption. Since then, the magnitude of oil supply disruptions tends to be relatively small. On the contrary, aggregate demand shock and oil-specific demand shocks seem to be large. There was a large negative followed by a large positive aggregated demand shock in 2007 (during the period of financial crisis).

Figure 7: SVAR-identified shocks have different cumulative effects. First, oil supply shocks seem to have small and transitory effects on oil price. On the contrary, aggregated demand and oil-market specific demand shocks have strong and lasting effects on oil price. Aggregate demand shock smoothly follows a business cycle movement while oil-market specific demand shock is more volatile.

[1]The database is obtained from the OECD and Euro Area comprises 19 countries, namely Austria, Belgium, Cyprus, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Portugal, Slovak Republic, Slovenia and Spain.

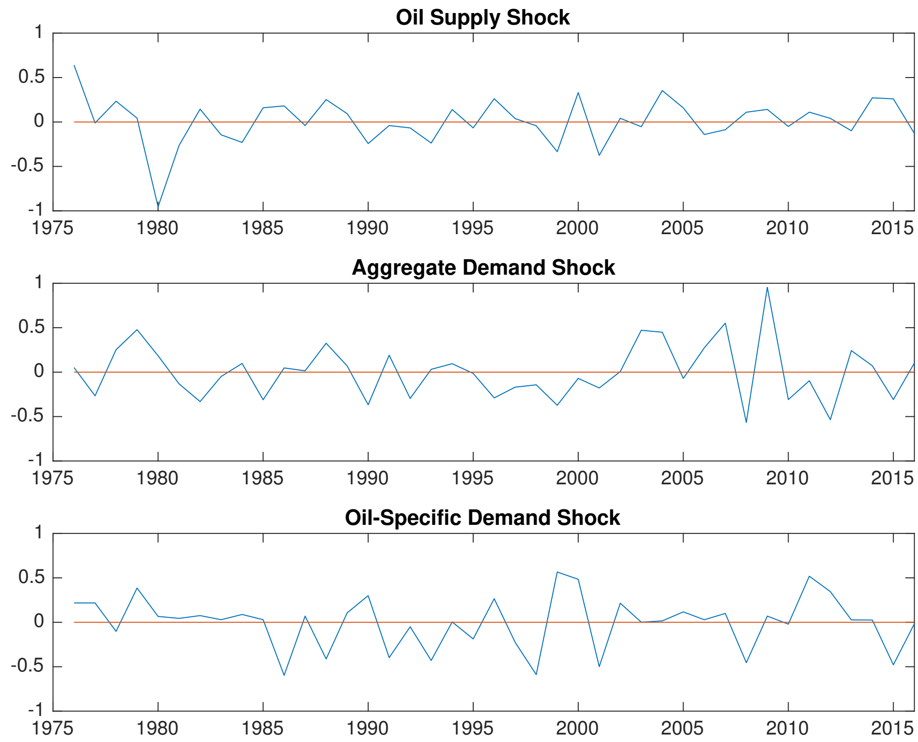


Figure 6: Historical Evolution of the Structural Shocks 1974-2017

Notes: Structural residuals obtained from Kilian (2009)'s identification strategy, averaged to annual frequency.

