Oil price shocks: Demand vs Supply in a two-country model*

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First Draft: June 2006. This Draft: December 2008

Abstract

From the last quarter of 2001 to the third quarter of 2005 the real price of oil increased by 103%. Such an increase is comparable to the one experienced during the oil shock of 1973. At the same time, the behavior of real GDP growth, Consumer Price inflation (CPI inflation), GDP Deflator inflation, real wages and wage inflation in the U.S. in the 1970s was very different from the one exhibited in the 2000s. What can explain such a difference? Within a two-country framework where oil is used in production, two kinds of shocks are analyzed: (a) a reduction in oil supply, (b) a persistent increase in foreign productivity (as proxy for the experience of China in the last years). It is shown that, while the 1970s are consistent with a supply shock, the shock to foreign productivity generates dynamics close to the one observed in the 2000s. A crucial role is played by the increased trade flows under the second shock. The availability of cheaper imports can more than offset the inflationary pressures caused by higher oil prices, keeping CPI inflation low. Some interesting conclusions on the desirability of monetary policy reactions to increased oil prices can be also drawn.

JEL Classification: E12, F41

Keywords: oil price, open economy, demand and supply shocks, monetary policy.

*I would like to thank Jordi Galí for excellent supervision. I am also thankful to Michael Reiter, Thijs van Rens, and all seminar participants at Universitat Pompeu Fabra, Magyar Nemzeti Bank, Central European University, Universitat Autonoma de Barcelona, Università di Roma Tor Vergata and conference participants at the "4th Annual Vienna Macroeconomic Workshop on Current Topics in Macroeconomic Theory and Policy", ASSET Meeting 2007 and RES 2008. A special thank to Stefano Gnocchi and Chiara Forlati for many useful discussions.

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1 Introduction

> *"China's oil demand certainly shot up in 2004, by 15%. That strong growth, along with political crises in Iran and Nigeria, appeared to explain why oil prices have been recently heading towards $70 a barrel again*[1]*".*

The oil price went from 27$ per barrel in January 2000 to 74$ per barrel in July 2006 and now is well above the 100$ (125$ in May 2008)[2]. Such an increase in the price of oil is of an even bigger magnitude than the one experienced during the 70s. But, is this *new oil shock* comparable with the one in the 70s? While in the 70s the rise in oil price was accompanied by a reduction in real GDP and an increase in inflation, the situation in the first half of the 2000s is quite different with no signs of either strong inflationary pressures or output slowdown[3].

When studying oil price changes, no attention is commonly dedicated to the source of the oil price increase. The implied assumption under this approach is that the only thing that matters for the economy is the sign (and the magnitude) of the oil price change. The contribution of the paper is twofold: first, to show the failure of this approach in explaining the differences between the oil price changes of the 70s and the current one; second, to propose and alternative approach where a "step back" with respect to the current literature is taken. Specifically, we develop a model where shocks of different nature can drive an increase in the oil price and we show that while the 70s are consistent with a supply shock, a demand shock delivers dynamics close to the one observed in the 2000. More importantly, the paper shows that not all oil price increases will necessarily feed into CPI inflation. This is a crucial point into the debate of whether the monetary authority should react directly to higher oil prices or not.

The intuition of why different sources of oil price increase can deliver different dynamics is a simple one. Consider an exogenous reduction in the supply of oil. This experiment is consistent with the hypothesis commonly used in the literature to study the oil shocks of the 70s[4]. As a consequence of that, the economy will experience an increase in oil price which will boost marginal costs therefore driving an increase in

[1] "Oil prices - New friendships and petropuzzles" Jan 26th 2006, The Economist.

[2] Spot Price: West Texas Intermediate, Source: Dow Jones & Company, Release: Wall Street Journal. FRED Economic Data.

[3] See section 3 for a detailed analysis of the data.

[4] For a detailed review of the literature on oil shocks presenting also alternative hypothesis see section 2.

inflation (both in prices and nominal wages), and a decrease in real wages and GDP. While this is consistent with the experience of the 70s, it is clearly at odds with what we observed in the first half of 2000s. Consider instead a two country model where an exogenous and persistent increase in the productivity of the foreign country drives an increase in foreign GDP. If this shock is very persistent (like it seems to be the case for a country like China), then several things will happen at the same time. First, given the increase in production, the foreign country will increase the oil demand therefore driving up the oil price. On the home economy this will have the same consequences of an oil price increase driven by a reduction in oil supply, i.e. marginal costs will increase therefore domestic inflation will increase too while GDP and real wages will decrease. But this is not the end of the story. Indeed, the second consequence will be a reduction in the price of the imported goods given that now the foreign country is more productive. As a result, CPI inflation in the home country may actually decrease therefore generating an increase in real wages. Finally, since the foreign country is richer, there will be an increase in the demand for home produced goods from foreign consumers and therefore home output will increase too. Therefore, the dynamics of oil price, inflation, real wages and GDP observed in the 2000s may be consistent with an increase in oil demand driven by the increased oil consumption in countries like China and India[5].

Up to now the theoretical literature (and also most of the empirical one[6]) has always considered exogenous increases to the oil price driven by reduction in oil supply and has tried to understand whether the oil price crises can be considered responsible for the high inflation and low output of the 70s. The novelty of this paper is to develop a theoretical model where the oil price is modelled endogenously therefore, allowing for the study of factors different from oil supply shocks that can affect its dynamics.

To this purpose, a two-country model like the one developed in Clarida, Galí and Gertler (2002) is used, with two main differences. First, in the production sector two inputs are needed, labour and oil. Oil is considered as a traded good therefore, the price is determined internationally and will depend on the demand of both countries (the importance of each country's oil demand depending on the relative size of the country). In order to simplify the analysis, no one of the two countries is an oil producer. It is

[5]Of course, at the same time more then one shock is responsible for the behaviour of the oil price and of the macro variables. Here we are focusing on the shocks we think to have played a major role in the oil price increase in the different years.

[6]For an exception see Kilian (2007c).

assumed that at each point in time there is a world oil endowment which may be subject to exogenous shocks. As in Clarida et al. (2002), firms' pricing decisions are subject to Calvo staggering. This is important to link the behaviour of real and nominal variables in order to study simultaneously the behavior of GDP and inflation. Second, in order to have the monetary authority facing a non trivial trade off between inflation and output gap stabilization, the presence of a wage mark-up fluctuating over time is endogenised by allowing for wage rigidities, as in Erceg, Henderson and Levin (2000). The reason for this is twofold. First, it allows to study also the dynamic of real wages and wage inflation in a realistic environment. Second, it will make it possible to study how the conduct of monetary policy is going to affect the results.

For the sake of simplicity, the model is derived under the assumption of perfect symmetry among countries and using a simple interest rate rule targeting CPI inflation in each country. The consequences of reacting directly to oil price increases will also be analyzed. Two kinds of shocks are considered. The first one is a shock to the oil supply, calibrated such that the real price of oil increases, on impact, by 100%. Such shock is an aggregate disturbance that, given the assumed symmetry, affects both countries in the same way. The second shock is an increase in foreign productivity calibrated in order to match the average quarterly increase in China GDP between 2001 and 2005. Since this shock is meant to represent the increase in productivity in China, a very high autocorrelation coefficient is assumed for this shock, as an approximation for a process that is likely to be stationary only in first differences. The behaviour of real oil price, output, CPI inflation, GDP deflator inflation (from now on domestic inflation), real wages and wage inflation under the two shocks is analysed. The focus is on the behaviour of the variables of the Home country that is supposed to represent the U.S.

After the shock to oil supply the price of oil rises, on impact, by 100%, and then goes back to its steady state level in one year. This is consistent with the experience of the 70s, where the oil price increase was sharp, but not with the current experience, where the real oil price rise is more smooth and prolonged[7]. Because of the increase in the production costs, the home economy experiences a sharp decrease in output, an increase in price inflation (both CPI inflation and domestic inflation) and wage inflation and a decrease in real wages. The model matches the change in those variables experienced in

[7]The current increase in oil price started in 2002 and is not yet over i.e., more than a one time shock is a 5 year period of price increase. In this period, the maximum quarter-by-quarter increase has been 18% (second quarter of 2002) while the average quarterly increase has been around 7%. Instead, in the 1973 oil shock, oil price increased by 82% in the first quarter of 1974.

the U.S. after the 1973-74 shock. It does not match instead the sign of the movements in the same variables after the 2003 shock.

On the contrary, after the shock to foreign country productivity (matching the increase in production in China in the last years), the model predicts an increase in oil price that can account for a 40% increase in the oil price in the period considered. It also generates a reduction of CPI inflation and an increase in real wages, due to the fact that home consumers can now buy foreign produced goods at a cheaper price. Finally, both output and domestic inflation increase. Also for these two variables, the sign is the same as the one experienced by U.S. variables, therefore confirming the original hypothesis that a change in the nature of the shocks driving up oil price is a good candidate to understand the differences between the oil shocks of the 70s and the oil shock of the 2000s. It also tells us that we should not always expect an increase in inflation and a decrease in output every time we observe an increase in the price of energy goods.

The paper proceeds as follow: section 2 reviews the related literature, section 3 presents some data evidence to clarify the different behaviour of the U.S. main variables during the different oil shock episodes, section 4 contains the model, section 5 shows the impulse responses of the variables to different types of shocks and section 6 concludes.

2 Related literature

There have been several papers studying the impact of oil shocks on the economy. Most of the literature has focused on the oil shock episodes of the 70s. An important contribution is the one by Hamilton (1983). He addresses two questions: first, the causes of the oil shocks between 1948 and 1972; second, whether there is a causality relation between the oil price increase and the recession episodes experienced by the U.S. His conclusions are first, that the rise in oil price was driven by either political crises in the Middle East or OPEC decisions, both bringing about a reduction in oil supply therefore pushing up the oil price. Second, those shocks appear to be important in explaining the periods of recession and high inflation experienced by the U.S. economy. For a different view on the relation between oil price and macroeconomy after 1973 see Hooker (1996) (and the reply by Hamilton (1996)) and Barsky and Kilian (2004)[8].

[8]See also Kilian (2007a) and Kilian (2007b)

Bernanke, Gertler and Watson (1997) and Barsky and Kilian (2002) argue that the conduct of monetary policy is crucial in explaining the periods of recessions and high inflation occurred after the oil shocks of the 70s.

On the theoretical side, Rotemberg and Woodford (1996) and Finn (2000) show that oil price shocks have a substantial impact on economic activity despite the fact that the proportion of oil used in the production process is relatively small. Both papers are in closed economy and with no nominal rigidities. Also, since they are interested in supply shocks, they use an exogenous process for the oil price. The paper by Backus and Crucini (2000) is a three-country model with no nominal rigidities, that shows that oil price shocks account for a big proportion of terms of trade volatility. They endogenise the oil price through the presence of a third country producing oil. Since there are no nominal rigidities this framework is not suitable for monetary policy analysis. Another work is the one by Leduc and Sill (2004). It is again a closed economy with an exogenous process for the oil price, but it is the first one with nominal rigidities. The main objective of the paper is to see whether the recessionary consequences of an oil shock are only due to the oil shock itself, or also to how monetary policy is conducted. They use a DSGE model to show that monetary policy plays only a secondary role in the recessionary process, but that a monetary authority more concerned about inflation better deals with the problem. Also in this case, the focus is on supply shocks, with the price of oil modelled as an exogenous process.

Two papers more closely related to the present one are Blanchard and Galí (2007) and Kilian (2007c). Like the present paper, Kilian (2007c) underlines the importance of identifying supply vs demand shocks to oil price. He provides a decomposition of real oil price into: oil supply shocks; shocks to the aggregate global demand for industrial commodities; demand shocks that are specific to the oil market (i.e., precautionary oil demand). Using this decomposition he claims that, while the oil price increase in the 70s is mainly do to precautionary demand increase, in the current increase a crucial role is played by aggregate demand shocks. However, to be notice is that the identified aggregate demand shocks "rise U.S. real GDP growth in the first year after the shock, but lower it in the second year. They also cause a persistent increase in CPI inflation[9]". This is not really consistent with the current U.S. situation where we do not observe an increase in CPI (see section 3). Blanchard and Galí (2007) try to understand the difference between the various oil shocks but their focus (differently from the present

[9]Kilian (2007c), page 3.

paper) is on the fact that the oil shocks seem to have a far lower impact on economic activity now than in the 70s[10] (in line with the literature on the great moderation) rather then on understanding the different directions in the movements of output and CPI following an oil price increase. They start from the assumption that the source of the change in oil price is always the same, i.e. an exogenous increase in oil price, and study how a different environment can affect the transmission of the same shock. As possible candidates, they consider differences in the monetary policy, in the degree of wage rigidity and in the proportion of oil used in the production and show that a change in each of them can reduce the volatility of both prices and quantities in response to the same oil shock. However, given that they always focus on supply shocks, their model is not suited to understand how an oil price increase can be accompanied by an increase in output and a reduction in CPI like it happened in the U.S. in 2000s.

