

Technology Shocks and Employment in Open Economies

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Abstract:

A growing body of empirical evidence suggests that a positive technology shock leads to a temporary decline in employment. A two-country model is used to demonstrate that the open economy dimension can enhance the ability of sticky price models to account for the evidence. The reasoning is as follows. An improvement in technology appreciates the nominal exchange rate. Under producer-currency pricing, the exchange rate appreciation shifts global demand toward foreign goods away from domestic goods. This causes a temporary decline in domestic employment. If the expenditure-switching effect is sufficiently strong, a technology shock also has a negative effect on output in the short run.

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1 Introduction

Gali (1999) examines the effects of technology shocks on output and employment (hours worked) using a structural VAR approach in a seminal paper. He shows that a positive technology shock causes a permanent increase in output, but the increase in output is more gradual than that of labour productivity. In the short run, output changes little or may even fall. The gap between the initial increase in output and the increase in productivity is reflected in a temporary and significant decline in employment. After the initial response, employment and output gradually increase. In the long run, employment returns to the initial level and output reaches a higher level permanently.

A growing body of empirical literature focuses on the connection between technological changes and macroeconomic fluctuations. Much of the recent empirical work supports the results of Gali (1999): Technology shocks have a negative effect on employment in the short run.¹ On the other hand, Christiano et al. (2004) find that employment rises after a technology shock. They show that Gali's (1999) results are sensitive to specifying the VAR in terms of the level (as opposed to the first difference) of employment. However, other empirical work finds evidence that Gali's (1999) results are robust to using different VAR specifications, data sets and measures for technological changes. The negative empirical relationship between productivity and employment has called into question the empirical relevance of Real Business Cycle (RBC) models and the view that technological changes are the driving force behind business cycles.

One strand of the literature has focused on explaining why the response of employment to a positive technology shock is negative. As pointed out by Gali and Rabanal (2004, Section 4), there are two broad classes of factors, able to explain this result, which are absent in standard RBC models. The first category is commonly referred to as "nominal explanations", since they rely on the presence of nominal frictions. Explanations in the second category are based on extended RBC models and do not lean on nominal rigidities. Thus, they can be referred to as "real explanations".

Several authors have extended standard (closed economy) RBC models to explain the fall in employment. Francis and Ramey (2005) use a calibrated RBC model to show that habit formation and capital adjustment costs imply that a technology shock can cause a decline in employment. A similar mechanism is proposed by Uhlig (2004) who shows that capital income taxation

¹This literature includes Basu, Fernald and Kimball (2004), Carlsson (2003), Francis, Owyang and Theodorou (2003), Francis and Ramey (2004, 2005), Franco and Philippon (2007), Gali (2004) and Gali and Rabanal (2004).

and labour hoarding can explain the decline in employment. Francis and Ramey (2005) also show that a labour-augmenting technical process with no capital-labour substitution can also explain the fall in employment. Rotemberg (2003) demonstrates that low levels of technology-adaptation mean that employment declines in response to a technology shock.

Collard and Dellas (2004, 2007) develop a two-country RBC model to show that a technology shock may cause a decline in employment if the elasticity of substitution between domestic and foreign goods is low. Sufficiently low substitutability implies that a technology shock causes a significant deterioration of the terms of trade. The deterioration in the relative price of domestic goods discourages output expansion. Employment declines because the level of output increases less than proportionately to the increase in productivity.

The most important nominal explanation is presented by Gali (1999), who develops a sticky price model to explain why the effect of a technology shock on employment can be negative. In his model, demand is determined by real balances, prices are set in advance and the central bank follows a simple money supply rule. When technology improves, employment declines unless the central bank expands the money supply at least in proportion to the improvement in technology. Gali (2003) demonstrates that this result generalises to a model with staggered price setting. When technology improves, only a fraction of firms lower their prices in the short run. The aggregate price level declines and consequently aggregate demand increases. Aggregate demand may increase less than proportionately to the improvement in technology if the fraction of firms adjusting their prices is sufficiently small. Employment may therefore decline.