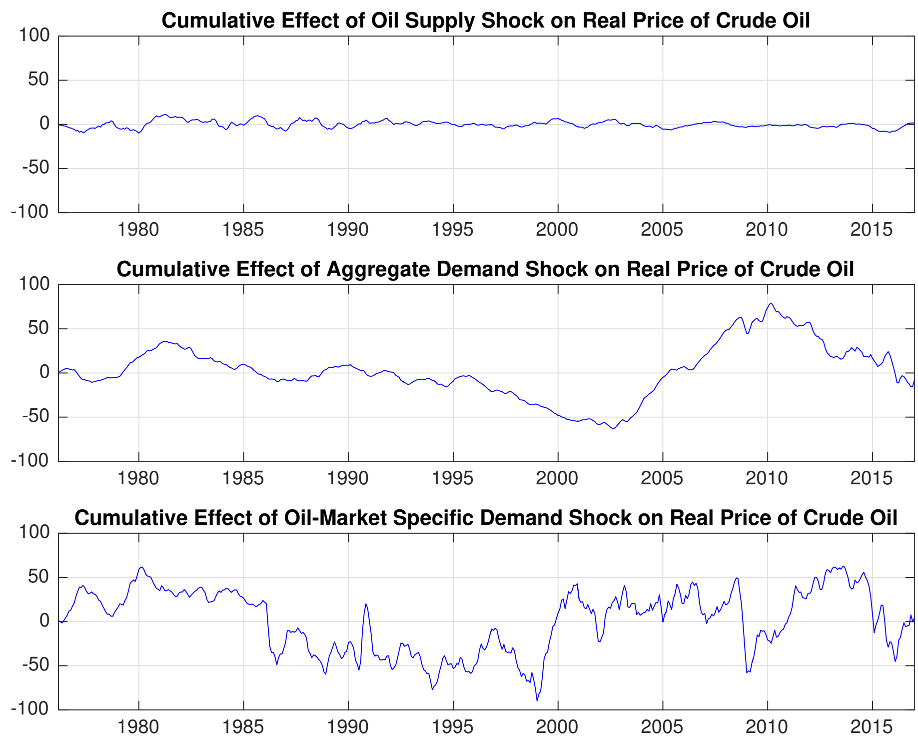


Figure 7: Historical decomposition of Real Price of Oil 1974-2017

Notes: Structural residuals obtained from Kilian (2009)'s identification strategy.

Variable	Coverage period
Gross Domestic Product	Jan 1974 - June 2017
Industrial Production Index	July 1975 - July 2017
Consumer Price Index	Jan 1997 - July 2017

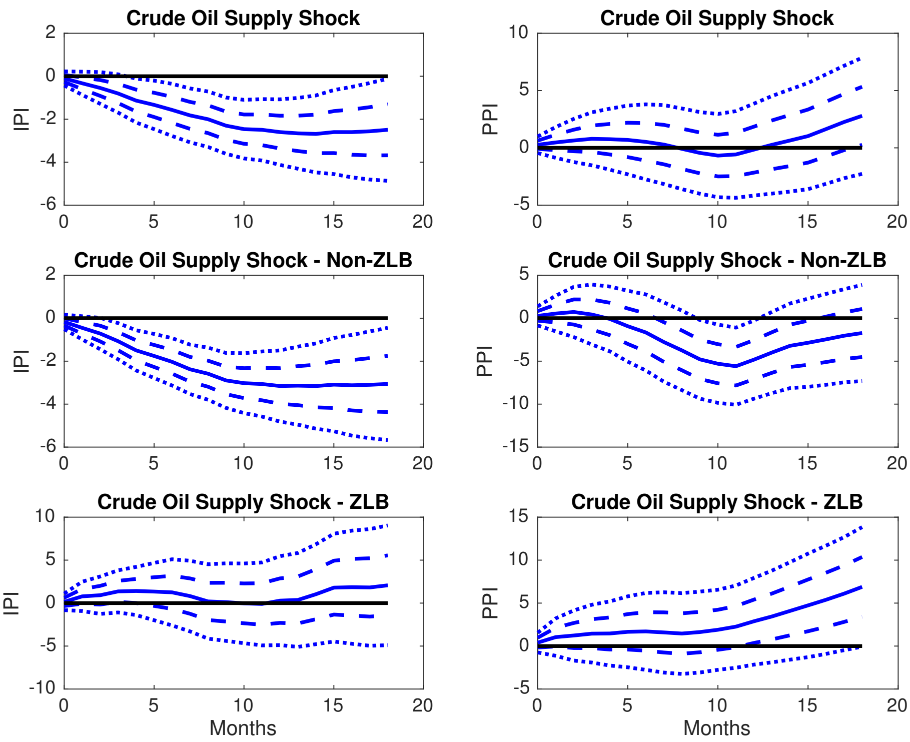
Table 3: Data Coverage

Figures 8: the impulse response functions (IRF) are obtained from the VAR model. The oil supply shock is extracted from the estimation of the structural VAR over the whole period (*i.e.* from January 1974 to July 2017). We extract the shock profile and the regression is carried out on different periods: the whole period, the ZLB and the non-ZLB period. The ZLB period is defined as the period from which the ECB policy rate is below 0.5%[2]. This date corresponds to September 2009.