To be noticed is that the story presented in Blanchard and Galí (2007) and the one developed in this paper are complements rather than substitutes. Indeed, it is reasonable to expect that shocks of different nature are hitting the economy at the same time, and also that the structure of the economy is evolving over time. The current increase in oil price is likely to be the consequence of both supply and demand shocks. The kind of changes in the structure of the economy analysed by Blanchard and Galí (2007) reduce the reaction of inflation and GDP to the oil price increase, i.e. reduce the increase in inflation and the decline in output following the oil price increase. If at the same time also a demand shock boosting oil price is at work, we show in the present paper that inflation decreases and output increases. The two shocks together increases oil price but offset each other in terms of movements in inflation and output and this explain the reduction in the volatility of those variables. Finally, if the demand shock is sufficiently strong, the overall result can be a positive growth in GDP and low or decreasing inflation, as observed in the U.S. in 2000s.

3 Stylized facts

Figure[11] (1) reports the behaviour of oil price from the first quarter of 1960 to the first quarter of 2008[12]. The top panel represents the nominal oil price expressed in dollars

[10] See also De Gregorio, Landerretche and Neilson (2007) for a study of the lower passthrough from oil price to CPI in the 2000s.

[11] Tables and figures follow at the end of the paper.

[12] See appendix for a detailed description of the data used in the paper

per barrel. In the bottom panel the nominal oil price has been divided by the CPI in order to express it in real terms. Taking logs it is possible to interpret the differences between two periods as percentage changes. The 1960 is the base year.

Following Blanchard and Galí (2007), we define an oil shock as an episode where the cumulative increase in oil price has been of more then 50% and has lasted for more than one year. Following this criteria four oil shocks are identified and for each of them the date at which the 50% threshold is reached has been reported in the graph. For each oil shock, table 1 reports the overall increase in the real oil price. In terms of the magnitude of the oil price increase, the four episodes are all alike, with an increase of oil price of around 100%. The main difference is that, while in the first two episodes (and, too a lesser extend, also in the third one) few quarters were needed to reach the 100% increase, in the last one the increase is much smoother. Therefore, the dynamics of the change in oil price in the last episode seems to differ from the first two.

The next step, after having identified the shock episodes, is to look at what happened to other variables during those periods. In pictures (2), (3) and (4) the following U.S. variables are represented: CPI inflation, GDP deflator inflation, real GDP growth rate, real wage[13] and wage inflation. The inflation rates and the growth rate are annualized rates while the real wage is expressed in logs with the 1960 as base year.

The first two episodes of oil price increase coincide with an increase in all inflation variables and a decrease in GDP growth and real wage. On the contrary, the last episode coincides with a positive GDP growth rate, an increasing real wage and low inflation rates. Things are even more clear looking at the results of tables 2 and 3. Following the same methodology used by Blanchard and Galí (2007), for each variable, table 2 (3) presents the percentage change between the average value one (two) year(s) after the shock and the average value one (two) year(s) before the shock. As reference quarter it has been used the one where the oil price reached the 50% increased needed to qualify the increase as an oil shock. Therefore, the interpretation of the table 2 is that average CPI inflation in the 1974 (the year after the shock) was 3.2 percentage points higher then it was the year before. At the same time the real GDP growth was 6 percentage points lower than in the previous year. During the first two oil shocks the U.S. economy experienced a period of stagflation with rising inflation and decreasing output. At the same time the real wage also decreased after the oil shocks while wage inflation was rasing. Results are basically unchanged if you consider a longer horizon

[13]Computed dividing the nominal hourly earnings by the CPI.

(table 3). Things are drastically different in the last two shocks and in particular in the one of 2003. During this last oil price increase, the U.S. economy experienced a positive GDP growth, an increase in real wages, a decrease in wage inflation and either a decrease (at the 4 quarters horizon) or only a moderate increase (at 8 quarters horizon) of CPI inflation.

Those simple observations underline how much different is the current experience from the oil shocks of the 70s.

Let us now look at the evolution of oil consumption over time. Figure (5) represents the average yearly world consumption (expressed as thousand barrels per day), with the relative contribution of OECD and non-OECD countries reported. As for the previous pictures, the oil price shock episodes are also reported. While, after the oil shocks of the 70s, world oil consumption decreased, this is not the case in the 2000s where, even with an increase of the oil price of more then 100%, the world oil consumption has increased steadily. This of course is not surprisingly given that in the 70s several countries experienced a recession while this is not the case today. Still, after a supply shock we should not expect to observe an increase in oil consumption. Figure (6) reports the evolution of crude oil production for the period 1970-2007 and shows no contraction in oil production when real oil price reached a cumulative increase of more than 50% in 2003.

Table 4 and 5 are useful to understand the role played by different countries in the dynamics of oil consumption. In particular, table 4 reports the growth rate of oil consumption for the period 2001-2006 for different areas in the world. Two things are worth noticing. First, most of the oil consumption growth seems to be driven by non-OECD countries which experienced a growth rate of around 20% against the 3% only of OECD countries. Second, China with its 46% is the country with the highest growth rate in that period[14]. Table 5 reports the contribution to the world oil consumption for the year 2006 of each geographical area reported in table 4. The contributions of the single countries are also reported when they account for at least around 2% of world oil consumption. Several things are worth noticing. Today non-OECD countries account for more than 40% of world oil consumption (while back in the 70s they accounted for only 26%). In particular, China's share of world oil consumption (8.51% of the world consumption) is second only to that of the United States (24.45%) and is far above

[14]There are a few countries with an even higher growth rate: Moldova, Qatar, Benin, Cape Verde, Mozambique, Seychelles, Togo, Fiji, Macau, Maldives, Papua New Guinea and Vietnam. However, they account all together for only 0.6% of the world oil consumption so they are negligible.

the one of any single other country[15]. Being the country with the second biggest share of oil consumption and having experienced the highest growth rate in oil consumption during the 2000s, it seems worthy trying to investigate the role played by the dynamics of this country in shaping the behaviour of oil price nowadays.

Finally, since the model developed in the next section is an open economy one and trade plays a crucial role, it is worthwhile to investigate the dynamics of U.S. imports and exports in the last 30 years. Figures (7) and (8) report the yearly average of U.S. imports and exports by country of origin and destination[16] for the period 1974-2007. While imports seem to have grown at a higher rate starting from 1995, China seems to be the country who benefitted the most from this tendency. Starting from 2001 imports from China have grown at a much higher rate than the one from the other trade partners. As a consequence of that, in 2007 China overtook Canada becoming the country exporting the most in the U.S. market. A similar tendency can be seen in the export market (figure (8)) even though the speed here seems to be somehow lower. Canada and Mexico are still the main destination countries for the U.S. exports, but starting from 2001 we can observe a sharp increase in the exports towards China which already overtook U.K, Germany, France and Japan becoming the third destination country for the U.S. exports.

To sum up, while the oil shocks of the 1970s are associated with increasing inflation (both in prices and wages), decreasing real GDP and decreasing real wage, US economy in the period 2000-2006 is characterized by stable inflation, increasing real wage and positive real GDP growth. At the same time, while oil consumption decreased during the first oil price shocks, this is not the case in the 2000s. Particularly interesting seems to be the case of China which experienced a vary high growth rate becoming the second country in terms of oil consumption in the 2000s. During the same period in U.S. both imports from and exports to China increased considerably.

In the next section a model is provided that reconciles those different evidences and shows the role which imports and exports may have played in contrasting the effects of oil price increases on U.S. economy in the 2000s, therefore providing an explanation of why the 2000s look different from the 70s.

[15]As you can see from table 5 Japan is also a "big player" accounting for 6.10% of world oil consumption. But during that period Japan was experiencing very low (sometimes negative) real GDP growth rates and oil consumption in Japan during the period 2001-2006 decreased by 4.35%.

[16]The major trade partner countries only are reported.

4 The model

The world is populated by a continuum $[0, 1]$ of agents. Agent $h \in [0, n]$ lives in the home country (H) while agent $h \in (n, 1]$ lives in the foreign country (F). Therefore, the two countries may have different size. For everything else, perfect symmetry is assumed. Variables are expressed in per capita terms. The reference model is Clarida et al. (2002). We follow their modelling strategy assuming that in each country there are as many final goods producers as households. In the final goods sector perfect competition is assumed. In order to keep the model as simple as possible, it is assumed that in each period there is a world endowment of oil. The world oil price is determined in equilibrium given the oil demand from firms in the two countries. The profits from selling oil are redistributed in each period among all the households of the two countries evenly (i.e. the per-capita share of profits is the same for home and foreign households), as a lump sum transfer.

4.1 Household problem

Each household supplies a differentiated labour service to each of the firms in the country. As usual in this class of models, labour is immobile across countries. The elasticity of substitution across workers is θ_w. Since each household acts as a monopolist in the supply of his labour, he chooses the wage in order to maximize the lifetime utility, subject to the labour demand schedule.

Household h in the domestic economy chooses $\{C_t, W_{H,t}(h), D_{t+1}\}$ in order to maximize:

$$E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t(h)^{1+\varphi}}{1+\varphi} \right) \right\} \tag{1}$$

subject to:

$$P_t C_t + E_t[Q_{t,t+1} D_{t+1}] = (1 + \tau_w) W_{H,t}(h) N_t(h) + D_t - T_t + \Gamma_t + \Upsilon_t \tag{2}$$

$$N_t(h) = \left[\frac{W_{H,t}(h)}{W_{H,t}} \right]^{-\theta_w} N_t \tag{3}$$

with:

$$C_t = C_{H,t}^n C_{F,t}^{1-n} \qquad P_t = \kappa^{-1} P_{H,t}^n P_{F,t}^{1-n} \qquad W_{H,t} = \left[\frac{1}{n}\int_0^n W_{H,t}(h)^{1-\theta_w} dh\right]^{\frac{1}{1-\theta_w}} \quad (4)$$

where $Q_{t,t+1}$ is the stochastic discount factor, D_t is the payoff in t of a portfolio held in $t-1$ and $\kappa \equiv n^n(1-n)^{1-n}$. Equation (3) is the labour demand, obtained solving the cost minimization problem of the firms. τ_w is a subsidy to labour that can be used by the fiscal authority in order to offset the distortion created by the presence of monopolistic competition in the labour market. Γ_t and T_t are two lump-sum components of household income representing, respectively, dividends from ownership of firms and taxes. Υ_t is the lump-sum transfer from the redistribution of profits from the sale of oil. Note the Cobb-Douglas aggregator for consumption implies the following assumptions: unit elasticity of substitution between home and foreign produced goods; no home bias in consumption; the number of final producer firms coincide with the number of households in each country. Far from being realistic, those assumptions are imposed here only for the sake of simplicity.

4.1.1 Consumption decision and intertemporal optimization

From the expenditure minimization problem we obtain:

$$P_{H,t}C_{H,t} = nP_tC_t \qquad P_{F,t}C_{F,t} = (1-n)P_tC_t \quad (5)$$

while, combining the first order conditions with respect to C_t and D_{t+1}, we find the standard Euler Equation:

$$1 = \beta R_t E_t \left[\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma} \frac{P_t}{P_{t+1}}\right] \quad (6)$$

with $R_t = \frac{1}{E_t(Q_{t,t+1})}$.

4.1.2 Wage decision

Following Erceg et al. (2000), it is assumed that in each period only a fraction $1-\xi_w$ of households can reset wages optimally, while for the others $W_{H,t}(h) = W_{H,t-1}(h)$. Therefore, each household maximizes its lifetime utility taking into consideration that,

with probability ξ_w^T, in period T his wage will still be $W_{H,t}(h)$. Given this, the first order condition with respect to wage is:

$$E_t \sum_{T=0}^{\infty} (\beta \xi_w)^T \left[C_{t+T}^{-\sigma} \frac{W_{H,t}(h)}{P_{t+T}} (1 - \Phi_w) - N_{t+T}(h)^{\varphi} \right] N_{t+T}(h) = 0 \tag{7}$$

with $1 - \Phi_w = (1 + \tau_w)\frac{\theta_w - 1}{\theta_w}$. When $\Phi_w = 0$ the fiscal authority completely offset the distortion caused by monopolistic competition in the labour market.

