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Anna Lipińska and Stephen Millard

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Anna Lipińska[1] and Stephen Millard[2]

Abstract

In this paper, we analyse the impact of a persistent productivity increase in a set of countries — which we think of as the BRIC economies — on inflation in their trading partners, the G7. In particular we want to understand conditions under which this shock can lead to tailwinds or headwinds in the economies of trading partners. We build a three-country DSGE model in which there are two oil-importing countries (home and foreign) and one oil-exporting country. We perform several experiments where we try to disentangle the importance of different factors that can shape inflation dynamics in the home country when the foreign country is hit by a persistent productivity shock. These factors are wage stickiness, the role of the oil sector and its share in both consumption and production, foreign monetary policy and the degree of completeness of financial markets. We find that the tailwinds effect, lowering inflation in the home economy, dominates the headwinds effect as long as there is scope for borrowing and lending across countries and the foreign country's production is not too oil intensive.

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Summary

Much has been written about the impact of globalisation on the economy. It is fairly clear that its pace increased after the early 1990s and an important part of this was the emergence of the so-called 'BRIC' economies – Brazil, Russia, India and, perhaps most importantly, China – which experienced rapid rises in productivity and GDP over this period. Many authors argued that increased trade with the BRIC economies helped keep inflation low in the developed world – so-called 'tailwinds' – by depressing import prices and increasing the share of imports in demand in the developed world. Furthermore, more intense global competition is likely to have reduced mark-ups and put downward pressure on wages in developed countries, as well as raising productivity growth, as firms were put under increasing pressure to innovate. Production costs also fell as firms increasingly found it easier to off-shore activities to low-cost countries and source low-cost labour from abroad. All these factors have been used to help explain why inflation was so low in the developed world over the past decade. But, there may have been an inflationary 'headwind' acting to counteract the tailwind. Rapid growth in emerging economies pushed up the global price of commodities such as oil and steel. Given such a rise in commodity prices, all countries importing these commodities suffered an increase in their production costs putting upwards pressure on their aggregate inflation rates. Although recent events following the world financial crisis have overlaid this picture, the underlying factors remain relevant in the longer term. But, in order properly to understand the processes at work, we need an organising framework for thinking about this problem.

Consequently, in this paper, we develop a stylised calibrated structural model within which we can begin to assess the quantitative impacts of the continuing rise of the BRIC economies on inflation in the developed world. Our aim is primarily to understand the mechanisms at work, so although we try to make broad features realistic it is a highly simplified and abstract model, which does not use actual data. Thus, for example, we consider only one commodity, 'oil'.

We build a three-country model in which there are two oil-importing countries – home and foreign, which can be thought of as the G7 and the BRIC economies, respectively – and one oil-exporting country, which sells its endowment of oil and spends the associated revenues on consumption of goods from both the developing and developed world. Oil is used to produce

intermediate tradable goods and is also consumed directly. Final goods in each country are produced using intermediate goods from both countries. International financial markets allow some borrowing and lending between countries, but are not complete (which means that it is impossible to buy insurance to completely remove international risks). In each country, a monetary authority sets interest rates in order to keep inflation close to target.

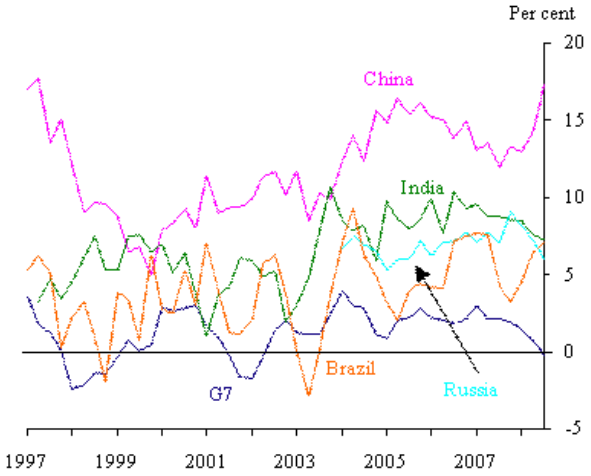
We use this model to examine the effects of a productivity shock in the foreign economy, such as was seen in the BRIC economies in recent years. In our baseline calibration, it turns out that the tailwinds outweigh the headwinds and home inflation is reduced as a result of the shock, suggesting that the rise of the BRIC economies acted to help keep inflation low in the developed world. This is, of course, not to say that at the time of writing the recent rises in non-agricultural commodity prices are unconnected with the resumption of growth in emerging economies.

We then perform several experiments where we try to disentangle the importance of different factors that can shape inflation dynamics in the home country when the foreign country is hit by a persistent productivity shock. These factors are wage stickiness, the role of the oil sector and its share in both consumption and production, foreign monetary policy and the degree of completeness of financial markets. We find that the tailwinds effect, lowering inflation in the home economy, dominates the headwinds effect only as long as there is scope for borrowing and lending across countries and the foreign country's production is not too oil intensive. This suggests that we need to examine the extent to which the BRIC economies use oil if we are to obtain a final answer to our question. Indeed, an exact quantification of the effects of the rise of the BRIC economies would require a more careful calibration of the model, in particular, proper estimation of asymmetries between the developed and developing economies.

1 Introduction

Much has been written about the impact of globalisation on the economy.[1] It is clear that its pace increased after the early 1990s and an important part of this was the emergence of the so-called 'BRIC' economies – Brazil, Russia, India and, perhaps most importantly, China – which experienced rapid rises in productivity and GDP over this period (see Chart 1).

Chart 1: GDP growth (source: Thomson Reuters Datastream)

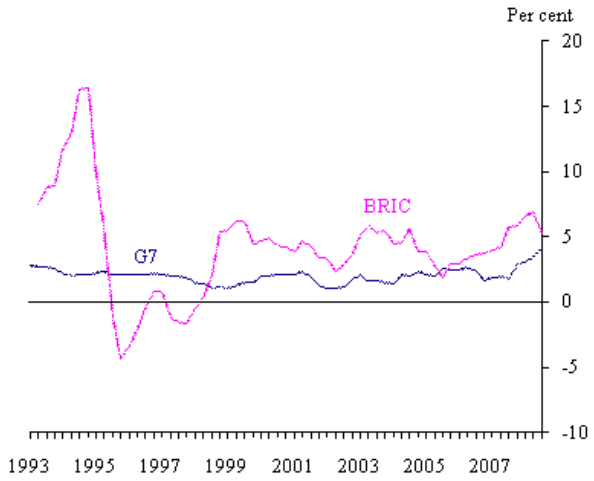


Many authors argued that increased trade with the BRIC economies helped keep inflation low in the developed world – so-called 'tailwinds' – by depressing import prices and increasing the share of imports in domestic demand.[2] Furthermore, more intense global competition is likely to have reduced the mark-ups of domestic producers and put downward pressure on wages as well as raising productivity growth, as firms were put under increasing pressure to innovate. Production costs also fell as firms increasingly found it easier to off-shore activities to low-cost countries and, through increased international mobility, found it easier to source low-cost labour from abroad rather than bidding up wages to attract workers from domestic firms. Aggregate production costs also fell as inefficient firms exited the market. All these factors could help explain why inflation was so low in the developed world over the past decade (Chart 2).

[1] See eg Bean (2006), Lomax (2007), Borio and Filardo (2007), IMF (2006).

[2] See eg Bean (2006), Nickell (2005), ECB (2006).

Chart 2: CPI inflation (source: Thomson Reuters Datastream)

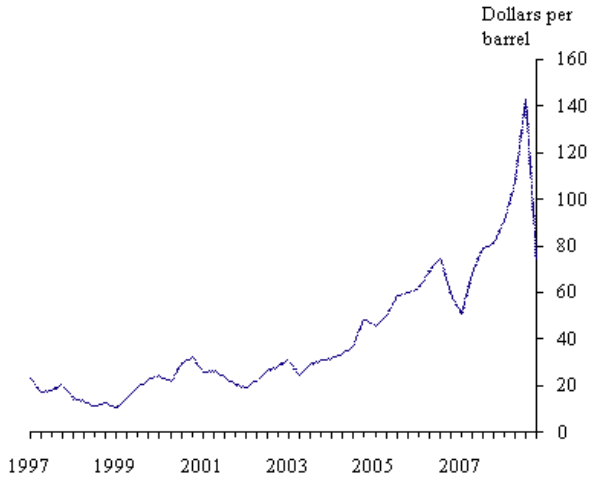


But, there may have been an inflationary 'headwind' acting to counteract the tailwind. As shown in Campolmi (2008), this arises because rapid growth in emerging economies can push up the global price for commodities, such as oil and steel. Indeed, Chart 3 shows that oil prices increased dramatically between 1999 and 2008, that is, at the same time as the rapid growth in the BRIC economies. Given such a rise in commodity prices, all countries importing these commodities suffered an increase in their production costs and, this had potential consequences for their aggregate inflation rates. Events following the world financial crisis have recently overlaid this picture, but the underlying factors remain relevant in the longer term.

The goal of this paper is to develop a calibrated structural model within which we can assess the quantitative impacts of cheaper intermediate and final foreign goods and more expensive commodities on home inflation. This will enable us to assess the quantitative impact of the continuing rise of the BRIC economies on inflation in the G7. We can then work out the key parameters determining how large the 'tailwind' and 'headwind' effects are and assess how robust our results are to reasonable changes to these parameter values. In doing this, we aim to increase our understanding of the links between growth in the BRIC economies, oil prices and G7 inflation.