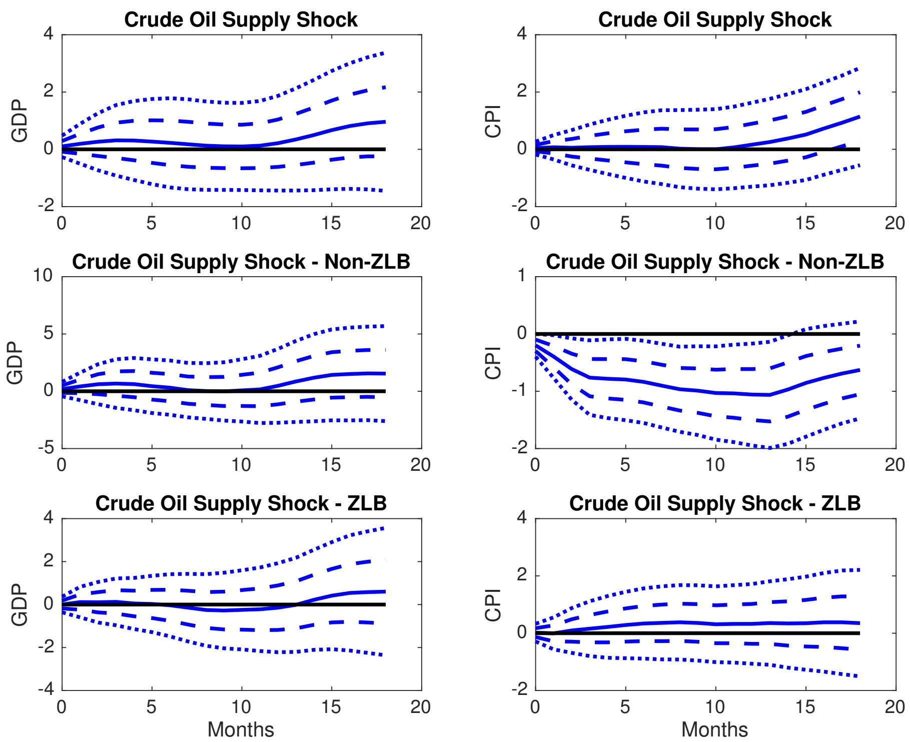
As for the manufacturing production index, the oil supply disruption causes a recessionary effect during the first six months over the total period and the non-ZLB period, as predicted by theory. However, its effect during the ZLB is unclear. The same result holds for GDP except the fact that the supply disruption tends to increase slightly the GDP after 12 months during the ZLB. The IRF for inflation shows that the oil supply disruption shock is inflationary during the total period or under the ZLB. However, the shock seems disinflationary outside the ZLB period.

The results imply that there might be a slight effect of the paradox of toil since we observe an increase in GDP and inflation. However, the effect is very small and its weak significance requires further investigation. As for the non-ZLB period, there is an issue with the effect of such supply shocks since we observe a decrease in inflation whereas an increase in inflation is expected.

[2]One of the difficulties of studying the ZLB period is the choice of date from which the economy is assumed to have entered the ZLB period. For the robustness, we aim at taking other dates *e.g.* the period in which the ECB policy rate is below 1%.



(a) Total manufacturing



(b) GDP

Figure 8: IRF after a oil supply disruption shock

4.3 Gas price shock

Similarly, we decompose gas price shock into gas supply, aggregate demand and precautionary (or gas-market specific) demand shocks using a structural VAR model with three monthly variables: the growth in global gas production, a measure of global real economic activity and real gas prices. Global gas production data come from the International Energy Agency (IEA). Global real economic activity is computed by Kilian on the basis of freight and shipping data. Finally, real price of oil is obtained from the IEA with the monthly exchange rate obtained on the OECD database. The data period ranges from July1997 to July 2017. All the variables (used in the first and second step of the identification scheme) are monthly-based and range from July 1997 to July 2017.

Figure 9: In 2005, there was a huge negative gas supply disruption. Since 2012, there is a huge positive gas supply shock. Aggregate demand shock seems to become less volatile over time while gas-specific shock seems to gain volatility.

Figure 10: SVAR-identified shocks have different cumulative effects. First, gas supply shocks seem to have large effects on real price of gas. Second, gas-specific shocks have more volatile effects even though its variance seems decreasing over time. Finally, the cumulative effect of aggregate demand shocks on real price of gas is rather small.

Figures 11: the impulse response functions (IRF) are obtained from the VAR model. The gas supply shock is extracted from the estimation of the structural VAR over the whole period (*i.e.* from July 1997 to July 2017). We extract the shock profile and the regression is carried out on different periods: the whole period, the ZLB and the non-ZLB period.

As for the GDP, gas supply disruption is recessionary over the whole period and during the ZLB period. The effect is unclear during the non-ZLB period. The shock reduces inflation over the whole time, increases after a quarter during the ZLB period and has a mitigated effect during the non-ZLB period. The effect of the supply shock on the manufacturing index is difficult to interpret.

On the whole, the paradox of toil does not seem to prevail for the gas market. If the paradox of toil held, it would imply that the supply shock causes co-movement in the same direction of the economic activity and inflation. However, we still observe during the ZLB and the non-ZLB period that there is a movement in opposite direction. One possible explanation for this is that contrary to oil, gas may have smaller effect on overall economic activity.