When wages are flexible, $T = 0$ and equation (7) becomes:

$$\frac{W_{H,t}(h)}{P_t} = N_t(h)^{\varphi} C_t^{\sigma} \frac{1}{1 - \Phi_w} \tag{8}$$

and $W_{H,t}(h) = W_{H,t}$ and $N_{H,t}(h) = N_{H,t}$ $\forall h \in [0, n]$.

Under sticky wages we need to log-linearize equation (7), obtaining the following wage inflation equation:

$$\pi_{w,t} = -\lambda_w \widehat{\mu}_{w,t} + \beta E_t[\pi_{w,t+1}] \tag{9}$$

where $\widehat{\mu}_{w,t} = \log(W_{H,t}) - \log(P_t) - \varphi \log(N_t) - \sigma \log(C_t) + \log(1 - \Phi_w)$, $\pi_{w,t}$ is the log of wage inflation, and $\lambda_w = \frac{1 - \xi_w}{\xi_w} \frac{1 - \beta \xi_w}{1 + \varphi \theta_w}$.

4.1.3 International tradability of state-contingent securities

Because of international tradability of state-contingent securities, the intertemporal condition for foreign consumers can be written as:

$$\beta \left[\frac{C_{t+1}^*}{C_t^*} \right]^{-\sigma} \frac{P_t^*}{P_{t+1}^*} \frac{e_t}{e_{t+1}} = Q_{t,t+1} \tag{10}$$

where e_t is the nominal exchange rate. Since there is no home bias in consumption and we assume that the law of one price holds, i.e. $P_t = P_t^* e_t$, then $C_t = C_t^* \quad \forall t$.

4.2 Firm problem - Final goods sector

Intermediate home produced goods are aggregated into final goods using the following technology:

$$Y_t = \left[\int_0^1 Y_t(j)^{\frac{\theta_p - 1}{\theta_p}} dj \right]^{\frac{\theta_p}{\theta_p - 1}} \tag{11}$$

In both countries there is a continuum $[0,1]$ of producers in the intermediate sector. In each country the final goods are produced using only intermediate goods produced within the country. There is a continuum $[0,n]$ of final good producers in the home country and a continuum $(n,1]$ in the foreign country. The final goods sector operates in perfect competition. Profit maximization yields to:

$$Y_t(j) = \left[\frac{P_{H,t}(j)}{P_{H,t}}\right]^{-\theta_p} Y_t \tag{12}$$

with $P_{H,t} = \left[\int_0^1 P_{H,t}(j)^{1-\theta_p} dj\right]^{\frac{1}{1-\theta_p}}$.

4.3 Firm problem - Intermediate goods sector

Intermediate goods sector firms produce accordingly to the following technology:

$$Y_t(j) = A_t N_t(j)^{\alpha} O_{H,t}(j)^{1-\alpha} \tag{13}$$

where $O_{H,t}(j)$ is the oil demand of firm "j", $N_t(j) = \left[\frac{1}{n}\int_0^n N_{tj}(h)^{\frac{\theta_w-1}{\theta_w}}\right]^{\frac{\theta_w}{\theta_w-1}}$ is firm "j" labour demand and the technology process is defined as:

$$a_{t+1} = \rho_a a_t + \varepsilon_{A,t}. \tag{14}$$

with $a_t \equiv \log(A_t)$ and where $\varepsilon_{A,t}$ is an i.i.d shock with zero mean. Whenever $\alpha = 1$ (i.e. oil is not used in the production function) we are back to the standard case. Each firm has to choose how to optimally combine labour and oil and, also, how much to demand of each labour type. Solving the cost minimization problem leads to:

$$\frac{W_{H,t}}{P_{o,t}} = \frac{\alpha}{1-\alpha}\frac{O_{H,t}(j)}{N_t(j)} \tag{15}$$

$$N_{tj}(h) = \left[\frac{W_{H,t}(h)}{W_{H,t}}\right]^{-\theta_w} N_t(j) \tag{16}$$

where $P_{o,t}$ is the price of oil (it is determined endogenously when computing the equilibrium in the oil market). Integrating (16) over all firms, we obtain the labour demand schedule for worker h, (3).

4.3.1 Marginal cost

Using (15) we can derive the following expression for firm nominal marginal cost:

$$MC_{H,t}(j) = \frac{1}{\alpha}\left[\frac{\alpha}{1-\alpha}\right]^{1-\alpha}\frac{1}{A_t}W_{H,t}^{\alpha}P_{o,t}^{1-\alpha} \tag{17}$$

As standard in this class of models, the marginal cost is not firm specific. When $\alpha = 1$ the expression for the marginal cost simplifies to the usual $MC_{H,t} = \frac{W_{H,t}}{A_t}$.

4.3.2 Pricing decisions

Firm j production is small with respect to the world production and the same is true with respect to firm j oil demand. Therefore, when undertaking production decisions, firm j takes oil price as given. This means that pricing decision is isomorphic to the one we obtain in the standard case. This implies that, assuming Calvo price setting and being ξ_p the probability of not being able to reoptimize next period, if firm j is allowed to reoptimize in t, it will choose $P_{H,t}(j)$ such that:

$$E_t\sum_{T=0}^{\infty}\xi_p^T Q_{t,t+T}Y_{t+T}(j)\left[P_{H,t}(j) - \frac{1}{1-\Phi_p}MC_{H,t+T}\right] = 0 \tag{18}$$

with $1-\Phi_p = (1+\tau_p)\frac{\theta_p-1}{\theta_p}$. When $\Phi_p = 0$, the fiscal authority is completely offsetting the distortion coming from the presence of monopolistically competitive goods market. Under flexible prices equation (18) simplifies to:

$$P_{H,t} = \frac{1}{1-\Phi_p}MC_{H,t} \tag{19}$$

i.e. the price is a constant mark-up over the marginal cost.
To solve the model under sticky prices, we need to log-linearize equation (18) around its the steady state, obtaining the Phillips Curve on home inflation:

$$\pi_{H,t} = \beta E_t[\pi_{H,t+1}] + \lambda\widehat{mc}_t \tag{20}$$

where $\pi_{H,t} = \log\frac{P_{H,t}}{P_{H,t-1}}$, $\lambda \equiv \frac{(1-\xi_p)(1-\beta\xi_p)}{\xi_p}$, and $\widehat{mc}_t = \log MC_{H,t} - \log P_{H,t} - \log(1-\Phi_p)$ is the log-deviation of the real marginal cost from the flexible price allocation.

4.4 Equilibrium conditions

4.4.1 Oil market equilibrium

Recall that up to now all the variables have been expressed in per-capita terms. As a consequence, to compute the world oil demand we need to multiply the per-capita oil demand coming from each country by the country size. The oil demand of the world economy is therefore:

$$O_t^d \equiv n \int_0^1 O_{H,t}(j)dj + (1-n) \int_0^1 O_{F,t}(j)dj \tag{21}$$

Since the focus is not on the consequences for an oil producer country of an increase in the oil demand, by assumption none of the countries is producing oil. To simplify the model as much as possible, it is assumed that at each point in time there is a world oil endowment O_t^s. We already clarified when studying the household's optimization problem that profits from selling oil $P_{o,t} * O_t^s$ are evenly redistributed as lump sum transfer to the world consumers. The reason for this is twofold: first, we do not want to deal with a third country producing oil and second, we do not want to introduce a source of asymmetry across the two countries, this is why the amount of per-capita profits redistributed is the same across the two countries. To account for supply shocks to the oil price, an exogenous, i.i.d. shock ξ_t to the otherwise constant oil endowment is introduced. In order not to complicate the analysis too much, oil is assumed to be non storable i.e., oil supplied in period t is consumed in the same period. The world oil supply is defined by the following process:

$$O_{t+1}^s = (O_t^s)^{\rho_o} e^{\xi_{t+1}} \tag{22}$$

where, ξ_t is an i.i.d. exogenous shock to the supply of oil. When $\xi_t = 0 \forall t$, $O_t = \overline{O} = 1 \forall t$. The total oil demand of home country is:

$$O_{H,t}^d \equiv n \int_0^1 O_{H,t}(j)dj = n \frac{1-\alpha}{\alpha} \frac{W_{H,t}}{P_{o,t}} N_t \tag{23}$$

The total oil demand of foreign country is[17]:

[17]Real variables with a star refer to the foreign country. For nominal variables, the subscript F refers to the foreign country and a star means that they are expressed in the foreign currency.

$$O^d_{F,t} \equiv (1-n)\int_0^1 O_{F,t}(j)dj = (1-n)\frac{1-\alpha}{\alpha}\frac{W^*_{F,t}}{P^*_{o,t}}N^*_t \tag{24}$$

For the oil market to be in equilibrium $P_{o,t}$ must verify[18]:

$$\frac{P_{o,t}}{P_t} = \frac{1}{O^s_t}\frac{1-\alpha}{\alpha}\left[n\frac{W_{H,t}}{P_t}N_t + (1-n)\frac{W^*_{F,t}}{P^*_t}N^*_t\right] \tag{25}$$

An exogenous shock to oil supply will affect the equilibrium price of oil through ξ_t. An exogenous shock to the productivity of one of the two countries will change the quantity produced by both and, therefore, it will affect the oil price through a change in the oil demand. Clearly, the bigger the country, the bigger the consequences of a change in his production.

4.4.2 Asset market equilibrium

Under the two assumptions that asset markets are complete and that the low of one price holds, the equilibrium condition implies that $C_t = C^*_t \ \ \forall\, t$.

4.4.3 Equilibrium in the goods market

Like in CGG, goods market clearing conditions imply that:

$$P_{H,t}Y_t = P_tC_t \qquad P^*_{F,t}Y^*_t = P^*_tC^*_t \tag{26}$$

Therefore,

$$C_t = \kappa Y^n_t (Y^*_t)^{1-n} \tag{27}$$

where the aggregate output in equilibrium is:

$$Y_t = \frac{A_t N^\alpha_t O^{1-\alpha}_{H,t}}{Z_t} \tag{28}$$

with $Z_t = \int_0^1 \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\theta_p} dj$.

Now that we have all the first order and the market clearing conditions, it is possible to study the dynamics of the model both in the case of no nominal rigidities (section

[18]Because of the low of one price, $\frac{P_t}{P_{o,t}} = \frac{P^*_t}{P^*_{o,t}}$.

4.5) and under sticky prices and wages (section 4.6).

4.5 Flexible prices and wages

Let us first study the case in which prices and wages are perfectly flexible in both countries. Using equations (8), (15), (19), (26), (27) and (28)[19], it is possible to derive the following expression for the natural level of output of the home country:

$$\overline{Y}_t = \alpha^{A_1} \left(\frac{1-\alpha}{\alpha}\right)^{(1-\alpha)A_2} \kappa^{A_3} [1-\Phi_p]^{A_1} [1-\Phi_w]^{A_4} A_t^{A_2} \left(\frac{\overline{P_{o,t}}}{P_t}\right)^{-(1-\alpha)A_2} (\overline{Y}_t^*)^{(1-n)A_3} \quad (29)$$

where:

$$A_1 = \frac{1+\varphi(1-\alpha)}{1+\varphi-n[1+\varphi(1-\alpha)-\alpha\sigma]} \qquad A_2 = \frac{(1+\varphi)}{1+\varphi-n[1+\varphi(1-\alpha)-\alpha\sigma]}$$
$$A_3 = \frac{1+\varphi(1-\alpha)-\alpha\sigma}{1+\varphi-n[1+\varphi(1-\alpha)-\alpha\sigma]} \qquad A_4 = \frac{\alpha}{1+\varphi-n[1+\varphi(1-\alpha)-\alpha\sigma]}$$

Doing the same for the foreign country and using the clearing condition for the oil market (25), the equilibrium oil price must satisfies:

$$\frac{\overline{P_{o,t}}}{P_t} = \left[\frac{1}{O_t^s}\right]^{\frac{1+\varphi(1-\alpha)}{\alpha}} \left[\frac{1-\alpha}{\alpha}\right] \left[\frac{1}{1-\Phi_w}\right] \left[\kappa \overline{Y}_t^n (\overline{Y}^*)^{1-n}\right]^{\sigma} \left[n\left[\overline{Y}_t A_t^{-1}\right]^{\frac{1+\varphi}{1+\varphi(1-\alpha)}} + (1-n)\left[\overline{Y}_t^* (A_t^*)^{-1}\right]^{\frac{1+\varphi}{1+\varphi(1-\alpha)}}\right]^{\frac{1+\varphi(1-\alpha)}{\alpha}} \quad (30)$$

Taking a log-linear approximation around the symmetric steady state of (29), of its counterpart for the foreign country and of (30) for the special case of log utility in consumption (i.e. $\sigma = 1$), it is possible to rewrite the natural level of output in the two countries and the real oil price as function of only exogenous shocks[20]:

$$\hat{y}_t = a_t + (1-\alpha)\xi_t \quad (31)$$

[19] In the flexible price equilibrium $Z_t = 1$.