Previous authors have looked at the question of why the rise in oil prices from 2003 to 2008 had

Chart 3: Oil price (source: Thomson Reuters Datastream)



a much smaller effect on output and inflation in the G7 than similar rises in the 1970s and early 1980s. Blanchard and Gali (2010) examine four different hypotheses: good luck, a smaller share of oil in production, more flexible labour markets and improvements in monetary policy. They conclude that all four were important in lowering the impact of the oil shock. Killian (2009) makes the point that it is the shock that caused oil prices to rise that matters. He uses a structural VAR approach to decompose oil price movements into crude oil supply shocks, shocks to global demand for all industrial commodities and shocks to global demand for oil specifically (capturing rises in precautionary demand associated with concerns about future supply shortfalls). He found that the recent increase in oil prices resulted from a global demand shock and this is why it had smaller output and inflation effects than previous oil shocks.

Campolmi (2008) takes this further by demonstrating that this is exactly what a theoretical model would suggest. More specifically, she used a two-country model to show that a positive productivity shock in the foreign economy (where she was thinking of China) led to a rise in the demand for, and hence price of, oil with the sort of effects on the home economy that were seen in the United States in the 2000s.[3] Her paper is clearly similar to ours, though our emphasis is on the effects of the productivity shock specifically rather than on explaining the effects of oil price rises. In addition, we also consider the factors examined by Blanchard and Gali (2010) and ask

[3]Unalmis, Unalmis and Unsal (2008) carry out a similar exercise using a small open economy model where the 'oil demand shock' results from an exogenous increase in output in the rest of the world.

to what extent they affect the response of the home economy to a foreign productivity shock.

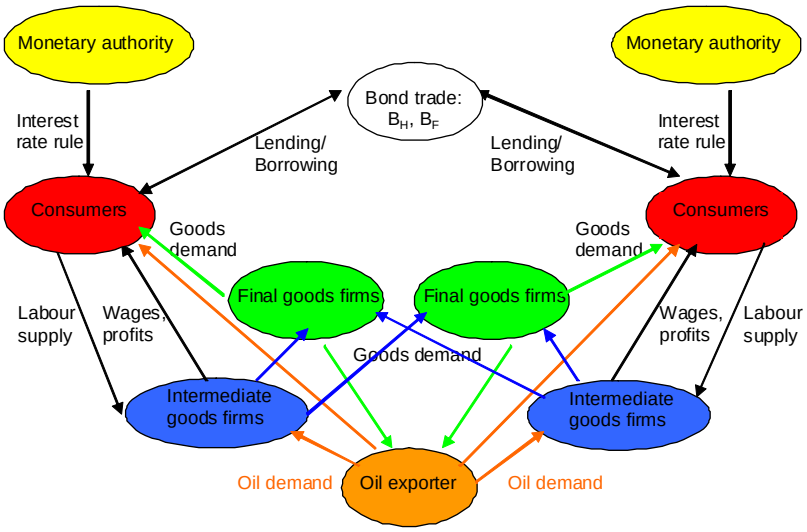
The structure of the paper is as follows. In Section 2, we develop the model we use to analyse these issues before discussing its calibration in Section 3. Section 4 considers the effects of globalisation on the responses of variables to monetary policy shocks and asks under what conditions does globalisation generate a 'tailwind' or a 'headwind'? Finally, Section 5 concludes.

2 The model

Our paper takes as its starting point the model of Campolmi (2008). Following Campolmi (2008), we consider a world of three countries: home and foreign, which can be thought of as the G7 and the BRIC economies, respectively, and an 'oil producer', which sells its endowment of oil and spends the associated revenues on consumption of goods from both the developing and developed world. We modify the model of Campolmi (2008) in several ways to take account of different channels through which oil may affect the transmission of shocks. In particular, we introduce additional 'headwind' channels. First, we assume that oil is directly consumed by households instead of being only used in production. In this way we account for a direct 'headwind' effect on households. Second, we introduce a constant elasticity of substitution (CES) production function and assume that oil and labour are complements in the production process. This enables us to capture an increased demand for oil in result of the rise in oil prices and thus stronger headwind effect on marginal costs. Third, we assume that financial markets are internationally incomplete. This assumption implies that international risk sharing is not complete. As a result, the strength of the tailwind effect coming from the cheaper goods in the developing world is reduced. Finally, following the literature (eg Obstfeld and Rogoff (2000)), we assume that home and foreign goods are substitutes and introduce a CES aggregator for home and foreign goods.

The home and foreign economies consist of consumers, firms producing final goods and firms producing intermediate goods. In addition, there is a monetary authority in each country that sets interest rates. A schematic showing how consumers and firms in the three countries interact with each other is shown in Chart 4. In what follows, we discuss the maximisation problems faced by agents in the domestic economy, derive their first-order conditions, and simply state the analogues for the foreign economy.

Chart 4: The model economy



2.1 Households

The economy consists of a unit continuum of households. The representative household – household j – derives utility from consuming home and foreign goods and disutility from working. Their problem is to maximise the current and present discounted value of their utility streams subject to their budget constraint. Mathematically we can write this as:

$$\max E_t \sum_{r=0}^{\infty} \beta^r \left(\frac{\sigma}{\sigma - 1} \left(\frac{c_{j,t+r}}{c_{t+r-1}^{\psi_{hab}}} \right)^{\frac{\sigma-1}{\sigma}} - \kappa_h \frac{\sigma_h}{\sigma_h + 1} h_{j,t+r}^{\frac{\sigma_h}{\sigma_h+1}} \right) \quad \textbf{(1)}$$

subject to:

$$B_{j,t+r} = B_{j,t+r-1}(1 + i_{t+r-1}) - P_{t+r} c_{j,t+r} + P_{t+r} w_{j,t+r} h_{j,t+r} + D_{j,t+r}, \quad \textbf{(2)}$$

where β is the discount factor, σ is the intertemporal elasticity of substitution, σ_h is the elasticity of labour supply, κ_h is a weight on leisure in the utility, ψ_{hab} is a parameter governing degree of habits in consumption, c_j is j's aggregate consumption, c is aggregate (economy-wide) consumption, h_j is j's supply of labour (total hours worked), B_j is household j's end-of-period holdings of domestically issued bonds, i is the domestic nominal interest rate, P is the domestic price level, w_j is the real wage earned by j and D_j represents the share of profits made by domestic firms that is distributed to household j. We can note that we have assumed financial markets to be incomplete in the sense that it is impossible to fully insure against country-specific risk.

Following the literature we assume that households have access to financial markets that enable them to insure against idiosyncratic wage risk. Given this, individual household consumption will equal aggregate consumption. The first-order conditions for consumption, domestic and foreign bond holdings will then imply:

$$(c_t)^{-\frac{1}{\sigma}-\psi_{hab}\left(\frac{1}{\sigma}-1\right)} c_{t-1}^{\psi_{hab}\left(\frac{1}{\sigma}-1\right)} = \beta\,(1+i_t)\,E_{t+r}\left(\frac{c_{t+1}^{-\frac{1}{\sigma}}}{1+\pi_{t+1}}\right), \qquad \textbf{(3)}$$

where π_t is the aggregate inflation rate in the home economy. For the foreign economy, we assume that their budget constraint is given by:

$$B^*_{f,j,t}+e_t B^*_{j,t} = B^*_{f,j,t-1}(1+i^*_{t-1})+e_t B^*_{j,t-1}(1+i_{t-1})-P^*_t c^*_{j,t}+P^*_t w^*_{j,t}h^*_{j,t}+D^*_{j,t}-\frac{\chi_{bf}}{2}(e_t B^*_{j,t})^2. \qquad \textbf{(4)}$$

Here c^*_j is foreign household j's aggregate consumption, c^* is aggregate foreign consumption, h^*_j is foreign household j's supply of labour (total hours worked), e is the nominal exchange rate (units of foreign currency per unit of domestic currency), B^*_j is foreign household j's end-of-period holdings of home bonds, $B^*_{f,j}$ is foreign household j's end-of-period holdings of foreign bonds, i^* is the foreign nominal interest rate, w^*_j is the real wage earned by foreign household j and D^*_j represents the share of profits made by foreign firms that is distributed to foreign household j. The final term represents costs to the foreign investors of adjusting their holdings of domestic bonds and ensures that the net foreign asset position of the two economies is pinned down in the steady state (see eg Benigno (2009)). In particular, we assume that in steady state neither economy is a net borrower from/lender to the other. To reduce notation, we also assume that no foreign bonds are issued in or out of steady state, ie, all international borrowing or lending is carried out via home bonds.