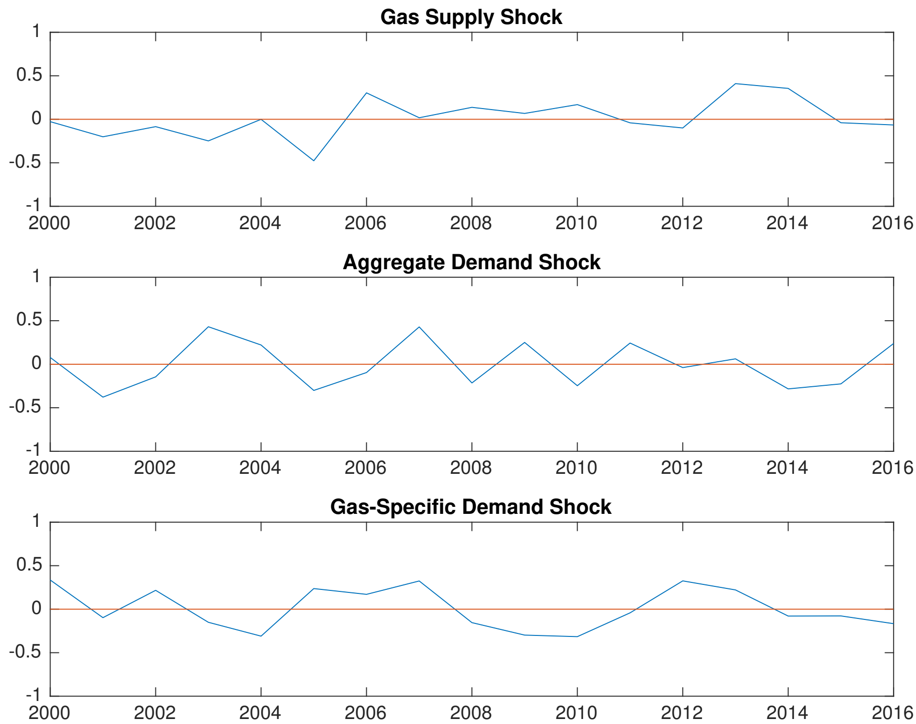


Figure 9: Historical Evolution of the Structural Shocks 1997-2017

Notes: Structural residuals obtained from Kilian (2009)'s identification strategy, averaged to annual frequency.