[20] As standard, $x_t = log(X_t)$ while $\hat{x}_t$ represents log deviations from the steady state.

$$\hat{y}_t^* = a_t^* + (1-\alpha)\xi_t \tag{32}$$

$$\widehat{\frac{P_{o,t}}{P_t}} = na_t + (1-n)a_t^* - \alpha\xi_t \tag{33}$$

The following things are worth noticing. First, the natural level of output does not move in reaction to foreign technology shocks. This is a standard result under the assumption of log utility in consumption that goes through even if oil (a tradable good) is introduced in the production function. Second, the natural level of output in the two countries reacts to global oil supply shocks[21]. The sensitivity of the natural level of output to those shocks depends crucially on the proportion of oil used in the production function, $1-\alpha$. Third, the oil price reacts both to exogenous oil supply shocks and to technology shocks in the two countries. The size of the country is crucial in determining the impact of its own technology shock on the global price of oil. Finally, under flexible prices and wages and when perfect symmetry across the two countries is assumed, the way a technology shock is transmitted to the other real variables does not depend on α i.e. the dynamics are the same that would arise under the standard $Y_t = A_t N_t$. In particular, if we consider the case of a home technology shock (setting $\xi_t = a_t^* = 0$) it is possible to show the following:

$$\begin{aligned} \hat{y}_t &= a_t & \hat{y}_t^* &= 0 \\ \hat{c}_t = \hat{c}_t^* &= na_t & \hat{n}_t = \hat{n}_t^* &= 0 \\ \hat{w}_t = \hat{w}_t^* &= na_t & \hat{o}_{H,t} = \hat{o}_{F,t}^* &= 0 \end{aligned}$$

In the next section we analyze the transmission mechanism when both prices and wages are sticky.

4.6 Sticky prices and wages

In this section we come back to the case where prices and wages are sticky in both countries. Using the log-linearized version of the equilibrium conditions in section 4.4

[21] Recall that a positive ξ_t means an exogenous increase in oil supply. It has an expansionary effect on output in both country.

and of the first order conditions derived in sections 4.1, 4.2 and 4.3, we can derive the New Keynesian Phillips Curve (NKPC) from equation (18)[22]:

$$\pi_{H,t} = \beta E_t[\pi_{H,t+1}] + \lambda \left[A\widehat{\mu}_{w,t} + B(y_t - \overline{y}_t) + C\widehat{\mu}^*_{w,t} + D(y^*_t - \overline{y}^*_t) \right] \tag{34}$$

where

$$\begin{aligned} A &\equiv \frac{\alpha + (1-\alpha)n(1+\varphi)}{1+\varphi(1-\alpha)} \qquad B \equiv \left[\sigma n + 1 - n + \varphi \frac{\alpha}{1+\varphi(1-\alpha)} + n(1+\varphi) \frac{1+\varphi(1-\alpha)-\alpha}{\alpha[1+\varphi(1-\alpha)]} \right] \\ C &\equiv \frac{(1+\varphi)(1-\alpha)(1-n)}{1+\varphi(1-\alpha)} \quad D \equiv \frac{(1-\alpha)(1+\varphi)^2(1-n)}{\alpha[1+\varphi(1-\alpha)]} \end{aligned} \tag{35}$$

and $\overline{y}_t$ and $\overline{y}^*_t$ represent, respectively, the log of the level of output in absence of nominal rigidities in the home and foreign country. $\widehat{\mu}^*_{w,t}$ represents the log-deviation of the wage mark-up from its frictionless level, in the foreign country.
It is useful to study how the NKPC becomes in some special cases.

4.6.1 No oil used in production, i.e. $\alpha = 1$

In this case, $C = D = 0$, $A = 1$ and $B = \sigma n + 1 - n + \varphi$, i.e. we are back to a standard NKPC with sticky wages. Because of the presence of sticky wages, the monetary authority faces a trade of between stabilizing output gap and stabilizing inflation.

4.6.2 General case

When $\alpha < 1$, i.e. when oil is used in the production function, the Phillips Curve of the home country is function also of the foreign output gap and of the foreign wage mark-up fluctuations. Therefore, the new assumption on the production process has amplified the *open economy dimension* of the model. The reason for this is simple. Even if, when solving their optimization decisions, foreign producers take home variables and oil price as exogenously given, in equilibrium their production decisions affect oil price through their impact on world oil demand. Therefore, through their impact on world oil price, foreign producers influence home marginal costs. Specifically, when foreign output is above its natural level, foreign oil demand is also going to be above the optimal level and this creates an upward pressure on oil price. Also, when the average wage markup

[22]For the complete derivation see Appendix A

charged by foreign workers is above the one charged under flexible wages, there is going to be a partial substitution between labour and oil in the production process and this will also generate an upward pressure on the oil price.

How much close we are to the standard case depends both on α and n. The role played by α is clear. As α approaches to 1, the role of oil in the production process approaches to 0, therefore we are closing this channel and going back to the standard model. On the other hand, as n approaches 1, the foreign country becomes small and, therefore, it is unable to affect the oil price that is determined at the world level. As a consequence, no matter how big can be the role played by oil in the production process (i.e. no matter how much α can be close to zero), since the oil price will not be affected in a significant way by foreign variables, this new channel will not play an important role and C and D will approach to 0.

4.7 Monetary Policy Rule

Home is assumed to follow and interest rate rule of the type:

$$log(R_t) = (1-\phi_R)*log(\beta)+\phi_R*log(R_{t-1})+(1-\phi_R)*\left[\phi * log(\pi) + \phi_{oil} * \left(log\left(\frac{P_{o,t}}{P_t}\right) - log\left(\frac{P_o}{P}\right)\right)\right] \tag{36}$$

A symmetric rule is assumed for Foreign. In the next section we will use impulse response functions to analyze the different transmission mechanism implied by a supply versus a demand shock.

5 Demand vs Supply Shock: Impulse Response Analysis

5.1 Baseline Calibration

The two countries are assumed to be perfectly symmetric. They also have the same size, i.e. $n = 0.5$. Most of the parameters have been set following Galí and Monacelli (2005).

Consumer

The discount factor β is set equal to 0.99, implying a riskless annual return of around 4%. The coefficient of relative risk aversion σ is set to 1, implying log utility in consumption. $\varphi = 3$ so that the labour supply elasticity is 1/3. $\theta_w = 6$ implies a wage markup of 1.2. Finally, $\xi_w = 0.75$ i.e. nominal wages adjust, on average, once a year.

Firm

Like for workers, $\theta_p = 0.6$ and $\xi_p = 0.75$. The share of oil in the production α is set equal to 0.05.

Fiscal subsidies

The fiscal authority sets the subsidies τ_w and τ_p such that the flexible (prices and wages) equilibrium is efficient from the single country point of view.

Monetary Policy

It is assumed that the monetary authorities in both countries follow an interest rate rule targeting CPI inflation with a coefficient $\phi = 1.5$. In the baseline calibration we also assume interest rate smoothing with $\phi_R = 0.9$ and no direct reaction to oil price movements i.e., $\phi_{oil} = 0$.

Exogenous Shocks

Two kind of shocks are considered. A negative shock to oil supply (exemplifying the oil shocks of the 70s) and a positive shock to foreign productivity (aimed at capturing a demand shock). The foreign productivity process is assumed to be very persistent with $\rho_{A*} = 0.999$. On the contrary oil supply is assumed to be much less persistent with $\rho_o = 0.5$. When studying the impulse responses to a foreign productivity shock we assume $corr_{A,A*} = 0$ in order to be able to disentangle the impact of foreign pressure on oil demand alone.

5.2 Demand vs Supply Shock

Two experiments are conducted. The first one is to simulate the model under an oil supply shock that generates an increase of 100% in the real price of oil and that

dies off very fast (the correlation coefficient of the process for the oil supply is indeed $\rho_o = 0.5$). Since the increase in the 70s of the oil price was always happening in a few quarters, this experiment is meant to replicate such circumstances. Figure 9 reports the impulse responses of the real price of oil plus the following home variables: CPI inflation, real output, domestic inflation, real wage and wage inflation. This shock reproduces in the model an episode of stagflation like the one observed in the 70s with a contraction in output accompanied by a rise in inflation (measured both in terms of domestic inflation and CPI inflation), a rise in wage inflation and a contraction of real wages. This shock is symmetric for both countries therefore the impulse response functions for the foreign country are exactly the same as for the home country. The reason behind those dynamics is that such a shock increases production costs in both countries, therefore it fuels inflation, both in terms of domestically produced goods and with respect to goods produced abroad. This decreases real wages and contracts total output. More in detail, the supply shock generates a reduction in the home output of 0.9%, consistent with a reduction in the yearly growth rate of GDP of around 3.6%. Inflation (measured both in terms of CPI inflation and domestic inflation) increases by 0.6%, implying an increase in the yearly rate of 2.4%. This generates a decrease in real wages of 0.4% i.e., a reduction in one year of 1.6% accompanied by an yearly increase in wage inflation of around 0.6%. The direction in the changes of those variables is consistent with the one observed in the 70s even if the magnitude is lower than the one reported in table 2. It is important to note however that, given that the supply side of the oil market is not explicitly modeled, while conducting this experiment it is not possible to evaluate whether the quantity reduction in the oil supply needed to deliver the 100% increase in the oil price is consistent with what happened in reality. This problem is common to all papers mentioned in the literature review which studies the transmission of oil price shocks considering an exogenous process for the oil price. In this model a more careful experiment can instead be conducted when studying a demand shock.

In the second experiment the idea is to approximate the increase in demand driven by the growth process involving Asian countries. As a first approximation, we calibrate the shock to the foreign technology in order to deliver an increase in foreign output (on impact) of 3%. This is approximately consistent with the quarterly growth rate experienced by China between 2001 and 2006. The results are shown in figure 10. We are aware the the correct experiment would be to consider an increase in the growth rate

of the foreign country. As a first approximation, we set the autocorrelation coefficient for the technology process close to one.

Since the foreign country is more productive, foreign produced goods become cheaper. Therefore, there will be an increase in the demand for those goods from foreign consumers (that are now richer) but also from home consumers. At the same time also the demand for home produced goods will increase because of the income effect affecting foreign consumers. As a consequence, home output is going to increase. The increase in production in both countries drives up world oil demand and, therefore, the oil price. This increases domestic inflation in the home country because of the increase in the production costs (the home country is producing more without being more productive). Home CPI inflation instead decreases because now home consumers are importing goods from abroad at a cheaper price[23]. This explain how we can be experiencing a reduction in CPI inflation and an increase in domestic inflation and output together with an increase in the oil price. Real wages increases because of the reduction in CPI. The direction of the change in those variables is consistent with the one experienced by the U.S. variables in the 2000s (see table 6). The only difference between the model and the data is in the behaviour of wage inflation. While wage inflation is decreasing in the data, it is increasing in the model. Two things are worth noticing. The first one is that even if wage inflation is increasing under the demand shock, this increase is lower then the one experienced under a supply shock. The second is that the direction of the change in wage inflation depends very much on the persistence of the technology shock. When $\rho_{A*} = 0.9$, wage inflation decrease after a positive shock to foreign technology. Quantitatively, the shock delivers an increase in the real oil price of 1.5% in one quarter. Since China experienced this growth rate for around 24 quarters, it can explain an increase in oil price of around 40%. This is a reasonable results given that other shocks are affecting the world economy at the same time. The movements in the other variables are of the right sign but the magnitude is bigger than the one observed in the data, especially for what concerns the home output. One possible explanation for this is that the model has been solved under the assumption of no home bias. Removing this assumption would capture the fact that most of China consumption is still on home produced goods. This would decrease the impact of the foreign productivity shock on home output. Before concluding, it is interesting to look

[23]Note that this difference in the behaviour of CPI inflation and domestic inflation is consistent with the one experienced by the U.S. in correspondence of the last oil price increase (see table 2).

at the consequences of different monetary policy rules in this context.