The first-order conditions for the foreign economy are:

$$\left(c^*_t\right)^{-\frac{1}{\sigma}-\psi_{hab}\left(\frac{1}{\sigma}-1\right)}\left(c^*_{t-1}\right)^{\psi_{hab}\left(\frac{1}{\sigma}-1\right)} = \beta\left(1+i^*_t\right)E_t\left(\frac{c^{*-\frac{1}{\sigma}}_{t+1}}{1+\pi^*_{t+1}}\right), \qquad \textbf{(5)}$$

$$\left(c^*_t\right)^{-\frac{1}{\sigma}-\psi_{hab}\left(\frac{1}{\sigma}-1\right)}\left(c^*_{t-1}\right)^{\psi_{hab}\left(\frac{1}{\sigma}-1\right)} = \beta\,(1+i_t)\,E_t\left(\frac{c^{*-\frac{1}{\sigma}}_{t+1}}{1+\pi^*_{t+1}}\frac{e_{t+1}}{e_t(1+\chi_{bf}e_t B^*_t)}\right). \qquad \textbf{(6)}$$

We can combine equations **(5)** and **(6)** to obtain the uncovered interest parity condition:

$$\frac{1+i_t}{1+i^*_t} = \frac{e_t(1+\chi_{bf}e_t B^*_t)}{e_{t+1}}. \qquad \textbf{(7)}$$

Now, we assume that aggregate consumption is a CES aggregator of consumption of (domestically produced) final goods and consumption of oil:

$$c = \left((1 - \psi_m)\, c_h^{\frac{\sigma_c - 1}{\sigma_c}} + \psi_m c_o^{\frac{\sigma_c - 1}{\sigma_c}} \right)^{\frac{\sigma_c}{\sigma_c - 1}}. \tag{8}$$

where σ_c is the elasticity of substitution between goods and oil consumption, ψ_m is the share of oil in the home consumption, c_h is consumption of home-produced final goods and c_o is consumption of oil. If we define the aggregate price index (normalised to unity) to be the minimum level of expenditure necessary to give a particular level of consumption then we obtain the following:

$$1 = (1 - \psi_m)^{\sigma_c} p_h^{1-\sigma_c} + \psi_m^{\sigma_c} p_o^{1-\sigma_c}. \tag{9}$$

where p_h and p_o are the relative (to the aggregate consumer price index) prices of home final goods and oil, respectively. Note that all relative prices represent the price of a unit of that particular good purchased in the home economy relative to the price of a unit of the home consumption good purchased in the home economy.

Demand for the two goods (conditional on aggregate demand) will be given by:

$$c_h = (1 - \psi_m)^{\sigma_c} p_h^{-\sigma_c} c, \tag{10}$$

$$c_o = \psi_m^{\sigma_c} p_o^{-\sigma_c} c. \tag{11}$$

The analogous equations for the foreign country are:

$$1 = (1 - \psi_m^*)^{\sigma_c} (p_f^*)^{1-\sigma_c} + (\psi_m^*)^{\sigma_c} (q p_o)^{1-\sigma_c}, \tag{12}$$

$$c_o^* = \psi_m^{*\sigma_c} (q p_o)^{1-\sigma_c} c^*, \tag{13}$$

$$c_f^* = (1 - \psi_m^*)^{\sigma_c} p_f^{*1-\sigma_c} c^*. \tag{14}$$

where ψ_m^* is the share of oil in the foreign consumption, p_f^* is the relative price of the foreign final good, q is the real exchange rate, c_o^* is foreign consumption of oil and c_f^* is foreign consumption of foreign-produced final goods.

2.2 Wage setting

We suppose that individual workers are monopolistic suppliers of their own type of labour. Given this, they will have market power and be able to set wages. Demand for a particular

household's worker will be given by:

$$h_t(j) = \left(\frac{w_t(j)}{w_t}\right)^{-\sigma_w} h_t, \tag{15}$$

where σ_w is the elasticity of demand for differentiated labour, w is the economy-wide real wage and h is the economy-wide supply of labour. Following Erceg, Henderson and Levin (2000), we assume that in each period, only a fraction, α_w, of workers are able to reset their wage optimally.

The problem for a worker able to reset his wage is to choose a wage w_j so as to maximise:

$$\max E_t \sum_{r=0}^{\infty} \beta^r (1-\alpha_w)^r \left[c_{t+r}^{-\frac{1}{\sigma}} c_{t+r-1}^{\psi_{hab}\left(1-\frac{1}{\sigma}\right)} w_t(j) h_{t+r}(j) - \kappa_h \frac{\sigma_h}{\sigma_h+1} \left[h_{t+r}(j)\right]^{\frac{\sigma_h+1}{\sigma_h}} \right]. \tag{16}$$

The first order condition for this problem is:

$$\widetilde{W}_t^{\frac{\sigma_h+\sigma_w}{\sigma_h}} = \frac{\sigma_w}{\sigma_w-1} W_t^{\frac{\sigma_w}{\sigma_h}} \frac{E_t \sum_{r=0}^{\infty} \beta^r (1-\alpha_w)^r \kappa_h \left[\left(\frac{W_t}{W_{t+r}}\right)^{-\sigma_w} h_{t+r} \right]^{\frac{\sigma_h+1}{\sigma_h}}}{E_t \sum_{r=0}^{\infty} \beta^r (1-\alpha_w)^r \frac{c_{t+r}^{-\frac{1}{\sigma}} c_{t+r-1}^{\psi_{hab}\left(1-\frac{1}{\sigma}\right)}}{P_{t+r}} \left(\frac{W_t}{W_{t+r}}\right)^{-\sigma_w} h_{t+r}} \tag{17}$$

where $\widetilde{W}$ is the nominal wage that will be set by all workers who are able to reset their wage and W is the economy-wide nominal wage. The aggregate wage index will be given by:

$$W_t^{1-\sigma_w} = (1-\alpha_w) W_{t-1}^{1-\sigma_w} + \alpha_w (\widetilde{W}_t)^{1-\sigma_w}. \tag{18}$$

Combining these two equations and log-linearising gives the wage 'Phillips curve':

$$\dot{W}_t = \frac{\sigma_h \alpha_w (1-\beta(1-\alpha_w))}{(\sigma_h+\sigma_w)(1-\alpha_w)} \left(\frac{1}{\sigma_h}\widehat{h}_t + \frac{1}{\sigma}\widehat{c}_t - \psi_{hab}\frac{\sigma-1}{\sigma}\widehat{c}_{t-1} - \widehat{w}_t\right) + \beta E_t \dot{W}_{t+1} \tag{19}$$

where $\dot{W}$ is the rate of nominal wage growth, which we have assumed to be zero in steady state, $\widehat{h}$ is the (log) deviation of total hours from steady state, $\widehat{c}$ is the (log) deviation of consumption from steady state and $\widehat{w}$ is the (log) deviation of the real wage from state. We can note that, by definition:

$$\widehat{w}_t = \widehat{w}_{t-1} + \dot{W}_t - \widehat{\pi}_t. \tag{20}$$

The analogous equations for the foreign economy are:

$$\dot{W}^*_t = \frac{\sigma_h \alpha_w (1-\beta(1-\alpha_w))}{(\sigma_h+\sigma_w)(1-\alpha_w)} \left(\frac{1}{\sigma_h}\widehat{h}^*_t + \frac{1}{\sigma}\widehat{c}^*_t - \psi_{hab}\frac{\sigma-1}{\sigma}\widehat{c}^*_{t-1} - \widehat{w}^*_t\right) + \beta E_t \dot{W}^*_{t+1}, \tag{21}$$

$$\widehat{w}^*_t = \widehat{w}^*_{t-1} + \dot{W}^*_t - \widehat{\pi}^*_t. \tag{22}$$

2.3 *Intermediate goods producing firms*

There is a continuum of monopolistically competitive firms each supplying a single differentiated intermediate good using oil and labour only. We assume that these firms face quadratic costs of adjusting its prices, Rotemberg (1982). Hence, we can write firm i's problem mathematically as:

$$\max E_t \sum_{r=0}^{\infty} \beta^r \left(\begin{array}{c} p_{d,t+r}(i) y_{d,t+r}(i) - W_{t+r} h_{t+r}(i) - p_{o,t+r} O_{d,t}(i) \\ -\frac{\chi_d}{2} \left(\frac{1+\pi_{d,t+r}(i)}{\left(1+\pi_{d,t+r-1}(i)\right)^{\varepsilon}} - 1 \right)^2 p_{d,t+r} y_{d,t+r} \end{array} \right) \tag{23}$$

$$y_{d,t+r}(i) = A_t \left(\psi_o O_{d,t+r}(i)^{\frac{\sigma_o - 1}{\sigma_o}} + (1-\psi_o) h_{t+r}(i)^{\frac{\sigma_o - 1}{\sigma_o}} \right)^{\frac{\sigma_o}{\sigma_o - 1}}, \tag{24}$$

$$y_{d,t+r}(i) = \left(\frac{p_{d,t+r}(i)}{p_{d,t+r}} \right)^{-\sigma_d} y_{d,t+r}, \tag{25}$$

where σ_o is the elasticity of substitution between labour and oil, σ_d is the elasticity of substitution between varieties of goods, χ_d is the menu cost weight and ε represents degree of inflation indexation, $\pi_{d,t}$ represents inflation of domestic intermediate goods, $y_d(i)$ is firm i's output, y_d is aggregate demand for the domestic intermediate good, $h(i)$ is the amount of labour used by firm i, $O_d(i)$ is the amount of oil used by firm i, A is (exogenous) total factor productivity and $p_d(i)$ is the price of firm i's output (relative to the aggregate price level). The first-order conditions for this problem imply:

$$y_d = A \left(\psi_o O_d^{\frac{\sigma_o - 1}{\sigma_o}} + (1-\psi_o) h^{\frac{\sigma_o - 1}{\sigma_o}} \right)^{\frac{\sigma_o}{\sigma_o - 1}}, \tag{26}$$

$$O_d = \psi_o^{\sigma_o} \left(\frac{p_o}{\mu p_d} \right)^{-\sigma_o} A^{\sigma_o - 1} y_d, \tag{27}$$

$$h = (1-\psi_o)^{\sigma_o} \left(\frac{w}{\mu p_d} \right)^{-\sigma_o} A^{\sigma_o - 1} y_d, \tag{28}$$

$$\sigma_d \mu_t y_{d,t} = p_{d,t} \left(\begin{array}{c} (\sigma_d - 1) y_{d,t} + \chi_d \left(\frac{1+\pi_{d,t}}{\left(1+\pi_{d,t-1}\right)^{\varepsilon}} - 1 \right) \frac{1+\pi_{d,t}}{\left(1+\pi_{d,t-1}\right)^{\varepsilon}} y_{d,t} \\ -\beta \chi_d \left(\frac{1+\pi_{d,t+1}}{\left(1+\pi_{d,t}\right)^{\varepsilon}} - 1 \right) \frac{\left(1+\pi_{d,t+1}\right)^2}{\left(1+\pi_{d,t}\right)^{\varepsilon}} y_{d,t+1} \end{array} \right), \tag{29}$$

where μ denotes real marginal cost, and we have used the fact that, in equilibrium, all firms will charge the same price. Log-linearising the last of these equations around a zero inflation steady state implies the New Keynesian Phillips Curve:

$$\widehat{\pi}_{d,t} = \frac{(\sigma_d - 1)}{\chi_d (1+\beta\varepsilon)} (\widehat{\mu}_t - \widehat{p}_{d,t}) + \frac{\varepsilon}{(1+\beta\varepsilon)} \widehat{\pi}_{d,t-1} + \frac{\beta}{(1+\beta\varepsilon)} E_t \widehat{\pi}_{d,t+1}. \tag{30}$$