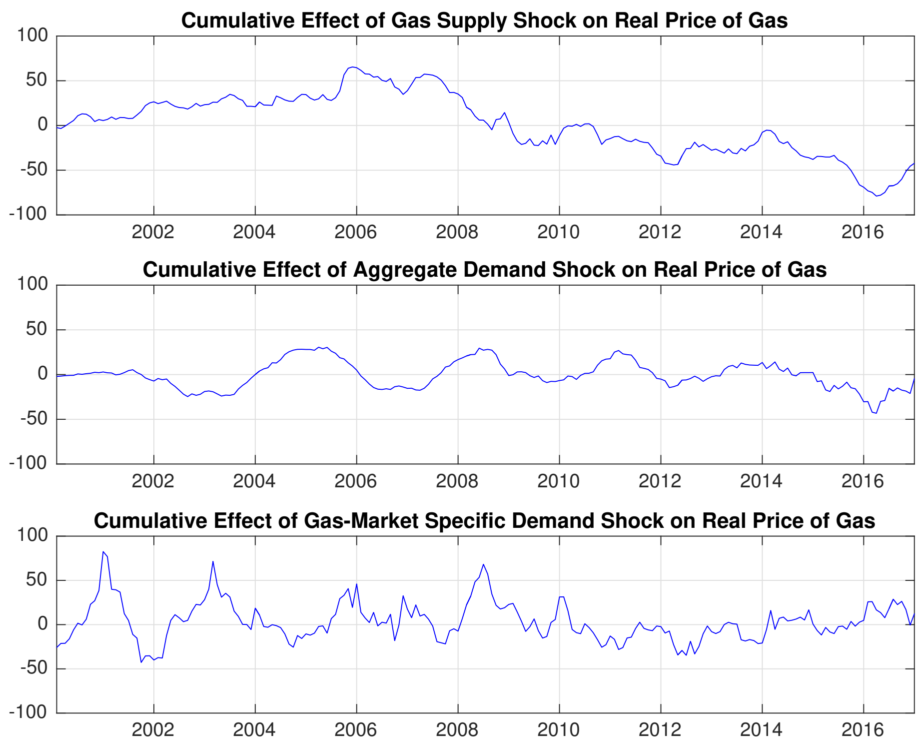
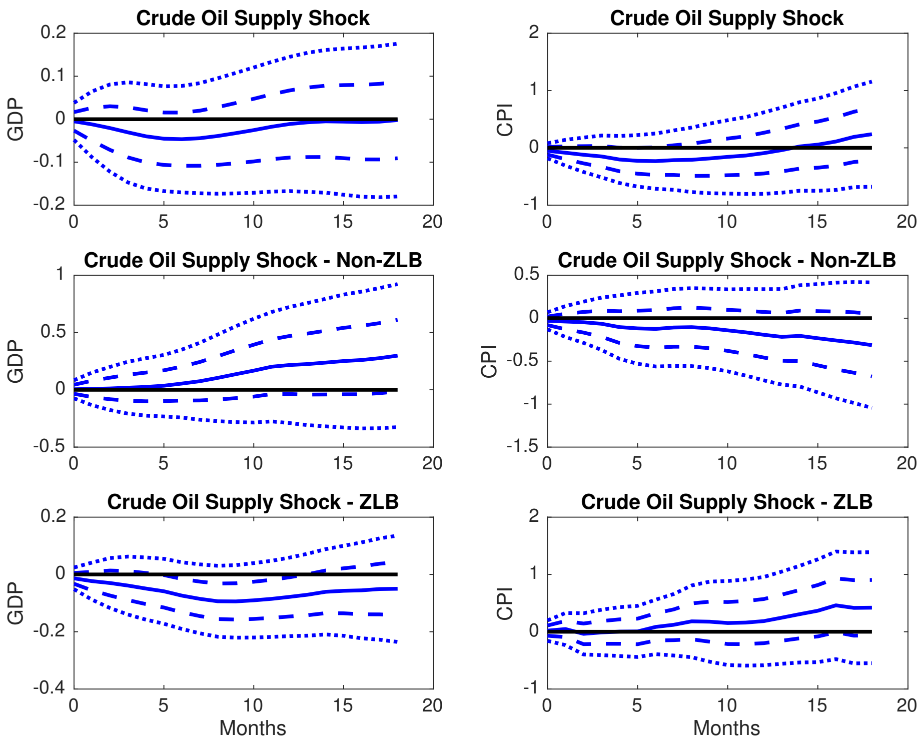
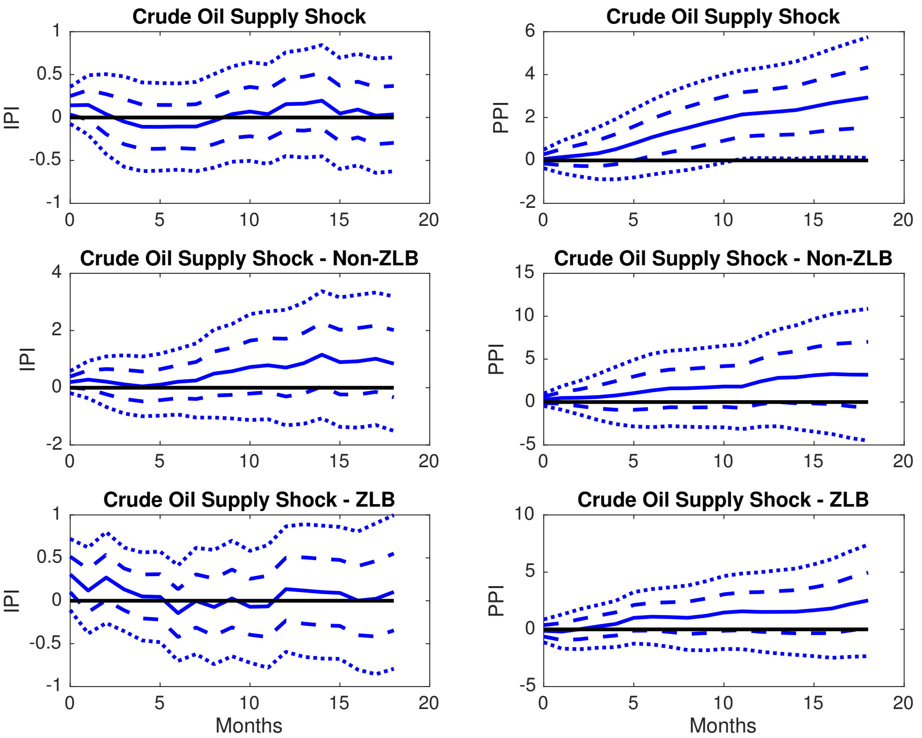


Figure 10: Historical decomposition of Real Price of Gas 1974-2017

Notes: Structural residuals obtained from Kilian (2009)'s identification strategy.



(a) Total manufacturing



(b) GDP

Figure 11: IRF after a gas supply disruption shock

4.4 World supply shock

In this section, we present two identification strategy for the world supply shock:

- World global shock: Enders and Hurn (2007) use a structural VAR model with three variables that are world real output, domestic real output and domestic price to identify the world supply shock. They improve the Blanchard and Quah (1993) identification strategy by allowing for the correlation between demand and supply disturbances;

- Emerging market shock: Autor *et al.* (2014) and Autor *et al.* (2016) study the effect of China on domestic labour market. More generally, Auer *et al.* (2013) and Auer and Fischer (2010) identify the supply shock coming from the Emerging countries.