5.3 Comparison across Monetary Policies

In the baseline calibration we considered a simple interest rate rule where both countries target their own CPI inflation. A question which comes out often in policy debates is whether the monetary authority should react immediately to higher oil prices or should wait for them to feed into inflation. To tentatively address this question figures (11) and (12) reports impulse responses of CPI inflation, domestic inflation, wage inflation and output gap for the Home country under three different specifications of the interest rate rule in the home economy while keeping the interest rate rule for Foreign as in the baseline calibration. As standard for an open economy model with both price and wage rigidities, does are the variables that would enter into a welfare function derived from a second order approximation of the utility. The objective of the monetary authority is to stabilize all those variables as much as possible. Three cases are considered: CPI targeting rule ($\phi = 1.5$); strict CPI targeting ($\phi = 100$); CPI targeting together with direct response to oil price movements ($\phi = 1.5$ and $\phi_{oil} = 0.01$). The figures show that when the economy is hit by a supply driven oil price shock, the volatilities of those variables is reduced if the monetary authority fight inflation strongly. Under a foreign TFP shock instead, a strong reaction to CPI inflation entails bigger movements in terms of all the other three variables. A rule targeting CPI inflation with $\phi = 1.5$, although generating higher volatility in CPI inflation dampens the reaction of the other variables. Reacting directly to oil price in this context makes the reaction of wage inflation and CPI inflation more persistent. An interesting extension of the paper would be to derive the welfare function in order to have a clear criteria for ranking the different policy rules.

6 Conclusions

The paper started asking the question of how is it possible that, despite the same magnitude in the increase in the price of oil, the 2000s appear to be so different from the 70s, with a positive output growth, a low (even decreasing) CPI inflation and increasing real wages. An explanation based on different shocks hitting the economy in the two periods, relating in particular the current behaviour of U.S. variables and

oil price with the growth in China has been provided. In particular, using a two-country model where the price of oil is determined endogenously, two kind of shocks have been considered: a negative shock to oil supply and a positive shock to foreign country productivity. The model, despite its simplicity, is able to generate changes in the relevant variables under the two types of shocks that are consistent with the ones observed in the data.

A Derivation of $\hat{\text{mc}}$

All lower case letters indicate the log of the variables. For a generic variable x_t, $\widehat{x}_t$ represents log deviation from the steady state when there are nominal rigidities, and $\widetilde{x}_t$ stands for log deviation from the steady state when there are no nominal rigidities. $\overline{x}_t$ characterizes the frictionless level of the variables. For simplicity, either both countries faces nominal rigidities or they both operate in a flexible environment.

Writing (17) in log-deviation from the steady state, remembering that $w_{h,t} - p_t = \mu_{w,t} + \varphi n_t + \sigma c_t$[24], and using (26) together with the fact that $\widehat{x}_t - \widetilde{x}_t = x_t - \overline{x}_t$, we can write:

$$\widehat{mc}_t = \alpha[\widehat{\mu}_{w,t} + \varphi(n_t - \overline{n}_t)] + (\alpha\sigma - 1)(c_t - \overline{c}_t) + \\ + (1-\alpha)\left[\log\left(\frac{P_{o,t}}{P_t}\right) - \overline{\frac{P_{o,t}}{P_t}}\right] + y_t - \overline{y}_t \quad (37)$$

Taking a first order approximation of (28) around the steady state and using (15), we have:

$$\widehat{n}_t = \widehat{y}_t - a_t - (1-\alpha)[\widehat{\mu}_{w,t} + \varphi\widehat{n}_t - \sigma\widehat{c}_t] + (1-\alpha)\widehat{\frac{P_{o,t}}{P_t}} \quad (38)$$

Taking a first order approximation of (25), using the fact that $c_t = c_t^*$, considering the fact that the steady state is symmetric across countries, and that also for the foreign country $w_{h,t}^* - p_t^* = \mu_{w,t}^* + \varphi n_t^* + \sigma c_t^*$, we have:

$$\widehat{\frac{P_{o,t}}{P_t}} = -\widehat{\xi}_t + n\widehat{\mu}_{w,t} + (1-n)\widehat{\mu}_{w,t}^* + n(1+\varphi)\widehat{n}_t + (1-n)(1+\varphi)\widehat{n}_t^* + \sigma\widehat{c}_t \quad (39)$$

From (27) we have that:

$$\widehat{c}_t = n\widehat{y}_t + (1-n)\widehat{y}_t^* \quad (40)$$

We can write an expression analogous to (38) for the foreign country. Using that equation together with (38), (39) and (40) we can write $\widehat{n}_t$ and $\widehat{\frac{P_{o,t}}{P_t}}$ as function only of

[24] $\mu_{w,t}$ is the wage mark-up charged each period.

the exogenous shocks (a_t,a_t^* and ξ_t), $\widehat{y}_t$, $\widehat{y}_t^*$, $\widehat{\mu}_t$ and $\widehat{\mu}_t^*$:

$$\widehat{\frac{P_{o,t}}{P_t}} = -\frac{1+\varphi(1-\alpha)}{\alpha}\widehat{\xi}_t - \frac{n(1+\varphi)}{\alpha}a_t - \frac{(1-n)(1+\varphi)}{\alpha}a_t^* + \\ + \left[\frac{n(1+\varphi)}{\alpha} + \sigma n\right]\widehat{y}_t + \left[\frac{(1-n)(1+\varphi)}{\alpha} + \sigma(1-n)\right]\widehat{y}_t^* + n\widehat{\mu}_{w,t} + (1-n)\widehat{\mu}_{w,t}^* \quad (41)$$

$$\widehat{n}_t = -\frac{1-\alpha}{\alpha}\xi_t + \frac{\alpha + n(1-\alpha)(1+\varphi)}{\alpha[1+\varphi(1-\alpha)]}(\widehat{y}_t - a_t) + \\ + \frac{(1-\alpha)(1-n)(1+\varphi)}{\alpha[1+\varphi(1-\alpha)]}(\widehat{y}_t^* - a_t^*) + \frac{(1-n)(1-\alpha)}{1+\varphi(1-\alpha)}(\widehat{\mu}_{w,t}^* - \widehat{\mu}_{w,t}) \quad (42)$$

Using the fact that $\widehat{x}_t - \widetilde{x}_t = x_t - \overline{x}_t$, we obtain:

$$\frac{P_{o,t}}{P_t} - \overline{\frac{P_{o,t}}{P_t}} = \left[\frac{n(1+\varphi)}{\alpha} + \sigma n\right](y_t - \overline{y}_t) + \\ + \left[\frac{(1-n)(1+\varphi)}{\alpha} + \sigma(1-n)\right](y_t^* - \overline{y}_t^*) + n\widehat{\mu}_{w,t} + (1-n)\widehat{\mu}_{w,t}^* \quad (43)$$

$$n_t - \overline{n}_t = \frac{\alpha + n(1-\alpha)(1+\varphi)}{\alpha[1+\varphi(1-\alpha)]}(y_t - \overline{y}_t) + \\ + \frac{(1-\alpha)(1-n)(1+\varphi)}{\alpha[1+\varphi(1-\alpha)]}(y_t^* - \overline{y}_t^*) + \frac{(1-n)(1-\alpha)}{1+\varphi(1-\alpha)}(\widehat{\mu}_{w,t}^* - \widehat{\mu}_{w,t}) \quad (44)$$

$$c_t - \overline{c}_t = n(y_t - \overline{y}_t) + (1-n)(y_t^* - \overline{y}_t^*) \quad (45)$$

Substituting equations (43), (44) and (45) into (37) we obtain the expression for the log deviation of the real marginal cost that, once substitute into (20), gives equation (34) in the text.

B Data description

All variables refer to U.S.A. All data are available for the period Q1:1960-Q1:2008 with the exception of oil consumption which is available at yearly frequency for the period 1970-2006, oil production which is available at yearly frequency for the period 1970-2007, and the imports/exports series which are available starting from 1974.

Nominal Oil Price
Spot Oil Price, West Texas Intermediate, dollars per barrel, quarterly observations constructed from monthly data. Source:http://www.eia.doe.gov/.

Nominal GDP
Gross Domestic Product, seasonally adjusted annual rate, billions of dollars, quarterly observations. Source: FRED, http://research.stlouisfed.org/fred2/.

GDP Deflator
Gross Domestic Product Implicit Price Deflator, seasonally adjusted, quarterly observations, index 2000 = 100. Source: FRED, http://research.stlouisfed.org/fred2/.

Consumer Price Index
Consumer Price Index For All Urban Consumers: All Items, seasonally adjusted, quarterly observations constructed from monthly data, index 2000 = 100. Source: FRED, http://research.stlouisfed.org/fred2/.

Nominal Wage
Hourly Earnings (MEI), quarterly observations, index 2000 = 100. Source: OECD, www.oecd.org.

Oil Consumption
OECD Countries and World Petroleum (Oil) Demand (consumption), yearly observations, thousand barrels per day. Source:http://www.eia.doe.gov/.

Crude Oil Production
U.S., Persian Gulf, OPEC and World Production, yearly observations, thousand barrels per day. Source:http://www.eia.doe.gov/.

Imports and Exports by Country

U.S. Imports and Exports by Country are available for the major trading partners: Canada, China, France, Germany, Japan, Mexico and U.K. Monthly frequency: 1974:01-2007:12. Not seasonally adjusted. The data presented in the pictures are yearly averages. Source: FRED, http://research.stlouisfed.org/fred2/.

The real GDP has been computed dividing the GDP by the GDP deflator. The real wage has been computed dividing the hourly earnings by the CPI. The real oil price has been computed dividing the nominal oil price by the CPI.

References

Backus, David K. and Mario J. Crucini, "Oil Prices and the Terms of Trade," *Journal of International Economics*, 2000, *50*, 185–213.

Barsky, Robert B. and Lutz Kilian, "Do We Really Know That Oil Caused the Great Stagflation? A Monetary Alternative," *NBER Macroeconomics Annual 2001*, 2002, pp. 137–183.

_ **and** _ , "Oil and the Macroeconmy Since 1970s," *Journal of Economic Perspectives*, 2004, *18* (4), 115–134.

Bernanke, Ben S., Mark Gertler, and Mark Watson, "Systematic Monetary Policy and the Effects of Oil Price Shocks," *Brookings papers on Economic Activity*, 1997, *1.*

Blanchard, Olivier J. and Jordi Galí, "The Macroeconomic Effects of Oil Price Shocks: Why are the 2000s so Different from the 1970s?," *NBER Working Paper*, 2007, *13368.*

Clarida, Richard, Jordi Galí, and Mark Gertler, "A Simple Framework for International Monetary Policy Analysis," *Journal of Monetary Economics*, 2002, *49*, 879–904.

Erceg, Christopher J., Dale W. Henderson, and Andrew T. Levin, "Optimal Monetary Policy with Staggered Wage and Price Contracts," *Journal of Monetary Economics*, 2000, *46*, 281–313.

Finn, Mary G, "Perfect Competition and the Effects of Energy Price Increases on Economic Activity," *Journal of Money, Credit and Banking*, 2000, *32* (3), 400–416.

Galí, Jordi and Tommaso Monacelli, "Monetary Policy and Exchange Rate Volatility in a Small Open Economy," *Review of Economic Studies*, 2005, *72*, 707–734.

Gregorio, José De, Oscar Landerretche, and Christopher Neilson, "Another Passthrough Bites the Dust? Oil Prices and Inflation," *mimeo*, 2007.

Hamilton, James D., "Oil and the Macroeconomy Since World War II," *The Journal of Political Economy*, 1983, *91* (2), 228–248.

_ , "This is What Happened to the Oil Price-Macroeconomy Relationship," *Journal of Monetary Economics*, 1996, *38*, 215–220.

Hooker, Mark A., "What Happened to the Oil Price-Macroeconomy Relationship?," *Journal of Monetary Economics*, 1996, *38*, 195–213.

Kilian, Lutz, "A Comparison of the Effects of Exogenous Oil Supply Shocks on Output and Inflation in the G7 Countries," *Journal of the European Eonomic Association*, 2007, *Forthcoming.*

_ , "Exogenous Oil Supply Shocks:How Big are They and How Much Do They Matter for the U.S. Economy?," *Review of Economics an Statistics*, 2007, *Forthcoming.*

_ , "Not All Oil Price Shocks Are Alike: Disentangling Demand and Supply Shocks in the Crude Oil Market," *mimeo*, 2007.