In this paper, I develop a two-country general equilibrium model to address the question of how technology shocks affect output and employment in open economies. The model is based on Betts and Devereux (2000). The model's basic structure is almost identical to Gali's (2003) closed economy model. I extend the Betts-Devereux model in two ways. First, I introduce shocks to the production technology. Second, I introduce a Calvo-type staggered price setting. The assumption of staggered pricing allows for richer, dynamic responses to technology shocks than the hypothesis of simultaneous one-step-ahead pricing. These richer dynamics are important for a realistic discussion of the relationship between technology shocks and employment.

In this paper, I show that the open economy dimension can enhance the ability of sticky price models to account for the empirical findings of Gali (1999). In an open economy, there is an additional factor that can cause a decline in employment and output in the short run: the expenditure-switching effect of a nominal exchange rate change. The traditional argument

goes that, when a country's currency appreciates, it experiences an increase in the relative price of its exports and world consumption shifts away from its products. It is shown in this paper that an improvement in technology leads to an appreciation of the exchange rate. In the case of producer-currency pricing (PCP), the appreciation increases the relative price of domestic goods, shifting global demand to foreign goods, away from domestic goods. This results in an additional decline in domestic employment in the short run. The decline in employment is therefore sharper and more persistent in open economies. On the other hand, in the case of local-currency pricing (LCP), the appreciation carries no expenditure-switching effect in the short run. In this case, a technology shock causes a decline in employment almost identical to the closed economy case. In this respect the findings of this paper are different to those of Corsetti and Pesenti (2005) who find that exchange rate pass-through has no impact on employment, following a technology shock. In this model, employment and output gradually increase after the initial response. In the long run, employment shows no significant change relative to the pre-shock level and output reaches a permanently higher level, consistent with the empirical evidence. In addition, I demonstrate that under PCP (LCP) a technology shock generates a negative (positive) effect on foreign welfare in the short run.

The findings regarding the role of the elasticity of substitution between domestic and foreign goods are dissimilar to those of Collard and Dellas (2004, 2007). As mentioned, the authors show that under flexible prices low elasticity discourages output expansion and consequently causes a fall in employment. Taking into account nominal rigidities, the elasticity of substitution between domestic and foreign goods is a key variable in determining the strength of the expenditure switching effect. Thus, I show that a decline in domestic employment depends positively on the elasticity of substitution between domestic and foreign goods in the short run.

The rest of the paper is organised as follows. Section 2 presents the model. Section 3 discusses the international transmission of country-specific technology shocks. As the title suggests, I pay attention to the effects of technology shocks on employment in particular. Section 4 concludes the paper.

2 The Model

To study the macroeconomic effects of technology shocks, I develop a model that extends the framework of Betts and Devereux (2000). As mentioned in the introduction, the model is modified in two ways. The first modifica-

tion is simple: the introduction of productivity shocks. The second is the introduction of a Calvo-type staggered price setting. This allows for assessing the consequences of technology shocks for the persistence of employment changes.

2.1 Country Size and Market Structure

The world economy consists of two countries, home and foreign. There is a continuum of firms and households distributed on the unit interval. The number of households and firms is normalised to unity and they are indexed by $z \in [0, 1]$. A fraction n of households and firms is domestic; $1 - n$ are foreign.

Each firm produces a differentiated good. There are two types of firms. A fraction b of firms in each country are in a position to "price-to-market". These firms set their prices in the currency of the buyer. I refer to these firms as LCP firms. A fraction $1 - b$ of firms sets a unified price across countries. These firms set their prices in the currency of the producer and I refer to these firms as PCP firms.