4.4.1 Exogenous world global shock

Following Enders and Hurn (2007), we aim at assessing the effect of the world shock on the domestic economy. They present a VAR model in which the real foreign output evolves independently of the other domestic variables. On the contrary, domestic variables depend on its lagged values and the lagged values of foreign output as well (small open economy assumption). The VAR system is given as follows:

$$\Delta y_t^* = \sum_{j=1}^{p} a_{11_j} \Delta y_{t-j}^* + e_{1t}$$

$$\Delta y_t = \sum_{j=1}^{p} a_{21_j} \Delta y_{t-j}^* + \sum_{j=1}^{p} a_{22_j} \Delta y_{t-j} + \sum_{j=1}^{p} a_{23_j} \Delta \pi_{t-j} + e_{2t}$$

$$\Delta \pi_t = \sum_{j=1}^{p} a_{31_j} \Delta y_{t-j}^* + \sum_{j=1}^{p} a_{32_j} \Delta y_{t-j} + \sum_{j=1}^{p} a_{33_j} \Delta \pi_{t-j} + e_{3t}$$

The reduced-form errors (e_{1t}, e_{2t}, e_{3t}) are related to three structural shocks: foreign productivity shock (current innovation in foreign output), domestic demand shock and a domestic supply shock.

4.4.2 Emerging market shock

Since the 90s and 2000s, the rise of emerging countries has engendered a large shift in advanced economies as well as the world trade pattern. China's accession to the WTO in 2002 has even accelerated this process by furthering the global value chain process. In this section, we study the supply shock stemming from the trade with China.

Autor *et al.* (2016) identify the trade shock from China using two strategies. First, they instrument the US import growth with the import growth in other advanced economies. By doing so, they clean the import-driven effect. However, this instrumentation is subject to a correlation between import growth and unobserved components of product demand that would be common to advanced economies. To overcome this instrumentation issue, the gravity-based approach can be used. The growth in US imports from China can be replaced with the inferred change in China's comparative advantage an market access vis-a-vis the US. This enables to remove the unobserved import growth component while keeping the effect stemming from the productivity change in China and tariffs between the US-China trade. The second approach can be presented as in Feenstra (2004) using a standard gravity specification.

$$\ln(X_{Cjk}) - \ln(X_{Cjk}) = \ln(z_{Cj}) - \ln(z_{Uj}) - (\sigma_j - 1)[\ln(\tau_{Cjk}) - \ln(\tau_{Ujk})]$$

Where X_{hjk} is the country h's export to country in industry j with h either China or US. z_{hj} is the export capability of country h ni industry j (determined by wages, labour productivity, and the number of product varieties produced in country h. τ_{hjk} is the iceberg trade cost between country h and country k in industry j. σ_j is the elasticity of substitution for inudstry j.

In the following regression, the first term on the RHS corresponds to China's differential comparative advantage relative to the US for industry j and the second term corresponds to China's differential trade cost relative to the US in industry j.

$$
\begin{aligned}
\ln(X_{Cjk}) - \ln(X_{Cjk}) &= \alpha_j + \alpha_k + \epsilon_{jkt} \\
&= \left[\ln\left(\frac{z_{Cj}}{z_{Uj}}\right) - \alpha_j\right] + \left[-(\sigma_j - 1)\ln\left(\frac{\tau_{Cjk}}{\tau_{Ujk}} - \alpha_k\right)\right]
\end{aligned}
$$

To carry out the empirical investigation, we would need monthly or at least, quarterly product-level data on bilateral trade between China and other advanced economies. However, at this stage, high-frequency data are available only for a short period of time (from 2010). For a longer period of time, only annual data are available. Unless we do not solve data issues, it seems difficult to carry on.

5 Reconciling the theory and the empirical observation

5.1 New Keynesian Paradoxes

The awkward character of the New Keynesian (NK hereafter) model is nothing new. The paradox of toil is an illustration of a potentially very large and negative effect of a positive supply shock at the ZLB. Eggertsson (2011) presents a model of paradox of toil in which a negative supply shock can be expansionary at the Zero Lower Bound. However, Wieland (2016) studies the effect of the earthquake in Japan in 1995 and the decline in oil price. Garin *et al.* (2016) identifies the positive adjusted TFP shocks. They both find that the New-Keynesian paradox is very small in reality, not to say unobservable.