Leduc, Sylvain and Keith Sill, "A Quantitative Analysis of Oil-Price Shocks, Systematic Monetary Policy and Economic Downturns," *Journal of Monetary Economics*, 2004, *51*, 781–808.

Rotemberg, Julio J. and Michael Woodford, "Imperfect Competition and the Effects of Energy Price Increases on Economic Activity," *Journal of Money, Credit and Banking*, 1996, *28* (4), 549–577.

Table 1: **% Change in the Real Oil Price During Each Oil Shock Period**

Q2:73 - Q1:74	Q4:78 - Q2:80	Q4:98 - Q4:00	Q4:01 - Q3:05
97%	79%	85%	103%

Table 2: **% Change between 4 quarters after and 4 quarters before the oil shock**

	Q1:74	Q3:79	Q3:99	Q1:03
CPI Inflation	3.29	3.26	1.15	-0.35
GDP Defl. Inflation	3.44	0.46	0.63	0.50
Real GDP Growth	-6.02	-3.29	0.41	1.75
Real Wage	-2.26	-4.76	0.69	0.67
Wage Inflation	3.1753	-0.8838	0.4428	-0.9325

Table 3: **% Change between 8 quarters after and 8 quarters before the oil shock**

	Q1:74	Q3:79	Q3:99	Q1:03
CPI Inflation	3.5680	2.9422	1.4251	0.5428
GDP Defl. Inflation	3.1880	1.5933	1.0106	0.5794
Real GDP Growth	-5.0952	-3.1710	-1.3663	2.4373
Real Wage	-1.7812	-5.4471	0.7128	1.6178
Wage Inflation	1.2753	0.7356	0.3578	-0.6904

Table 4: **Oil Consumption (%) Growth Rates - 2001:2006.** *The data on which growth rates have been computed have been downloaded from the Energy Information Administration and refer to Thousand Barrels per Day.*

Region/Country	**(%) Growth Rate**
North America	5.21
Central & South America	4.78
Europe	2.09
Eurasia	11.24
Middle East	24.75
Africa	16.55
Asia & Oceania	15.84
Total OECD	2.90
Total Non-OECD	19.79
Total World	9.33
China	46.43

Table 5: **Oil Consumption by Country as % of World Consumption in 2006.** *Data on oil consumption have been downloaded from the Energy Information Administration and refer to Thousand Barrels per Day. Each entry in the table reports the % of world consumption accounted for by each region/country.*

Region/Country	**Country Consumption/World Consumption** (%)
United States	24.45
North America	**29.49**
Central & South America	**6.59**
France	2.32
Germany	3.15
Italy	2.05
Spain	1.88
United Kingdom	2.16
Europe	**19.39**
Russia	3.32
Eurasia	**4.97**
Iran	1.99
Saudi Arabia	2.53
Middle East	**7.29**
Africa	**3.58**
China	8.51
India	3.04
Japan	6.10
South Korea	2.57
Asia & Oceania	**28.69**
Total OECD	**58.30**
Total Non-OECD	**41.70**