2.2 Households

All households have identical preferences. Households derive utility from consumption C_t and real balances M_t/P_t but they dislike work ℓ_t , which decreases their utility. The representative domestic household seeks to maximise

$$U_t(z) = \sum_{s=t}^{\infty} \beta^{s-t} \left[\log C_s + \frac{\chi}{1-\varepsilon} \left(\frac{M_s}{P_s} \right)^{1-\varepsilon} - \frac{\ell_s(z)^2}{2} \right]. \quad (1)$$

Here, β is the discount factor, χ and ε are positive parameters. The composite consumption index is defined as

$$C_t = \left[\int_0^1 c_t(z)^{\frac{\theta-1}{\theta}} dz \right]^{\frac{\theta}{\theta-1}},$$

where $c_t(z)$ denotes consumption of good z at time t and θ denotes the elasticity of substitution between consumption goods. The consumption-based price index is given by

$$P_t = \left[\int_0^n p_t(z)^{1-\theta} dz + \int_n^{n+(1-n)b} p_t(z^*)^{1-\theta} dz + \int_{n+(1-n)b}^1 (E_t q_t(z^*))^{1-\theta} dz \right]^{\frac{1}{1-\theta}},$$

where prices p represent domestic currency prices, prices q represent foreign currency prices and E is the exchange rate (the domestic currency price of foreign currency). In general, foreign country variables are indicated by asterisks but in the context of goods prices an asterisk means a price set by foreign firm z^* . Thus, $p_t(z)$ is the domestic currency price of the domestically-produced good, $p_t(z^*)$ is the domestic currency price of foreign good z^* and $q_t(z^*)$ is the foreign currency price of a foreign good.

Households receive an earned income, dividends from firms and transfers from the government (seigniorage revenues). Households can use income to purchase consumption goods and to accumulate money and nominal bonds. Each household owns an equal share of all domestic firms. There is free and costless trade in nominal bonds. Domestic bonds are denominated in domestic currency. The budget constraint is given by

$$M_t + \delta_t D_t = D_{t-1} + M_{t-1} + w_t \ell_t(z) - P_t C_t + \pi_t + P_t \tau_t, \quad (2)$$

where δ_t is the nominal price of the bond ($\delta_t = (1 + i_t)^{-1}$, where i_t denominates the domestic nominal interest rate) maturing in period $t + 1$, D_t holdings of the bond, w_t denotes the nominal wage, π_t nominal dividends (profits) and τ_t denominates government transfers. The government rebates all seigniorage revenues to households:

$$\tau_t = \frac{M_t - M_{t-1}}{P_t}. \quad (3)$$

Since the bond is denominated in domestic currency, the budget constraint of foreign households is

$$M_t^* + \delta_t \frac{D_t^*}{E_t} = \frac{D_{t-1}^*}{E_t} + M_{t-1}^* + w_t^* \ell_t^*(z) - P_t^* C_t^* + \pi_t^* + P_t^* \tau_t^*. \quad (4)$$

The global asset-market-clearing condition requires $nD_t + (1 - n)D_t^* = 0$. Assuming open capital markets, uncovered interest parity must hold

$$1 + i_t = (1 + i_t^*) \left(\frac{E_{t+1}}{E_t} \right).$$

Households maximise the utility function subject to the budget constraint. The first order conditions for the maximisation problem of domestic and foreign households are

$$\delta_t P_{t+1} C_{t+1} = \beta P_t C_t, \quad (5)$$

$$\delta_t P_{t+1}^* C_{t+1}^* E_{t+1} = \beta P_t^* C_t^* E_t, \quad (6)$$

$$\ell_t = \frac{w_t}{C_t P_t}, \quad (7)$$

$$\ell_t^* = \frac{w_t^*}{C_t^* P_t^*}, \quad (8)$$

$$\frac{M_t}{P_t} = \left(\frac{\chi C_t}{1 - \delta_t} \right)^{\frac{1}{\varepsilon}}, \quad (9)$$

$$\frac{M_t^*}{P_t^*} = \left(\frac{\chi C_t^*}{1 - \frac{\delta_t E_{t+1}}{E_t}} \right)^{\frac{1}{\varepsilon}}. \quad (10)$$

Equations (5) and (6) are consumption Euler equations. Equations (7) and (8) govern the optimal labour supply. Finally, equations (9) and (10) govern the optimal money demand. Money demand is determined by consumption and the nominal interest rate.