The foreign analogues of these equations are:

$$y_f = A \left(\psi_o^* O_f^{\frac{\sigma_o - 1}{\sigma_o}} + (1-\psi_o^*) h^{*\frac{\sigma_o - 1}{\sigma_o}} \right)^{\frac{\sigma_o}{\sigma_o - 1}}, \tag{31}$$

$$O_f = \psi_o^{*\sigma_o} \left(\frac{p_o}{\mu^* p_d^*} \right)^{-\sigma_o} A^{*\sigma_o - 1} y_f, \tag{32}$$

$$h^* = (1 - \psi_o^*)^{\sigma_o} \left(\frac{w^*}{\mu^* p_d^*} \right)^{-\sigma_o} A^{*\sigma_o - 1} y_f, \tag{33}$$

$$\widehat{\pi}_{d,t}^* = \frac{(\sigma_d - 1)}{\chi_d^*(1 + \beta\varepsilon^*)} (\widehat{\mu}_t^* - \widehat{p}_{d,t}^*) + \frac{\varepsilon^*}{(1 + \beta\varepsilon^*)} \widehat{\pi}_{d,t-1}^* + \frac{\beta}{(1 + \beta\varepsilon^*)} E_t \widehat{\pi}_{d,t+1}^*. \tag{34}$$

where y_f is the aggregate demand for foreign intermediate, O_f is the amount of oil used by foreign intermediates, p_d^* is the relative price of foreign intermediates, μ^* denotes real marginal cost of foreign intermediates and $\widehat{\pi}_{d,t}^*$ represents inflation of foreign intermediates.

2.4 Final goods producing firms

The representative final goods producing firm combines intermediate goods produced at home and abroad to produce a final good. Trade takes place at the aggregate level. We assume that the final good firm operates a CES production function in the two intermediate goods. In addition, we assume that this sector is perfectly competitive. Hence, we can write the firm's problem mathematically as:

$$\max p_h y - p_d y_{dd} - \frac{p_d^*}{q} y_{fd} \tag{35}$$

subject to:

$$y = \left(\omega y_{ff}^{\frac{\sigma_i - 1}{\sigma_i}} + (1 - \omega) y_{fd}^{\frac{\sigma_i - 1}{\sigma_i}} \right)^{\frac{\sigma_i}{\sigma_i - 1}} \tag{36}$$

where ω is the weight of domestic intermediates in the domestic final good production, σ_i is the elasticity of substitution between home and foreign intermediates, y is output of the home final good, y_{dd} is the amount of domestic intermediates used in home economy, y_{fd} is the amount of foreign intermediates used in home economy, p_d is the price of domestic intermediates (relative to the aggregate consumer price index) and $\frac{p_d^*}{q}$ is the price (in domestic currency) of imported intermediates (relative to the aggregate consumer price index). The first-order conditions for this problem imply

$$p_h^{1-\sigma_i} = \omega^{\sigma_i} p_d^{1-\sigma_i} + (1 - \omega)^{\sigma_i} \left(\frac{p_d^*}{q} \right)^{1-\sigma_i}, \tag{37}$$

$$y_{dd} = \omega^{\sigma_i} \left(\frac{p_d}{p_h} \right)^{-\sigma_i} y, \tag{38}$$

$$y_{fd} = (1-\omega)^{\sigma_i}\left(\frac{p_d^*}{p_h q}\right)^{-\sigma_i} y. \tag{39}$$

The foreign analogues of these equations are:

$$p_f^{*1-\sigma_i} = \omega^{*\sigma_i}(p_d^*)^{1-\sigma_i} + (1-\omega^*)^{\sigma_i}(p_d q)^{1-\sigma_i}, \tag{40}$$

$$y_{ff} = \omega^{*\sigma_i}\left(\frac{p_d^*}{p_f^*}\right)^{-\sigma_i} y^*, \tag{41}$$

$$y_{df} = (1-\omega^*)^{\sigma_i}\left(\frac{p_d q}{p_f^*}\right)^{-\sigma_i} y^*, \tag{42}$$

where ω^* is the weight of foreign intermediates in the foreign final good production, y^* is output of the foreign final good, y_{ff} is the amount of foreign intermediates used in foreign economy, y_{fd} is the amount of domestic intermediates used in foreign economy, p_d^* is the price of foreign intermediates (relative to the foreign aggregate consumer price index).

2.5 Oil producer

The oil-producing country spends their revenues on final goods produced in the two countries. To keep things simple, we suppose that the representative consumer in this country maximises the following utility function:

$$\max E_t \sum_{r=0}^{\infty} \beta^r \left((1-\psi_{m,O})\left(c_{O,h,t+r}\right)^{\frac{\sigma_{c,O}-1}{\sigma_{c,O}}} + \psi_{m,O}\left(c_{O,f,t+r}\right)^{\frac{\sigma_{c,O}-1}{\sigma_{c,O}}} \right)^{\frac{\sigma_{c,O}}{\sigma_{c,O}-1}} \tag{43}$$

where $\sigma_{c,O}$ is the elasticity of substitution between home and foreign goods in the oil producing country, $\psi_{m,O}$ is the share of foreign goods in his consumption basket, $c_{O,h}$ is his consumption of the home country's goods and $c_{O,f}$ is his consumption of the foreign country's goods. His budget constraint is given by:

$$p_{o,t+r} O_{t+r} = p_{h,t+r} c_{O,h,t+r} + \frac{p_{f,t+r}}{q_{t+r}} c_{O,f,t+r} = \frac{c_{O,t+r}}{q_{O,t+r}}, \tag{44}$$

where O is the (exogenous) supply of oil, q_O is the real exchange rate between the oil producer and the home economy, and we have assumed that oil is costless to transport and that the oil producer does not have access to world capital markets; he simply recirculates the revenues from his production of oil. Solving this problem implies:

$$c_{O,h} = \left(1 - \psi_m\right)^{\sigma_{c,O}} \left(p_h q_O\right)^{-\sigma_{c,O}} c_O, \tag{45}$$

$$c_{O,f} = \psi_m^{\sigma_{c,O}} \left(\frac{p_f q_O}{q}\right)^{-\sigma_{c,O}} c_O, \tag{46}$$

and the price index:

$$1 = \psi_{m,O}^{\sigma_{c,O}} \left(\frac{q_O p_f}{q}\right)^{1-\sigma_{c,O}} + \left(1 - \psi_{m,O}\right)^{\sigma_{c,O}} \left(q_O p_h\right)^{1-\sigma_{c,O}}. \tag{47}$$

2.6 Monetary policy

The central bank in each country is assumed to operate a Taylor rule:

$$i_t - r = \rho_m \left(i_{t-1} - r\right) + \left(1 - \rho_m\right) \phi_\pi \pi_t, \tag{48}$$

$$i_t^* - r = \rho_m^* \left(i_{t-1}^* - r\right) + \left(1 - \rho_m^*\right) \phi_\pi^* \pi_t^*, \tag{49}$$

where r is the steady-state real (and nominal) rate of interest, ρ_m and ρ_m^* are the smoothing parameters and ϕ_π and ϕ_π^* are the weights on inflation in the Taylor rule. (Recall that we have assumed zero inflation in both countries in steady state.) The nominal interest rate in each country will be related to the real interest rate in each country via the Fisher equations:

$$1 + i_t = (1 + r_t)\,(1 + E_t \pi_{t+1}), \tag{50}$$

$$1 + i_t^* = \left(1 + r_t^*\right)(1 + E_t \pi_{t+1}^*). \tag{51}$$

2.7 Market clearing and some definitions

We assume that in steady state neither country is a net debtor/creditor of the other country; that is, $B = B_f^* = 0$. Out of steady state, if home is running a current account deficit, it will sell domestic bonds to foreign; if it is running a surplus, it will buy domestic bonds from foreign households. (That is, the way we have set the model up, the total amount of domestic bond issuance can be negative.) Of course, the world as a whole cannot borrow. Hence, we have the world aggregate resource constraint:

$$c_t + \frac{c_t^*}{q_t} = p_{d,t} y_{d,t} + \frac{p_{d,t}^*}{q_t} y_{f,t} - p_{o,t}(O_{d,t} + O_{f,t}). \tag{52}$$

The following set of equations represents the market clearing conditions for the final goods market in the two countries, the intermediate goods market in the two countries and for the market for oil.