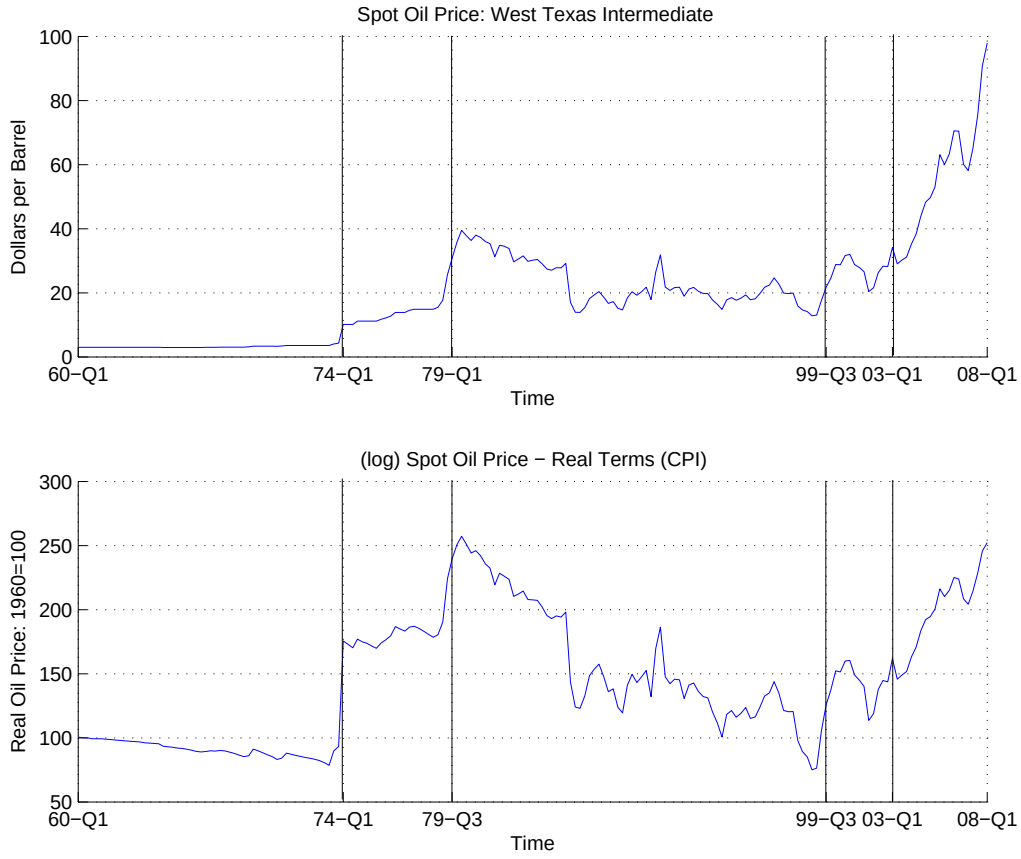


Figure 1: Oil Price - Nominal and Real - Q1:1960 - Q1:2008

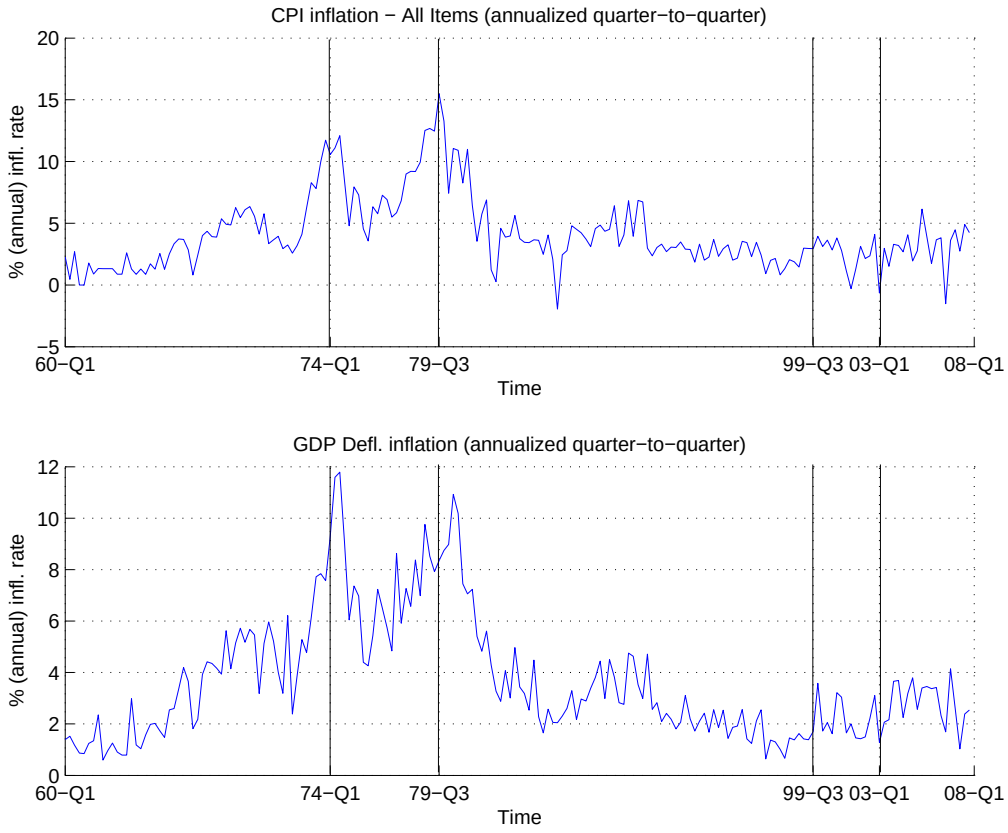


Figure 2: CPI (All Items) and GDP Deflator Inflation Rates - Q1:1960 - Q1:2008

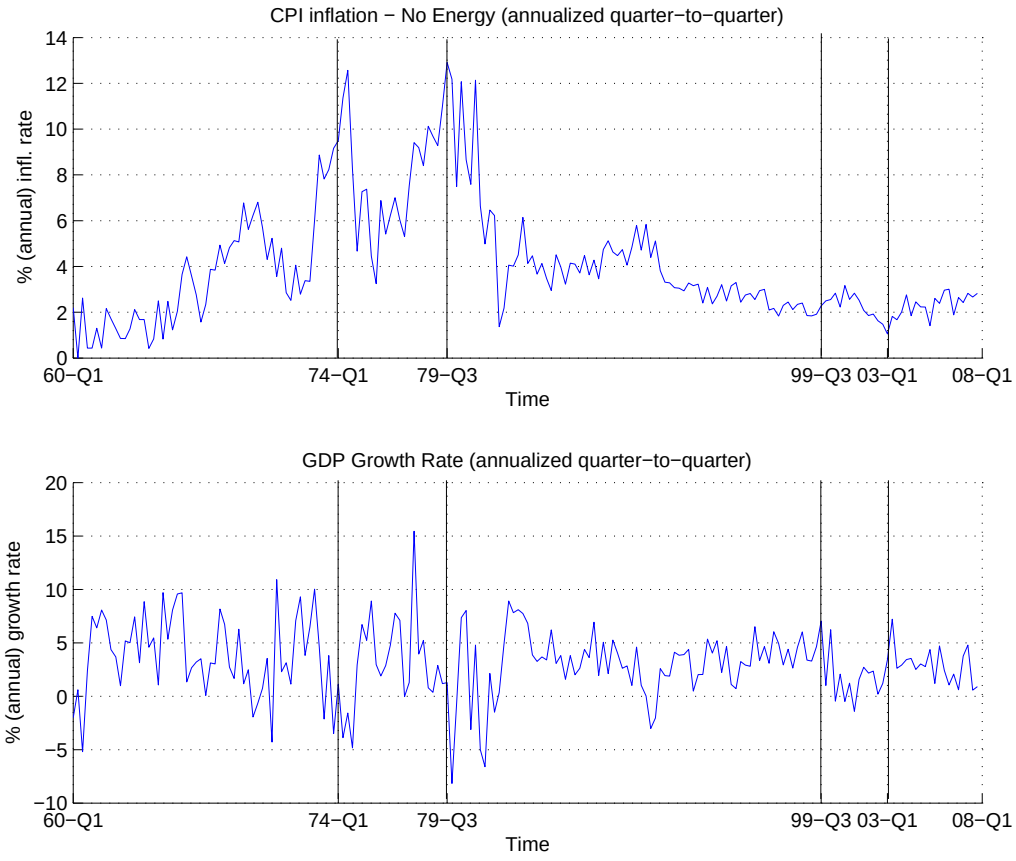


Figure 3: CPI (No Energy) Inflation and Real GDP Growth Rate - Q1:1960 - Q1:2008

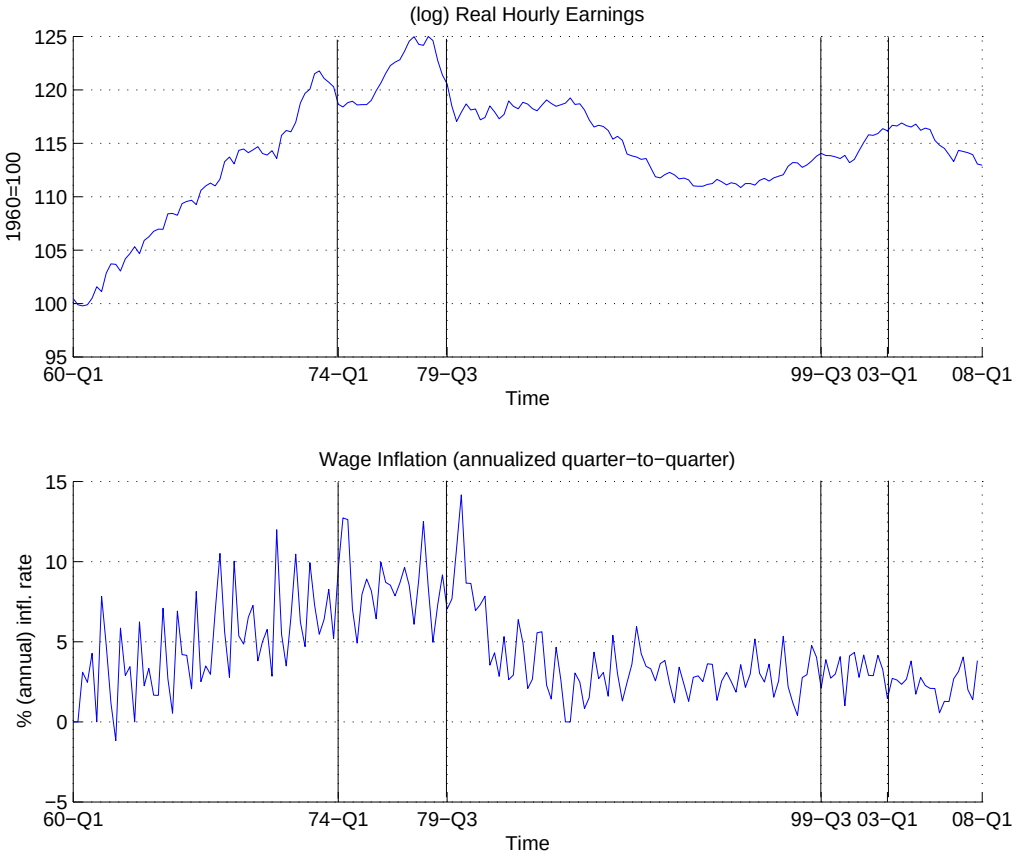


Figure 4: Real Wage and Wage Inflation - Q1:1960 - Q1:2008

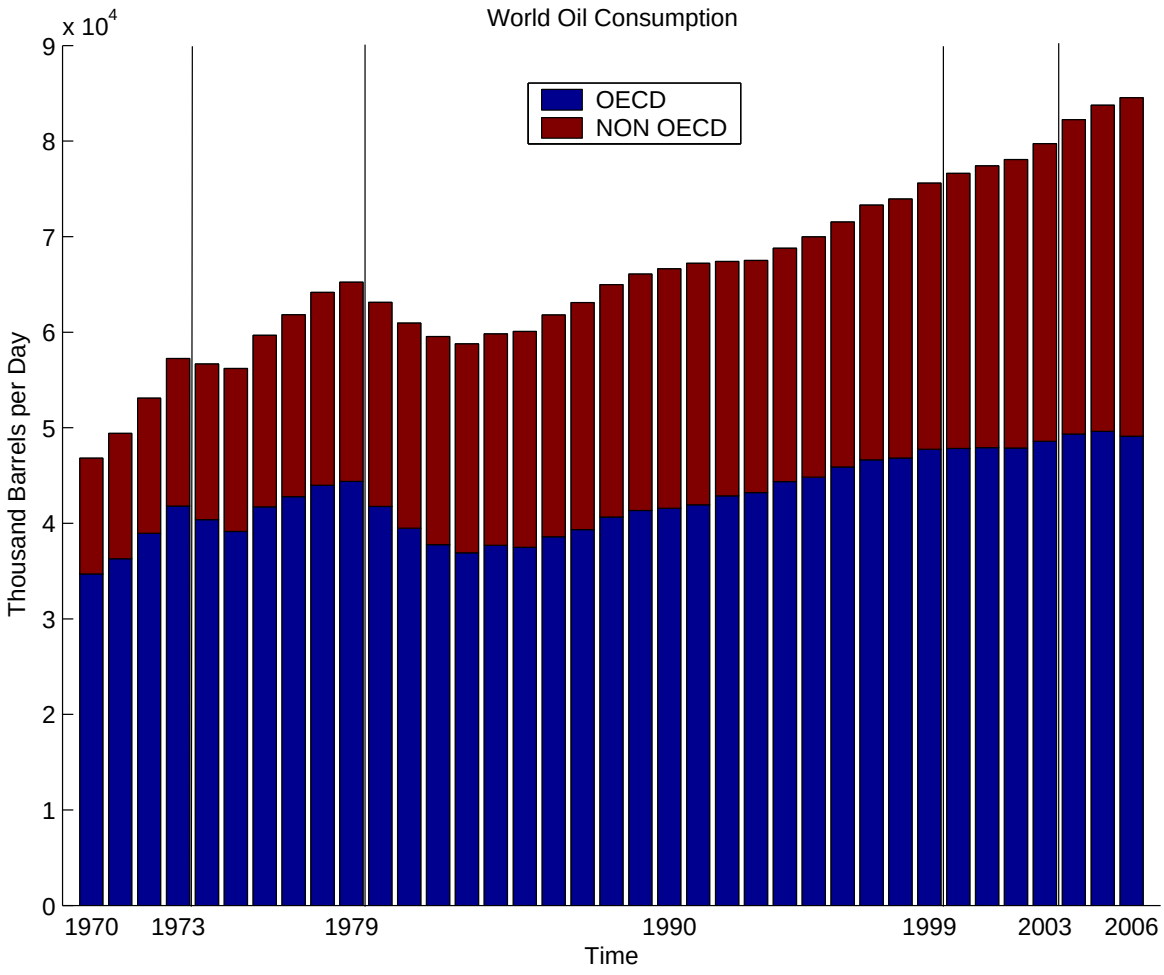


Figure 5: World Oil Consumption - Yearly Average - 1970 - 2006

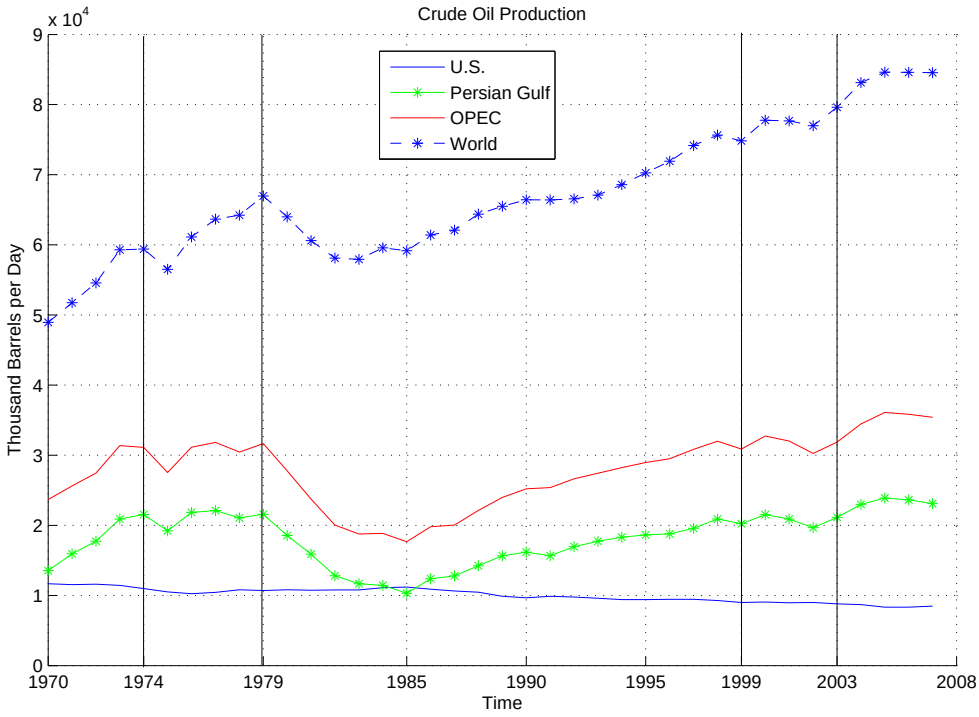


Figure 6: World Oil Production - Yearly Average - 1970 - 2007