2.3 Firms

2.3.1 Technology and Profits

Each firm produces a differentiated good with a production technology

$$y_t(z) = a_t \ell_t(z), \quad (11)$$

where $y_t(z)$ is the output of firm z , a_t denotes an exogenous technology parameter and $\ell_t(z)$ denotes labour input used by firm z . Technology shocks are country specific and technology is assumed to follow an AR(1) process

$$\hat{a}_t = \hat{a}_{t-1} + \epsilon_t,$$

where ϵ_t is an unpredictable shift in the level of domestic technology and the hat notation is used to represent the percentage deviations from the initial steady state. Firms minimise costs $w_t \ell_t(z)$ subject to the above production function. The nominal marginal cost is

$$MC_t(z) = \frac{w_t}{a_t}.$$

Firms maximise profits taking into account the downwards-sloping demand for their products. PCP firms set a unified price across the countries. LCP firms, however, are able to price-discriminate across countries. For LCP

firms, total output is divided between output sold at home, $x_t(z)$, and output sold abroad, $v_t(z)$. Profits are given by

$$\pi_t^{PCP}(z) = p_t(z) y_t(z) - w_t \ell_t(z), \quad (12)$$

$$\pi_t^{LCP}(z) = p_t(z) x_t(z) + E_t q_t(z) v_t(z) - w_t \ell_t(z), \quad (13)$$

$$\pi_t^{PCP}(z^*) = q_t(z^*) y_t^*(z^*) - w_t^* \ell_t^*(z^*), \quad (14)$$

$$\pi_t^{LCP}(z^*) = (p_t(z^*) v_t^*(z^*)) / E_t + q_t(z^*) x_t^*(z^*) - w_t^* \ell_t^*(z^*). \quad (15)$$

Equations (12) and (13) show the profits of a domestic PCP firm and of a LCP firm, respectively. Equations (14) and (15) show the profits of the corresponding foreign firms.

The demands for the products are given by

$$y_t(z) = \left(\frac{p_t(z)}{P_t} \right)^{-\theta} n C_t + \left(\frac{p_t(z)}{E_t P_t^*} \right)^{-\theta} (1-n) C_t^*, \quad (16)$$

$$x_t(z) = \left(\frac{p_t(z)}{P_t} \right)^{-\theta} n C_t, \quad (17)$$

$$v_t(z) = \left(\frac{q_t}{P_t^*} \right)^{-\theta} (1-n) C_t^*, \quad (18)$$

$$y_t^*(z^*) = \left(\frac{E_t q_t(z^*)}{P_t} \right)^{-\theta} n C_t + \left(\frac{q_t(z^*)}{P_t^*} \right)^{-\theta} (1-n) C_t^*, \quad (19)$$

$$v_t^*(z^*) = \left(\frac{p_t(z^*)}{P_t} \right)^{-\theta} n C_t, \quad (20)$$

$$x_t^*(z^*) = \left(\frac{q_t(z^*)}{P_t^*} \right)^{-\theta} (1-n) C_t^*. \quad (21)$$

Equation (16) shows the demand for a domestic PCP firm. Equations (17) and (18) show the demand for a domestic LCP firm in domestic and foreign markets, respectively. Corresponding foreign equations are (19)-(21).

2.3.2 Price Setting

In the absence of nominal rigidities, domestic LCP firms maximise $\pi_t^{LCP}(z)$ with respect to $p_t(z)$ and $q_t(z)$. This implies

$$p_t(z) = E_t q_t(z) = \frac{\theta}{\theta - 1} MC_t(z). \quad (22)$$

The assumption of an isoelastic demand function implies that the price of good z is a constant markup over marginal cost. Without nominal rigidities, the law of one price holds and good z is sold at the same price in both markets, when expressed in the same currency. Domestic PCP firms maximise $\pi_t^{PCP}(z)$ with respect to $p_t(z)$. The price of good z is a constant markup over marginal cost, as per equation (22).