A large literature has been developed around these paradoxes and proposed different ways to solve them. There are basically four NK paradoxes mentioned in Kiley (2016):

- Forward guidance (commitment of the central bank to keep the interest rate low for a given period) has huge effect on real activity and inflation, namely at the Zero Lower Bound (ZLB hereafter);
- The government expenditure has a large multiplier if the monetary policy remains passive and the effect is even much larger at the ZLB;
- A negative supply shock can be expansionary (the so-called "paradox of toil") by increasing demand and production;
- Higher price flexibility yields raise volatility in response to shocks rather than getting closer to the neoclassical model (the so-called "paradox of volatility").

5.2 Solving techniques

The NK paradox has been widely investigated. There are mainly two mechanisms at stake that can affect the economy:

- **Interest rate channel** the Euler equation relating the intertemporal allocation of consumption to the real interest rate:McKay *et al.* (2016) finds that the power of forward guidance stems from the complete market assumption. By relaxing the market completeness *i.e.* with the incomplete market assumption, the interest rate channel is weakened and thus, the power of forward guidance can be significantly reduced to fit the observed reality. Households facing uninsurable idiosyncratic shocks increase their savings in a precautionary motive and consequently, the Euler equation does not work at full capacity, reducing thus the power of forward guidance.

- **Pricing channel** the sticky price assumption (Calvo pricing): Kiley (2016) replaces the price stickiness with the information stickiness. More precisely, the pricing mechanism is based on the expectation of future prices given the current information set. By doing so, NK paradoxes disappear.

Variant models have been put forward to overcome these somewhat artefacts of the New Keynesian models.

- Eggertsson, Mehrotra and Robbins (2016) model of secular stagnation based on the OLG model. Future variation of interest rates affect much less current control variables

- Gabaix (2017) develops a behavioural NK model in which agents opt for a myopic behaviour, thus limiting the propagation of the backward channel

- McKay *et al.* (2016) builds a model incorporating the incomplete market assumptions.

6 Concluding remarks

The Effective Lower Bound (also called the Zero Lower Bound) creates a peculiar environment when theoretical predictions change. Government spending, a commitment to keep the interest rate low in the future or negative supply policies such as the technological regress and capital destruction can be extremely expansionary. The debate is open. While some believe that these are artefacts of the theoretical model that does not match the reality, the others conceive certain policies based on the model to a certain extent. In this paper, we focus on one particular type of paradox, the "Paradox of Toil'. When the monetary policy is constrained to be zero or simply does not react to the economic environment, a positive supply shock may be recessionary and the converse for a negative supply shock.

Despite a large number of theoretical research articles, there has been only few empirical papers that do document this paradox. To our knowledge, there has been no empirical investigation on the Euro Area. Given this, our goal was to document and carry out empirical identification of the effects of supply shocks during the ZLB period and compare them to the non-ZLB times.

We consider three types of supply shocks: First, utilisation-adjusted total factor productivity shock is taken as a domestic supply shock. Second, we consider the change in energy price such as oil price and gas price and finally, the world supply shock stemming from the emerging market and in particular, from China.

At this stage, the results do not enable to cut short even though the paradox seems rather small or insignificant. As for the utilisation-adjusted total factor productivity shock, the effect on the working hours seems slightly negative during the ZLB and it is unclear on the overall output. Concerning the energy price, the effect of oil supply disruption (negative oil supply shock) seems to have different effects between the ZLB and the non-ZLB period. Finally, given the data availability issue, China trade shock could not be done. Indeed, to infer the results, it is necessary to have at least monthly data or quarterly data. Unless we have not overcome this issue, it would be difficult to come up with some results.

In the last section, we present theoretical models that enable to reconcile theory and the empirical observation.