$$y = c_h + c_{O,h}, \tag{53}$$

$$y^* = c_f + c_{O,f}, \tag{54}$$

$$y_d = y_{dd} + y_{df}, \tag{55}$$

$$y_f = y_{fd} + y_{ff}, \tag{56}$$

$$O = O_d + O_f + c_o + c_o^*. \tag{57}$$

We also have the following definitions:

$$1 + \pi_{d,t} = \frac{p_{d,t}}{p_{d,t-1}}(1 + \pi_t), \tag{58}$$

$$1 + \pi^*_{d,t} = \frac{p^*_{d,t}}{p^*_{d,t-1}}\frac{q_t}{q_{t-1}}(1 + \pi^*_t). \tag{59}$$

2.8 Equilibrium

An equilibrium in this world is one in which consumers in both economies are maximising their utility, firms in both countries are maximising their profits and trade is balanced. In practice, this means that the 42 equations – **(3)**, **(5)**, **(7)**, **(9)-(14)**, **(19)-(22)**, **(26)-(28)**, **(30)-(34)**, **(37)-(42)** and **(45)-(59)** – hold. These equations solve for the following 42 variables: the real wage in each country, w and w^*, the rate of nominal wage inflation in each country, $\dot{W}$ and $\dot{W}^*$, total hours worked in each country, h and h^*, aggregate consumption in each country and in the oil producer, c, c^* and c_O, consumption of final goods and oil in each country and in the oil producer, c_h, c_o, c_o^*, c_f^*, $c_{O,h}$ and $c_{O,f}$, output of final goods in the two countries, y and y^*, output of intermediate goods in the two countries, y_d and y_f, the demand for domestically produced intermediates from domestic and foreign producers, y_{dd} and y_{fd},the demand for foreign-produced intermediates from domestic and foreign producers, y_{df} and y_{ff}, the demand for oil in production in the two countries, O_d and O_f, the price of home and foreign final goods relative to the consumption deflator in home and foreign economy, p_h and p_f, the price of home and foreign intermediate goods relative to the consumption deflator in home and foreign economy, p_d and p_d^*, the price of oil relative to the home consumption deflator, p_o, nominal and real interest rates in the two countries, i, i^*, r and r^*, real marginal cost in the two countries, μ and μ^*, the rates of inflation in the two countries, π and π^*, the rate of inflation for home and foreign-produced intermediates, π_d and π_d^*, and the real exchange rates between the home and foreign country, q, and the home country and the oil producer, q_O.

3 Calibration

The values of our parameters are shown in Table A. Our calibration is fairly standard. We set the discount factor, β, to 0.99 implying a risk-free rate of around 4% per annum, the coefficient of relative risk aversion, σ, to 0.25, and the 'habits' terms on aggregate consumption, ψ_{hab}, to 0.69. We set the elasticity of substitution between produced final goods and oil in consumption in each country, σ_c, to 0.3 and ψ_m and ψ_m^*, to 0.05, implying a weight of oil in domestic consumption of 5% (roughly in line with the share of petrol consumption in UK CPI).

Table A: Parameter values

Parameter	Symbol	Value
Preferences		
Discount rate	β	0.99
intertemporal elasticity of substitution	σ	0.25
Degree of habits in consumption	ψ_{hab}	0.69
Elasticity of substitution between goods and oil	σ_c	0.3
Weight of oil in consumption	ψ_m, ψ_m^*	0.05
Cost of holding foreign bonds	χ_{bf}	0.01
Labour market		
Weight on leisure in utility function	κ_h	1.7326
Elasticity of labour supply	σ_h	0.43
Elasticity of demand for differentiated labour	σ_w	8.3
Probability of being able to change wage	α_w, α_w^*	0.2
Intermediate producers		
Elasticity of substitution between labour and oil	σ_o	0.15
Weight on oil in production function	ψ_o, ψ_o^*	0.018
Elasticity of demand	σ_d	10
Menu cost weight	χ_d, χ_d^*	130
Degree of inflation indexation	$\varepsilon, \varepsilon^*$	0.5
Final goods producers		
Elasticity of substitution between domestic and foreign intermediates	σ_I	1.59
Weight on domestic intermediates in production function	ω, ω^*	0.67
Oil producer		
Elasticity of substitution between home and foreign goods in consumption	$\sigma_{c,O}$	1.77
Weight on foreign goods in the utility function	$\psi_{m,O}$	0.5
Monetary policy		
Smoothing parameter	ρ_m, ρ_m^*	0.65
Weight on inflation in Taylor rule	ϕ_π, ϕ_π^*	1.5

Following Harrison and Oomen (2010), we set the labour supply elasticities, σ_h, to 0.43 and σ_w to 8.3, implying wage mark-ups of 1.14. We set the steady-state mark-ups for the domestic and foreign intermediate goods producing firms to 1.11. This implies a value for σ_d of 10. We set

the menu cost parameters, ψ_d and ψ_d^*, to 130, implying that around 23% of prices get reset every quarter, ie, prices are, on average, reset once every year. In addition, we set the indexation parameters on prices, ε and ε^*, to 0.5. We set probability of changing wages, α_w and α_w^*, to 0.2, implying that wages are also adjusted roughly once a year on average. The assumed symmetry between the countries in the steady state implies that the real exchange rate, q will equal unity in steady state. Finally, with everything else symmetric in steady state, this implies that each country will demand half of the oil producer's output of oil. In return we assume that the oil producer spends half of its income on each country's goods, that is, we set $\psi_{m,O}$ to 0.5. We set the elasticity of substitution between final goods for the oil producer, $\sigma_{c,O}$, to 1.77.

We assume that the share of domestic intermediates in the total 'bundle' of intermediates is 2/3, that is we set $\omega = \omega^* = 0.67$. We set the elasticity of substitution between foreign and domestic intermediates, σ_I, to 1.59. We set the elasticity of substitution between labour and oil, σ_o, to 0.15. Finally, we normalise productivity, total hours worked and intermediate output to unity in each country. This implies that the demand for oil in intermediate production in the two countries, O_d and O_f, will be equal to unity. We set ψ_o equal to 0.018 implying a share of oil in gross output of 1.6% (in line with UK data).

4 Tailwinds vs. headwinds

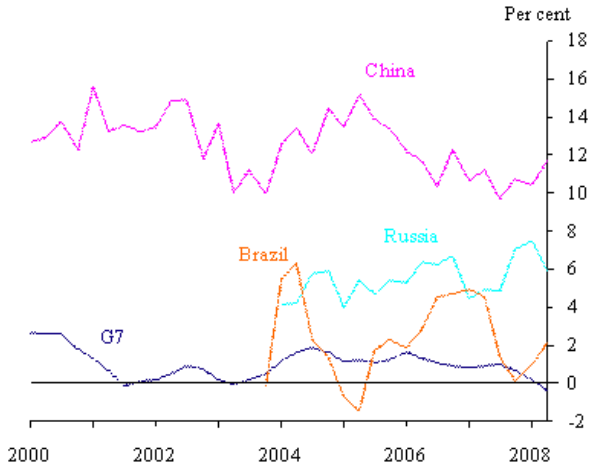
In this section we use our model to answer the question: under what conditions might we expect the increase in productivity in the BRIC economies we have seen over recent years to lead to higher or lower inflation in the G7? The answer to this question is likely to depend upon the relative importance of imports in developed economies' production of final goods, the relative importance of oil in developed economies' consumption and production and the extent to which consumers and producers can switch in and out of oil, the degree of nominal rigidities in the developed economies and how their monetary authorities react to the shock. We consider the effects of varying these in a 'sensitivity' analysis, below.

4.1 Baseline results

In this subsection, we consider the effects of a 1% shock to foreign productivity. We assume that the shock follows an AR(1) process with an AR(1) coefficient of 0.99. This ensures that the

effects of the shock are felt for a long time; specifically, 17 years after the initial shock, foreign productivity has grown by 50% more than home productivity. This might seem a little extreme, but the available data suggests that Chinese, Russian and Brazilian productivity growth has been consistently higher than that in the G7 during the past decade, and this has been no different during the current recession (Chart 5).