Take into account nominal rigidities, firms set the price at time t before observing the impact of the technology shock. To model price rigidities, I follow the formulation of Calvo (1983). This formulation assumes that each firm retains its price in any given period with a probability $1 - \gamma$, independently of other firms and the amount of time since the last adjustment. When setting its profit-maximising price, each firm has to take into account that there is a probability $0 < \gamma < 1$ in every subsequent period that it will not be able to revise its price setting decision. When setting a new price in period t , each firm seeks to maximise the present value of profits weighting future profits by the probability that the price will still be effective in that period. For example, a domestic LCP firm seeks to maximise

$$\max_{p_t(z), p_t^*(z)} V_t^{LCP}(z) = \sum_{s=t}^{\infty} \gamma^{s-t} \zeta_{t,s} \pi_t^{LCP}(z),$$

where $\zeta_{s,t} = \prod_{j=s}^t (1 + i_j)^{-1}$ is the domestic nominal discount factor between period t and period s . As a result the pricing rules are given by

$$p_t(z) = \left(\frac{\theta}{\theta - 1} \right) \frac{\sum_{s=t}^{\infty} \gamma^{s-t} \zeta_{t,s} C_s \left(\frac{1}{P_s} \right)^{-\theta} MC_s(z)}{\sum_{s=t}^{\infty} \gamma^{s-t} \zeta_{t,s} C_s \left(\frac{1}{P_s} \right)^{-\theta}}, \quad (23)$$

$$q_t(z) = \left(\frac{\theta}{\theta - 1} \right) \frac{\sum_{s=t}^{\infty} \gamma^{s-t} \zeta_{t,s} C_s^* \left(\frac{1}{P_s^*} \right)^{-\theta} MC_s(z)}{\sum_{s=t}^{\infty} \gamma^{s-t} \zeta_{t,s} C_s^* \left(\frac{1}{P_s^*} \right)^{-\theta} E_t}. \quad (24)$$

Equation (24) shows that domestic export prices, expressed in foreign currency, do not change when the nominal exchange rate changes. This implies

that exchange rate pass-through to export prices is zero. The pricing rule for a domestic PCP good is the same as equation (23). This implies that PCP firms let foreign currency prices move one-to-one with the exchange rate, i.e. there is complete exchange rate pass-through to export prices. The pricing rules for foreign firms are the same as equations (23) and (24), except that the exchange rate should be replaced by the term $1/E_t$ and prices, of course, depend on foreign marginal costs rather than domestic marginal costs.

2.4 Symmetric Equilibrium

All firms in a country are symmetric and every firm that changes its price, in any given period, chooses the same price and output. The structure of price setting implies that each period a fraction of firms, $1 - \gamma$, sets a new price and and the remaining firms keep their prices unchanged.

The consolidated budget constraint of the domestic economy is derived by substituting equations (3), (12), (13) into equation (2). Analogously, the consolidated budget constraint of the foreign economy is derived by using corresponding foreign equations and the asset-market-clearing condition. The consolidated budget constraints can be written as

$$\delta_t D_t = D_{t-1} + (1 - b) p_t(z) x_t(z) + b [p_t(z) x_t(z) + E_t q_t(z) v(z)] - P_t C_t, \quad (25)$$

$$\begin{aligned} -\frac{n}{1-n} \delta_t \frac{D_t}{E_t} &= -\frac{n}{1-n} \frac{D_{t-1}}{E_t} + (1 - b) q_t(z^*) y_t^*(z^*) \\ &+ b \left[q_t(z^*) x_t^*(z^*) + \frac{p_t(z^*) v_t^*(z^*)}{E_t} \right] - P_t^* C_t^*. \end{aligned} \quad (26)$$

The model is log-linearised around a symmetric steady state where all exogenous variables, including technology, are constant. In addition, consider the special case where initial net foreign assets are zero and the level of technology is normalised to one. Variables with an initial steady state value of zero are normalised by consumption. The log-linearisation is implemented by expressing the model in terms of percentage deviations from the initial steady state. Equations (7), (11) and (22) imply that in initial equilibrium

$$\bar{y}_0 = \bar{\ell}_0 = \left(\frac{\theta - 1}{\theta} \right)^{\frac{1}{2}},$$

where zero-subscripts on barred variables denote initial steady state.