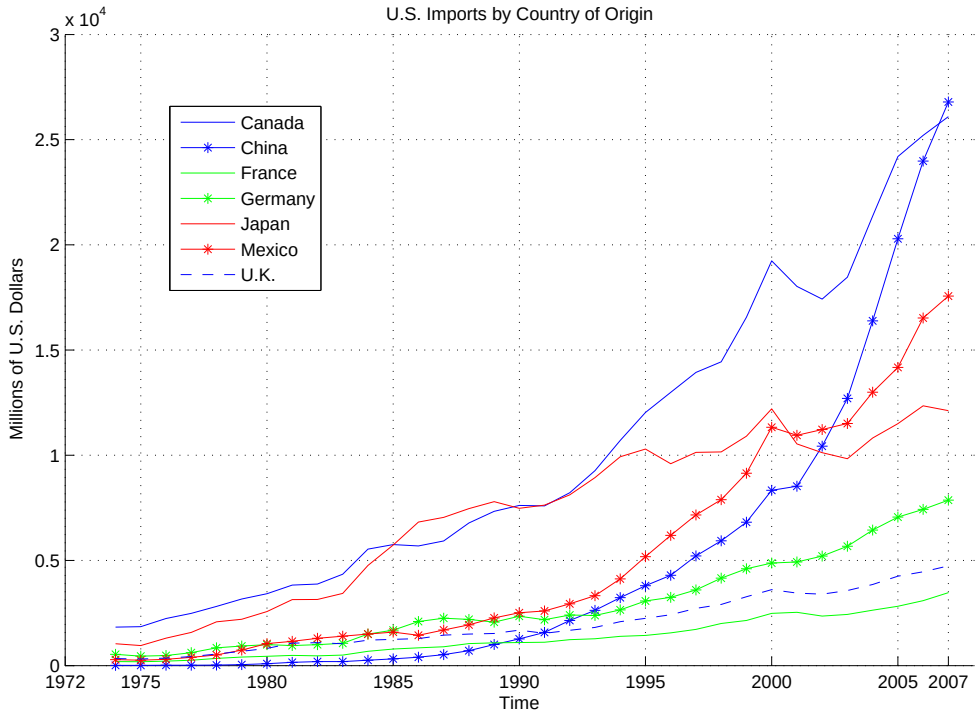


Figure 7: U.S. Imports by Country of Origin - Yearly Average - 1974 - 2007

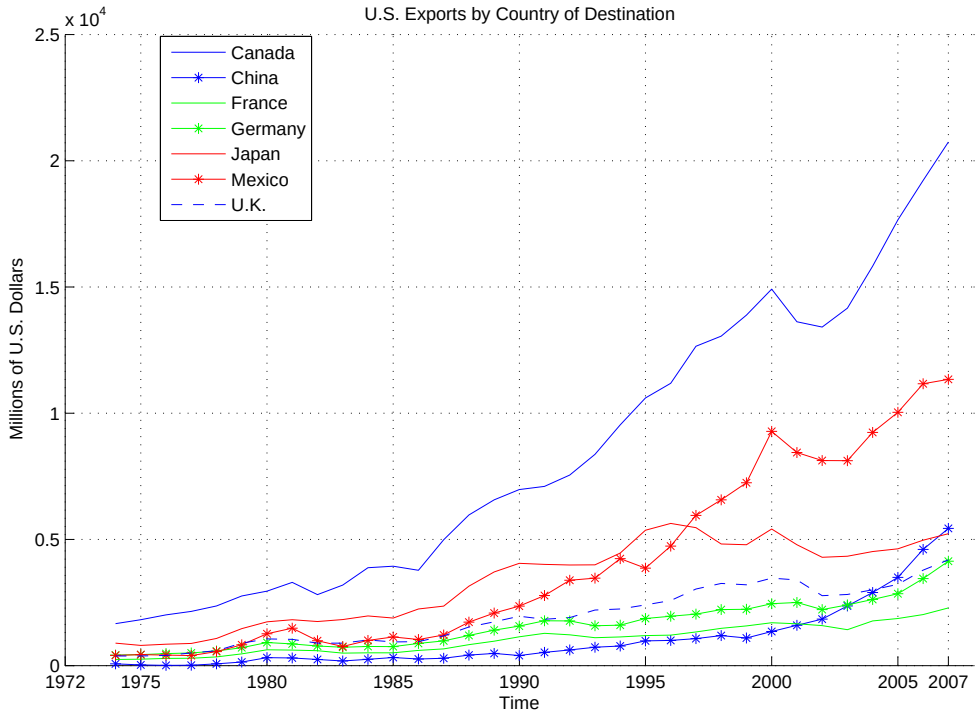


Figure 8: U.S. Exports by Country of Destination - Yearly Average - 1974 - 2007

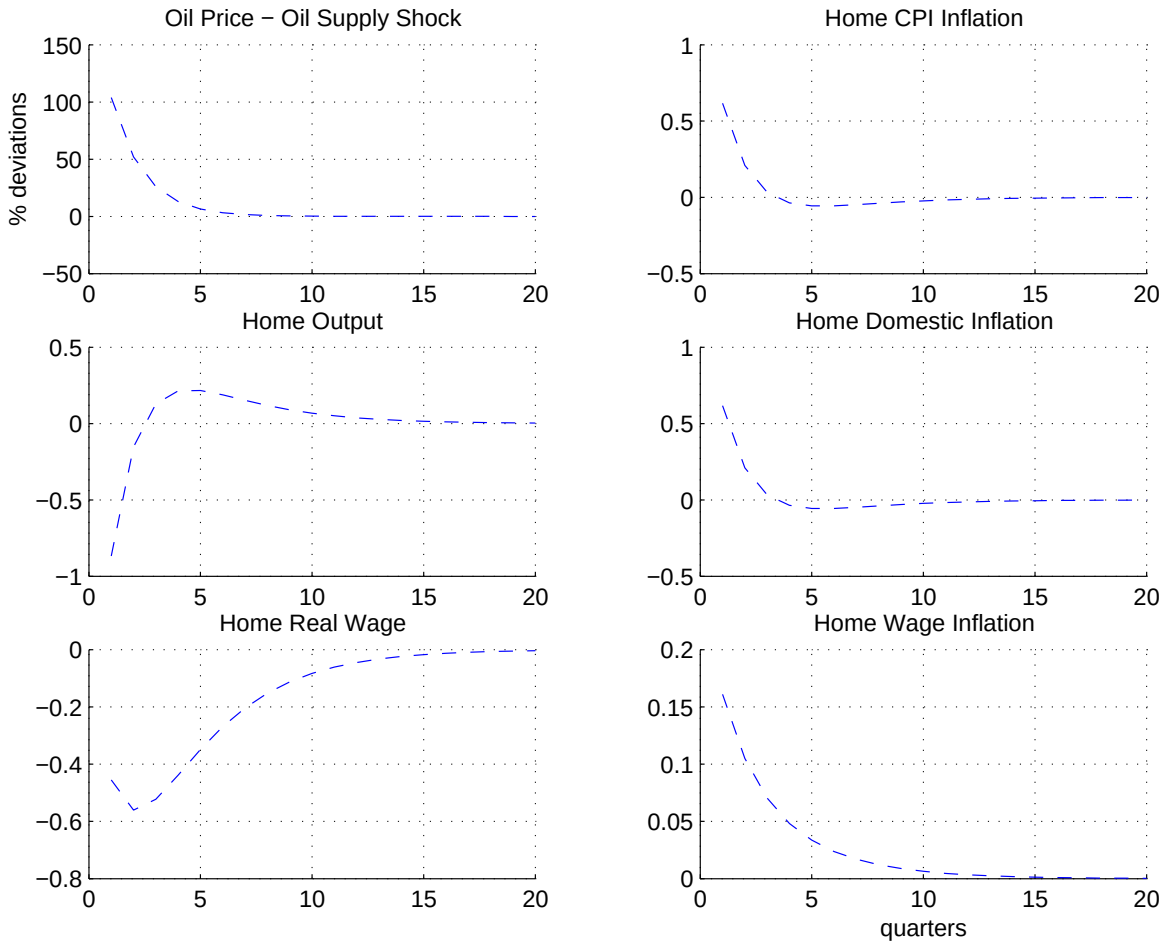


Figure 9: Impulse Responses: Oil Supply Shock

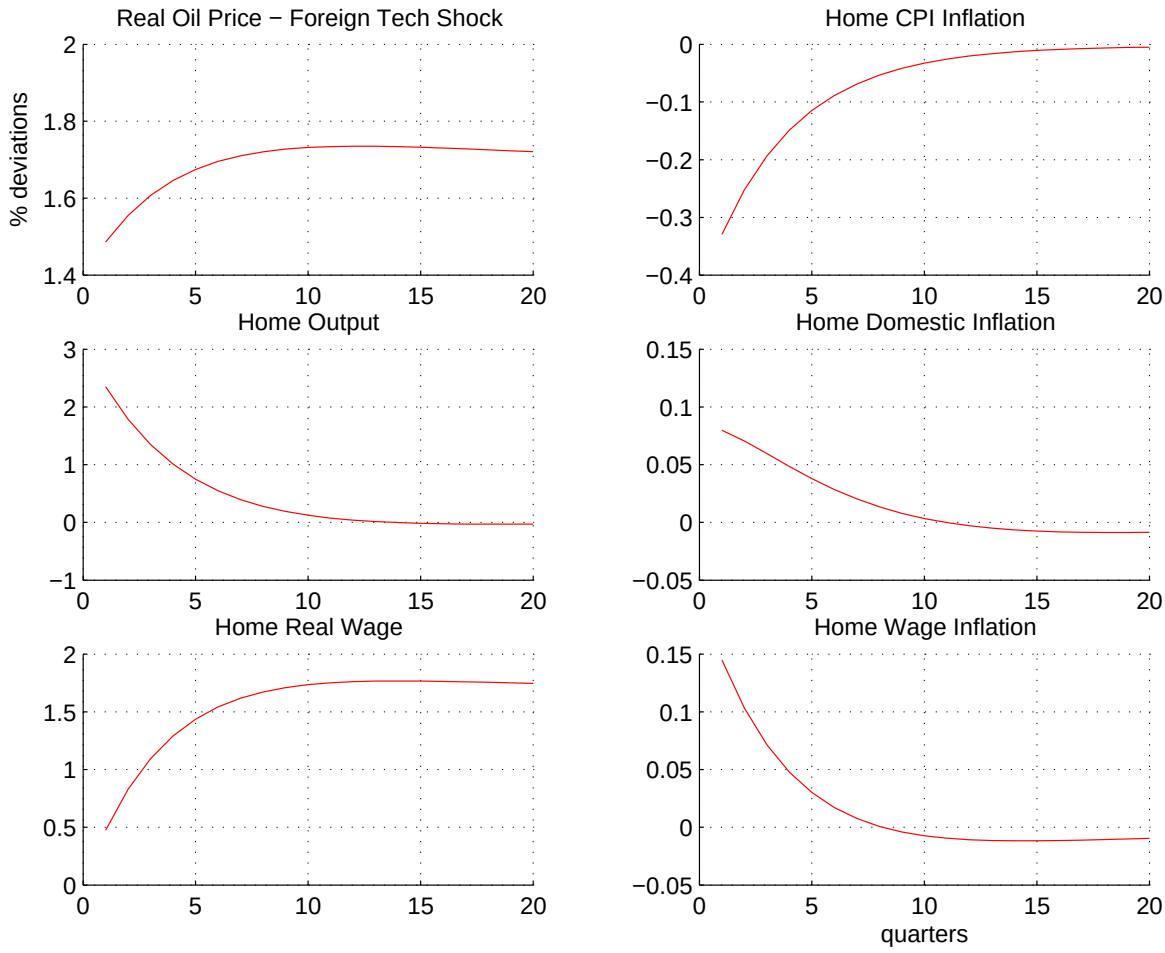


Figure 10: Impulse Responses: Foreign Technology Shock

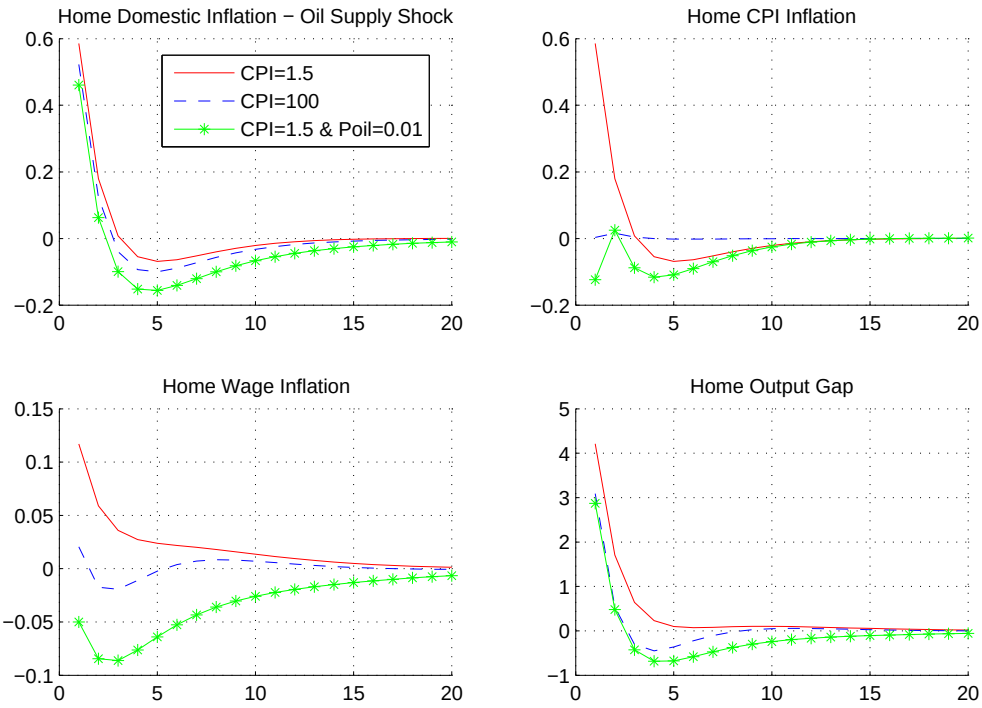


Figure 11: Comparison across different Monetary Policies: Oil Supply Shock

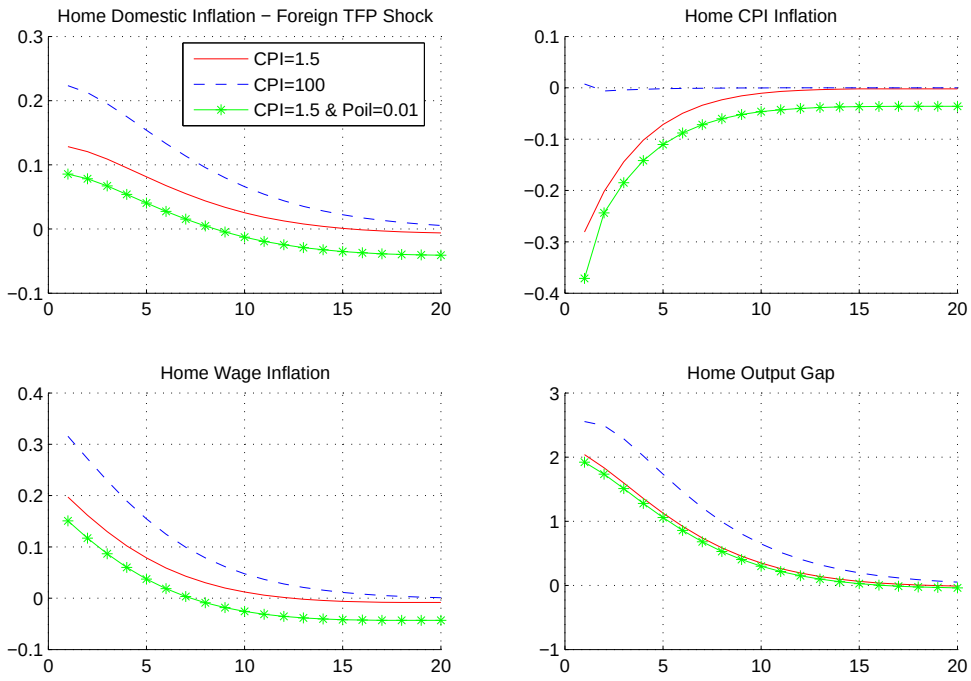


Figure 12: Comparison across different Monetary Policies: Foreign Productivity Shock