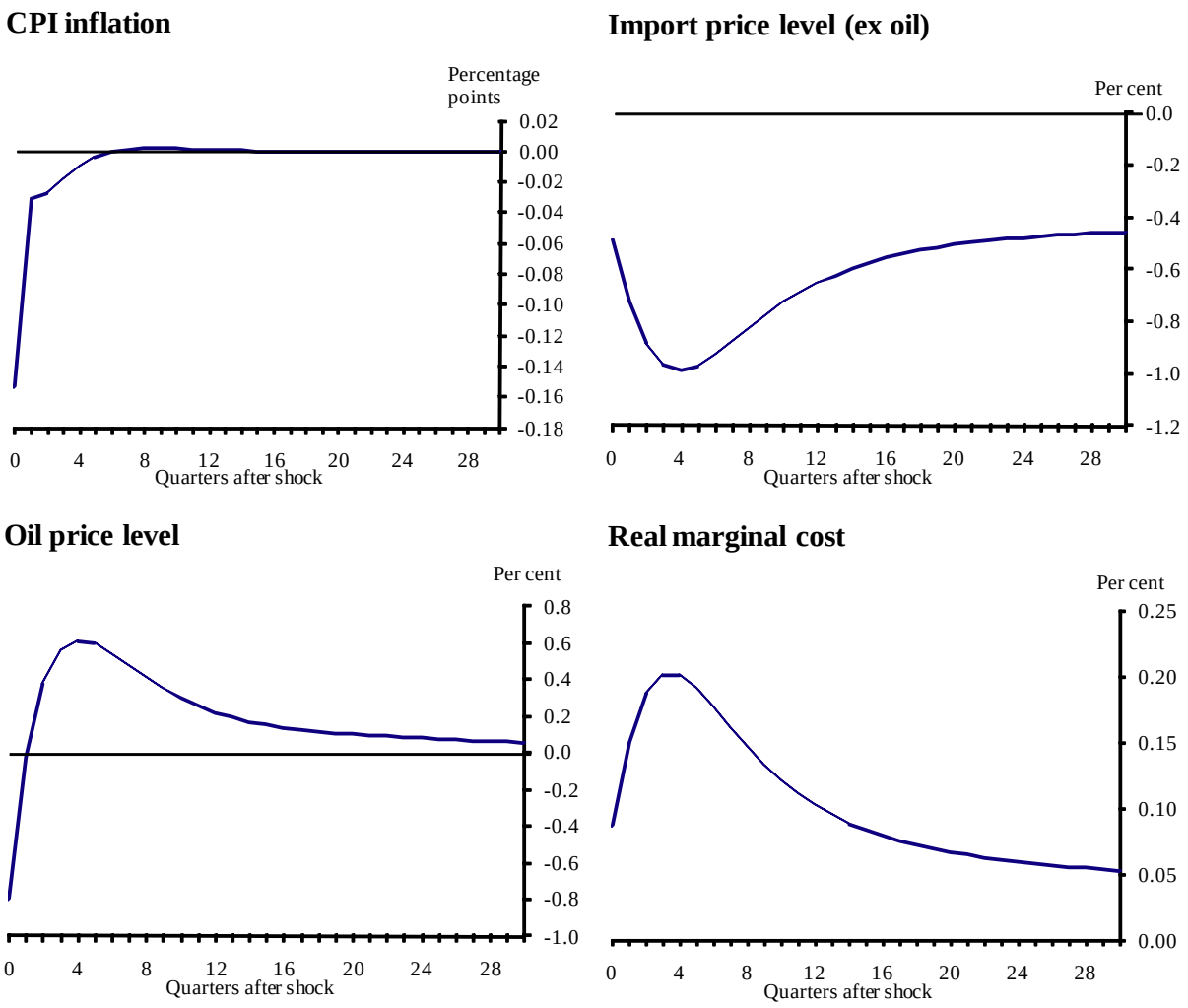
Chart 5: Productivity growth (source: Thomson Reuters Datastream)



The upper left panel of Chart 6 shows the effect of this shock on home aggregate (consumer price) inflation. As can be seen, the shock leads to a temporary reduction in domestic consumer price inflation. Looking beneath this, the upper right panel of Chart 6 shows that the shock results in falling import prices for a year, with import prices winding up around 0.8% below their initial steady-state level. Global demand for foreign goods rises as they become cheaper – expenditure switching – and the domestic terms of trade appreciate. Foreigners invest some of their increased wealth in home bonds, facilitating a rise in home consumption. The terms of trade appreciation leads to higher domestic output price inflation but lower consumer price inflation. This is the 'tailwinds' effect of the foreign productivity shock.

But what is going on with oil prices? The lower left panel of Chart 6 shows that, after an initial fall, oil prices rise and stay high for a long time. The initial fall in oil prices comes about since the productivity increase initially causes foreign demand for oil, like that for labour, to fall. This, in turn, results from the fact that labour and oil are complements in the baseline calibration. The

Chart 6: The effects of a foreign productivity shock on the home economy



rise in oil prices acts directly to raise consumer price inflation, via the effect on petrol prices, and indirectly, via the effect on marginal cost for the intermediate producers. (See the lower right panel of Chart 6.) In addition, since the oil exporter's revenues rise, it will demand more home goods, again pushing up on domestic inflation. These channels combine to produce a 'headwinds' effect of the foreign productivity shock.

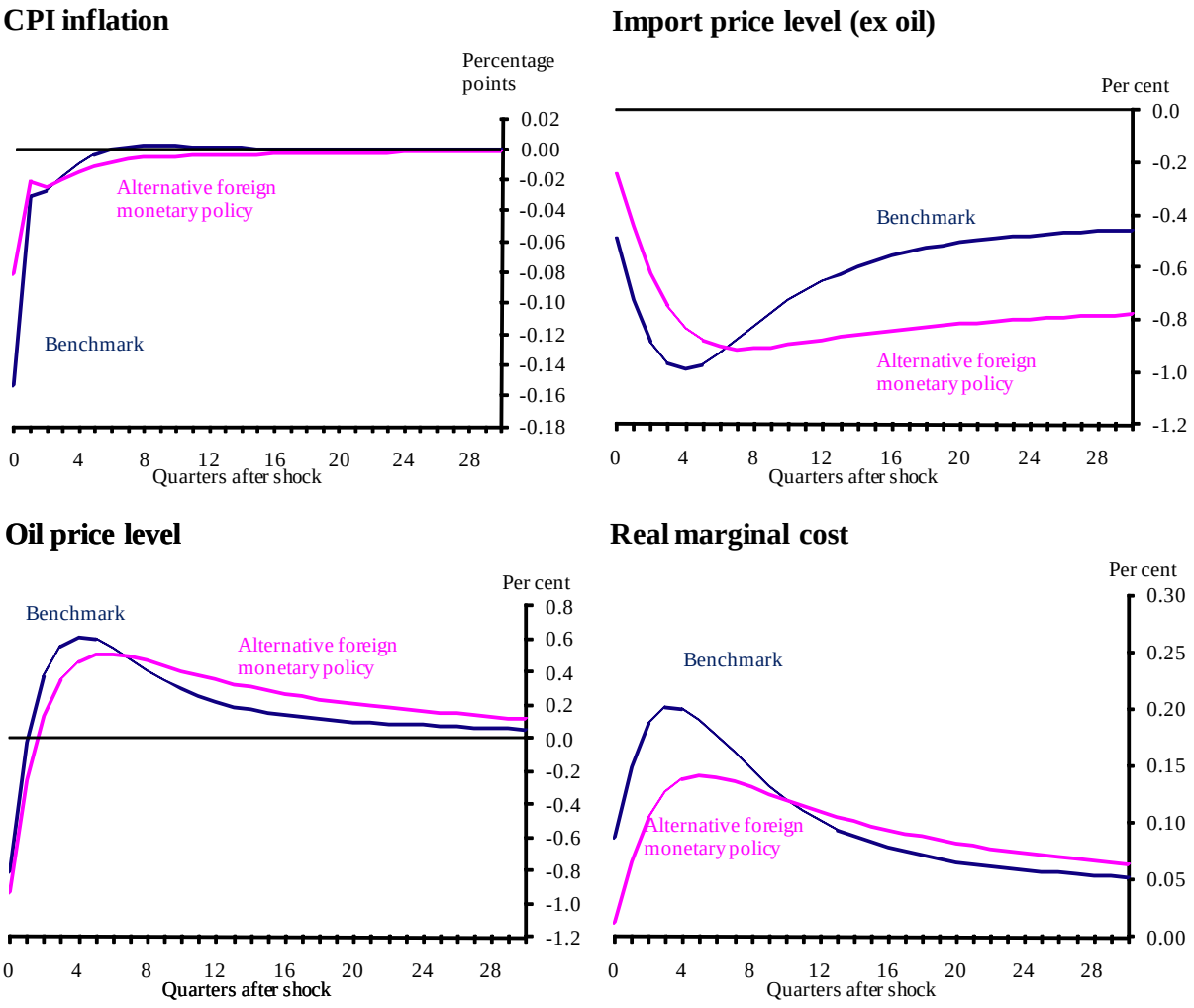
Given our baseline calibration, we see that the tailwinds effect outweighs the headwinds effect and inflation is temporarily lowered relative to its steady-state rate. This provokes a monetary policy reaction that brings inflation back to its steady state in about six quarters after the shock hits. In the next subsection, we examine how sensitive these results are to our calibrated

parameter values. In particular, we ask the question under what conditions might the headwinds outweigh the tailwinds and inflation be raised relative to its steady state.

4.2 Sensitivity

In this subsection, we consider how sensitive our results – particularly the relative importance of headwinds and tailwinds – are to changes in key parameters. In particular, we consider the effects of alternative foreign monetary policy, making oil and labour substitutes (rather than complements), making wages flexible, increasing the share of oil in production and lowering the degree of financial integration between our economies (to financial autarky).