A Appendix: recap of the log-linearised model

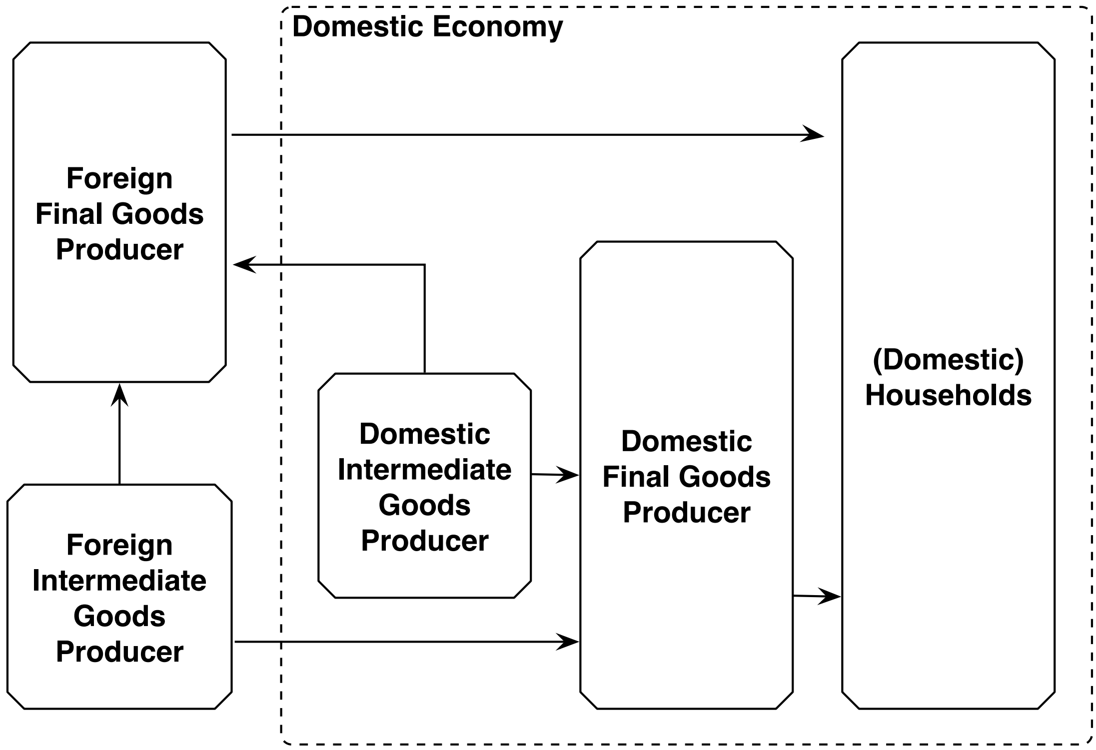


Figure 12: A sketch of the supply side links

Euler equation and risk sharing

$$\mathbb{E}_t\{c_{t+1}\} - c_t = \frac{1}{\sigma}\left(r_t - \mathbb{E}_t\{\pi_{t+1}\} + \underbrace{\mathbb{E}_t\{\lambda_{t+1}\} - \lambda_t}_{\text{preference shock}} \right)$$
$$c_t - c_t^* = \frac{1}{\sigma}(q_t + \lambda_t)$$

PPI dynamics (NK Phillips Curve)

$$\pi_{H,t} = \beta\mathbb{E}_t\{\pi_{H,t+1}\} + \frac{(1-\psi\beta)(1-\psi)}{\psi}\left(\varphi n_t + \sigma c_t - a_t + \alpha s_t + \gamma\sigma_t\right)$$
$$\pi^*_{F,t} = \beta\mathbb{E}_t\{\pi^*_{F,t+1}\} + \frac{(1-\psi\beta)(1-\psi)}{\psi}\left(\varphi n^*_t + \sigma c^*_t - a^*_t\right)$$

CPI dynamics

$$\pi_t = \pi_{H,t} + \alpha\Delta s_t$$
$$\pi^*_t = \pi^*_{f,t}$$

Consumption goods market clearing

$$y_t = c_t + \frac{\alpha}{\sigma}\left(\sigma\eta + (1-\alpha)(\sigma\eta - 1)\right)s_t$$
$$y^*_t = c^*_t$$

Intermediate goods market clearing

$$
\begin{aligned}
a_t + n_t &= (1-\gamma)y_t + \gamma y_t^* + \phi\gamma(1+(1-\gamma))\rho_t \\
a_t^* + n_t^* &= y_t^*
\end{aligned}
$$

Terms of trade

$$
\begin{aligned}
q_t &= (1-\alpha)s_t \\
\rho_t &= (1-\alpha)s_t + \varphi(n_t^* - n_t) + (c_t^* - c_t) + a_{t-1}^* \\
\mathbb{E}_t\{\Delta\varepsilon_t\} &= r_t - r_t^* \\
\Delta s_t &= \Delta\varepsilon_t + \pi_{F,t}^* - \pi_{H,t}
\end{aligned}
$$

Monetary Policy

$$
\begin{aligned}
r_t &= \rho_r r_{t-1} + (1-\rho_r)(\varphi_\pi \pi_t + \varphi_y y_t) + \xi_{r,t} \\
r_t^* &= \rho_r r_{t-1}^* + (1-\rho_r)(\varphi_\pi \pi_t^* + \varphi_y y_t^*) + \xi_{r^*,t}
\end{aligned}
$$

Exogenous productivity process

$$
\begin{aligned}
a_t &= \rho_a a_{t-1} + \xi_{a,t} \\
a_t &= \rho_a^* a_{t-1}^* + \xi_{a^*,t}
\end{aligned}
$$

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