Chart 7: Benchmark case vs. the case where the foreign country pegs its currency

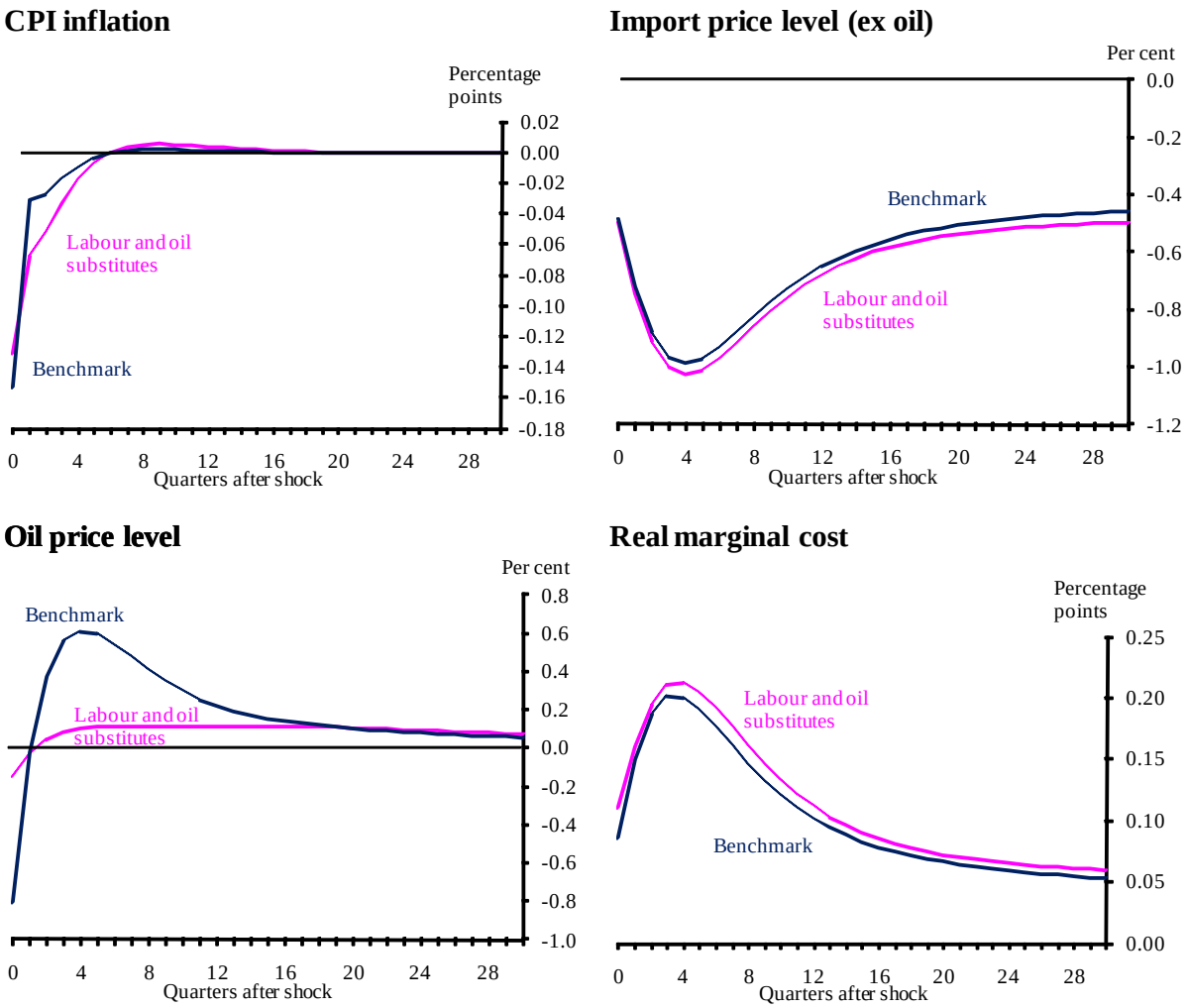


We start by supposing that the foreign economy pegs its exchange rate to the home economy. In practice, this means we add an exchange rate term to its Taylor rule:

$$i_t^* - r = 0.65\left(i_{t-1}^* - r\right) + 0.35(1.5\pi_t^* + 1000e_t). \qquad \textbf{(60)}$$

This means that foreign monetary policy will depend upon domestic monetary policy. In the case of a foreign productivity shock, the foreign monetary policy response will be much tighter. As a result, foreign output and, hence, oil prices will not increase as much as in the benchmark case. Moreover the real exchange rate movement will be muted. These two effects will result in a smaller decline of import prices. (See upper left panel of Chart 7.) As a result, CPI inflation falls by less than in the benchmark case despite a smaller increase in oil prices.

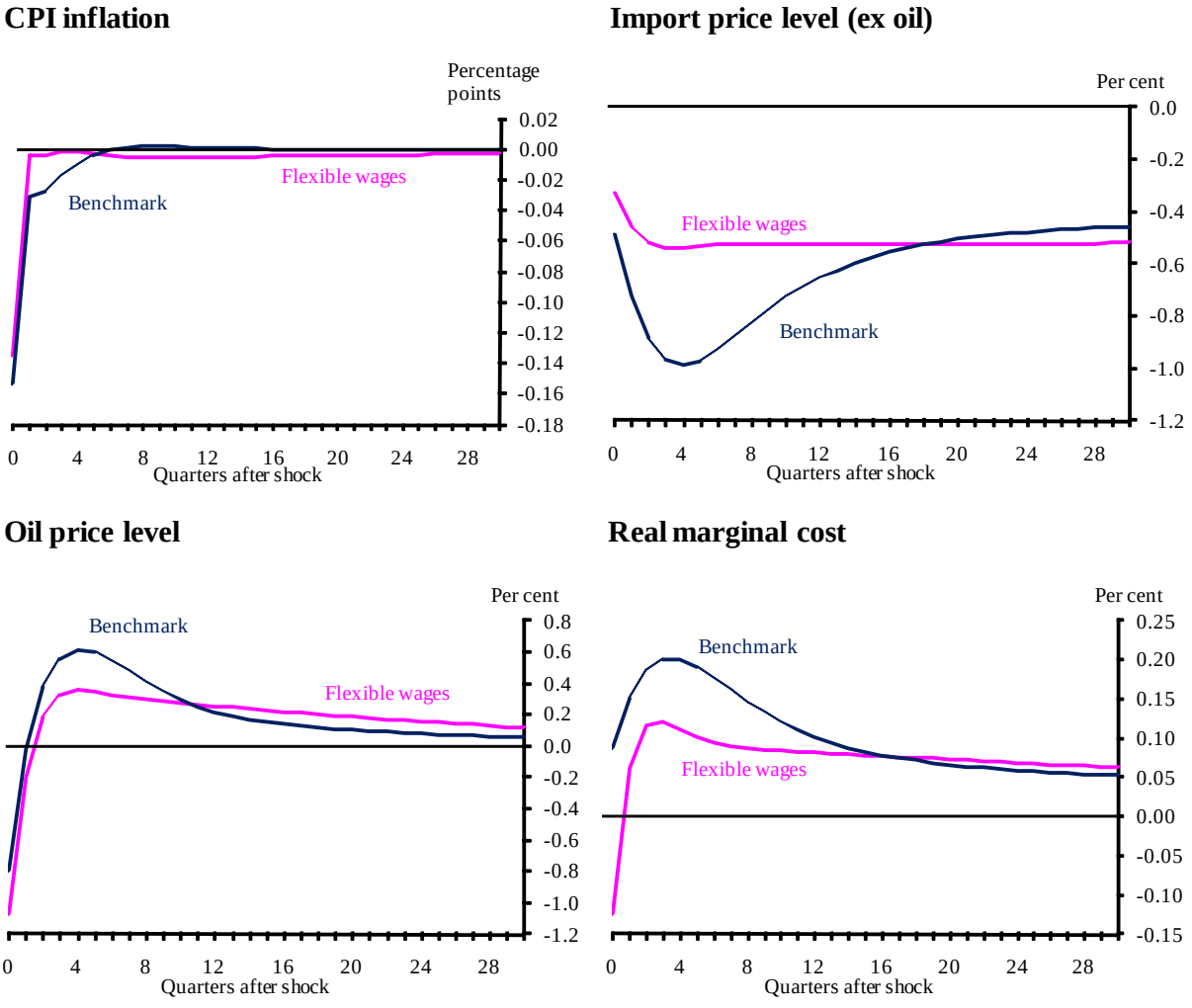
Chart 8: Benchmark case vs. the case where oil and labour are substitutes



We next consider the effect of making oil and labour substitutes in production as opposed to

complements. Specifically, we raise the elasticity of substitution between oil and labour, σ_O, to 1.5. This implies that the increase in demand for oil (resulting from the foreign productivity shock) will not be as large as in the benchmark. On the other hand, demand for labour will increase by more, which is reflected in higher real marginal costs. As a result, oil prices will not increase as much as in the benchmark case, making import prices decrease by more (as can be seen in the lower left and upper right panels of Chart 8). This will translate into a reduced headwind effect (despite an increased real marginal cost) and lower home CPI inflation. (See upper left panel of Chart 8.)

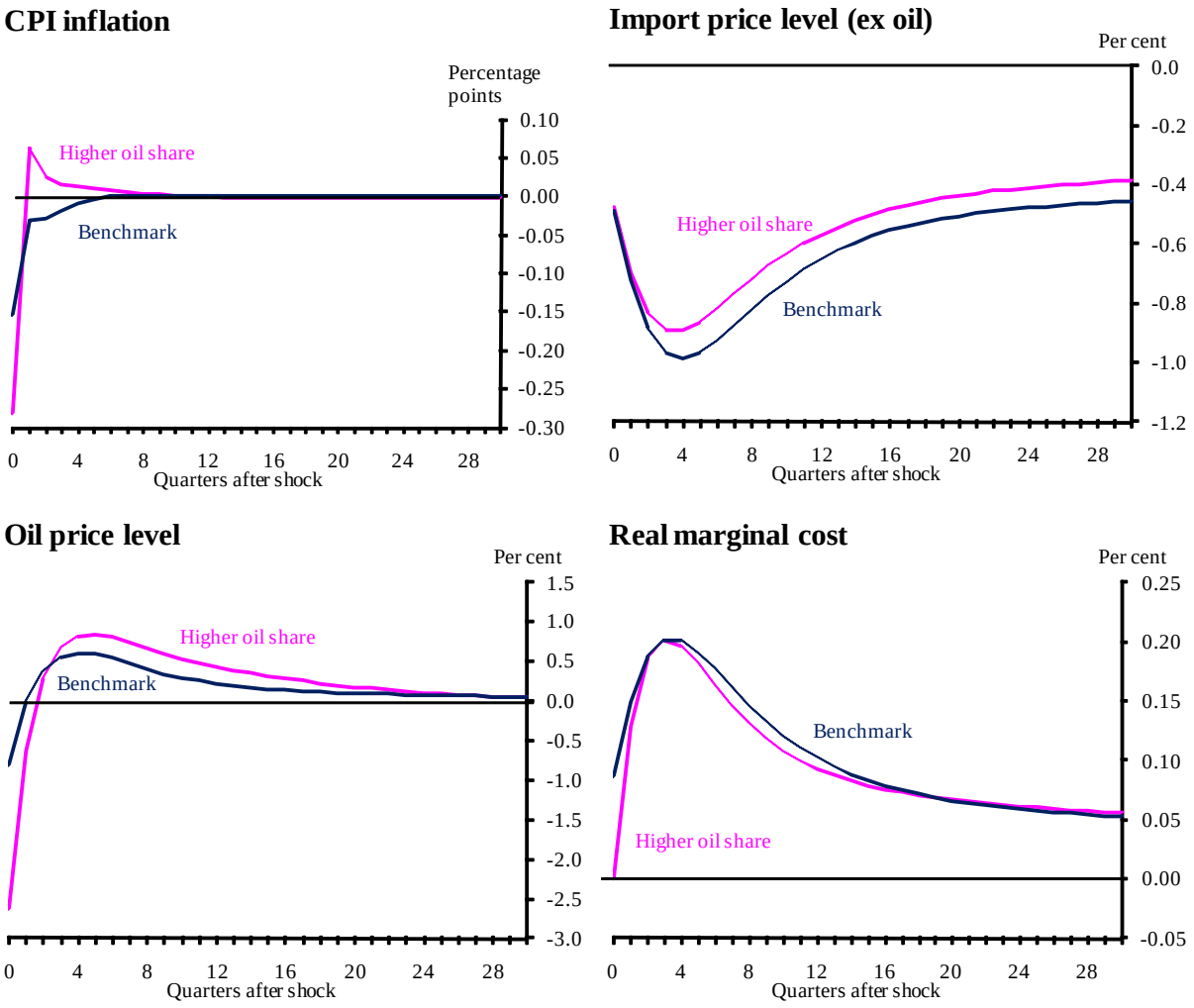
Chart 9: Benchmark case vs. the case of flexible wages



We next consider the effect of making wages perfectly flexible in both economies (Chart 9). Real wages adjust quickly, ie, foreign real wages increase on impact by more than in the

benchmark case. This limits the increase in foreign demand for oil. As a result oil prices increase by less. The headwind effect coming from wages dominates the effect of lower oil prices and thus makes import prices at home decrease by less than in the benchmark. (See upper right panel in Chart 9.) Lower oil prices and reduced expenditure switching lead to a smaller increase in home real wages and subsequently marginal cost. (See lower left panel in Chart 9.) The net results is that the impact on CPI inflation is smaller and less persistent.

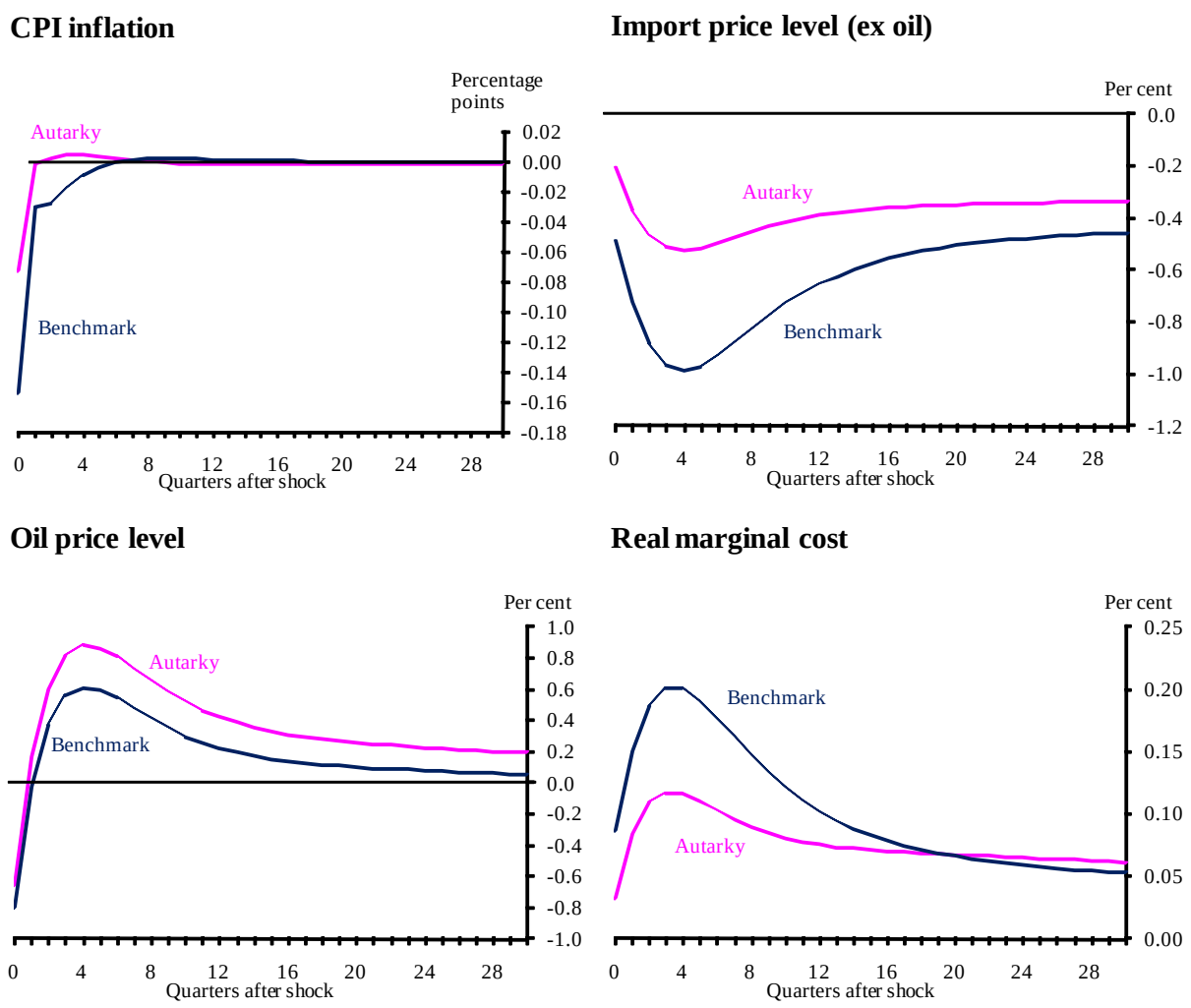
Chart 10: Benchmark case vs. the case of a higher share of oil in foreign production



Clearly, the strength of the headwind will depend on the share of oil in production in the expanding economies. For a given rise in productivity in the foreign economy, the more oil they use in production, the higher will be the effect on oil prices – as shown in the lower left panel of Chart 10 – and the more inflationary pressure will be affecting the home country. In accordance

with this, import prices decrease by less than in the benchmark. Moreover home consumers, faced with higher oil prices, feel poorer and want to work more, which is reflected in lower real wages and lower real marginal cost. (See lower right panel of Chart 10.) Higher import prices and higher oil prices translate into a reasonably long-lived rise in home inflation as a result of this shock; that is, the headwinds effect can outweigh the tailwinds effect.

Chart 11: Benchmark case vs. the case of financial autarky



Finally, we consider the effect of financial integration on our results. In particular, Chart 11 shows what would happen if there were no international borrowing or lending. In this case, the expenditure switching effect is diminished and, thus, the home currency appreciates by less against the foreign currency. As a result oil prices are a bit higher. Moreover, domestic consumers cannot benefit from cheaper foreign goods since trade has to be in balance. They feel

poorer and want to work more, as compared with the benchmark case, which is reflected in lower real wages and lower real marginal cost. This implies that the fall in import prices is much less marked. As a consequence, the decline in CPI inflation will be much smaller and less persistent.

5 Conclusions

In this paper, we have analysed the impact of a large productivity increase in a set of countries – which we think of as the BRIC economies – on inflation in their trading partners, the G7. We used a three-country DSGE model in which there are two symmetric economies (home and foreign) that are oil importers and an oil exporting country and performed several experiments where we disentangled the importance of different factors that shape inflation dynamics in the home country when the foreign country is hit by a persistent productivity shock. We found that, in our baseline calibration, the foreign productivity shock resulted in a temporary fall in home inflation: the favourable 'tailwinds' coming from the BRIC economies outweighed the 'headwinds'. This fall only lasted five quarters, since the home central bank was assumed to stabilise inflation. Our robustness analysis suggested that this result depends on home and foreign monetary policy, the degree of financial integration and the share of oil in production.

Although these results are certainly suggestive, an exact quantification of the effects of the rise of the BRIC economies would require a more careful calibration of the model, in particular, proper estimation of asymmetries between the developed and developing economies. This has been left for future work. In addition, we could consider different nominal and real rigidities and different pricing strategies of the exporting firms: pricing to market vs. the producer currency pricing implicit in our model. We could also consider adding capital to the model and allow intermediate goods producing firms to use foreign inputs of labour and materials. Finally, we have neglected the extensive margin of trade, that is, the creation and destruction of varieties of products. Recent work by Sbordone (2007) and Monacelli (2010) have emphasised the effects of this additional margin on the slope of the Phillips curve and Corsetti (2007) has shown that the transmission of productivity shocks will depend on whether such shocks enhance efficiency or lower entry costs. It would be well worth investigating the effects that this margin might have on the relative importance of headwinds and tailwinds in domestic inflation.

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