Equilibrium is defined as a sequence of variables that satisfy a number of conditions: Firstly, the optimality conditions for consumption evolution,

given by (5) and (6), must be satisfied. Secondly, the labour markets must be in equilibrium, in each country and in each period. For example, under PCP, the domestic labour supply is given by (7) and the domestic labour demand is determined by the production function (11) and the demand for goods (16). Thirdly, the constant money supply must equal the demand for money, given by (9) and (10). Fourthly, equilibrium must satisfy the optimal pricing rules. For example, domestic PCP firms set the new price based on equation (23). Finally, the intertemporal budget constraints, equations (25) and (26), must be satisfied.

3 The International Transmission of Technology Shocks

In this section I analyse the effects of technology shocks on employment and output as well as the international transmission of such shocks. First, since I use numerical simulations to solve the model, I briefly discuss the choice of parameter values. Then I discuss the international transmission of technology shocks under LCP. The next step is to discuss the international transmission of technology shocks under PCP. Finally, I implement a sensitivity analysis to study to what extent the effects of technology shocks on employment may be sensitive to the choice of some key parameter values.

3.1 Parameterisation

The choice of parameter values follows Betts and Devereux (2001) with one exception. Betts and Devereux (2001) use these parameter values to study whether the international effects of monetary and fiscal policy are sensitive to the currency of export pricing. I believe these parameter values are the best values to examine the question of how the international effects of a technology shock depend on the currency of export pricing.

The rationale for the choice of parameter values is as follows. Periods are defined as quarters. Thus, I assume $\beta = 0.99$ which implies a 4 percent annual real interest rate. The price adjustment parameter γ is set to 0.75. This implies that the average time until a price is reset is one year (4 periods). The parameter χ is set to 1. The parameter ε governs the consumption and interest elasticity of money demand. In this model, the consumption elasticity of money demand is $1/\varepsilon$. Empirical estimates of this elasticity are close to or below unity (Mankiw and Summer 1986; Helliwell et al. 1990). Following Betts and Devereux (2001), the baseline choice is $1/\varepsilon = 0.85$.

In this model, unlike in Betts and Devereux (2001), the same parameter (θ) governs the elasticity of substitution between two goods produced in the same country as well as the elasticity of substitution between two goods produced in different countries. Rotemberg and Woodford (1992) estimate the former elasticity to be approximately 6. Obstfeld and Rogoff (2000a, Section 2.3) briefly survey the literature on empirical estimates of the elasticity of substitution between domestic and foreign goods. They quote estimates in the range of 1.2 to 21.4. Typical estimates, however, are in the range of 5 to 6 (Sutherland 2006, 1161). I set θ equal to 6. This parameter value is widely used in the related literature, as e.g., in Sutherland (1996). I simulate the model using the algorithm developed by Klein (2000) and McCallum (2001).²

3.2 Simulation Results: The LCP Benchmark

I begin by examining the effects of a domestic technology shock under full LCP ($b = 1$). The analysis assumes a one percent unexpected (permanent) increase in the level of technology occurring in period 1. The dashed lines in Figure 1 show the dynamic effects of a technology shock under LCP. In all figures, the vertical axes show percentage deviations from initial equilibrium. The change in bond holdings is, however, expressed as a deviation from initial consumption. The domestic terms of trade are defined as the relative price of domestic imports in terms of domestic exports. Thus the domestic terms of trade deteriorate if this index rises. A log-linearised version of the utility function (1) implies that the change in utility in period t is given by³

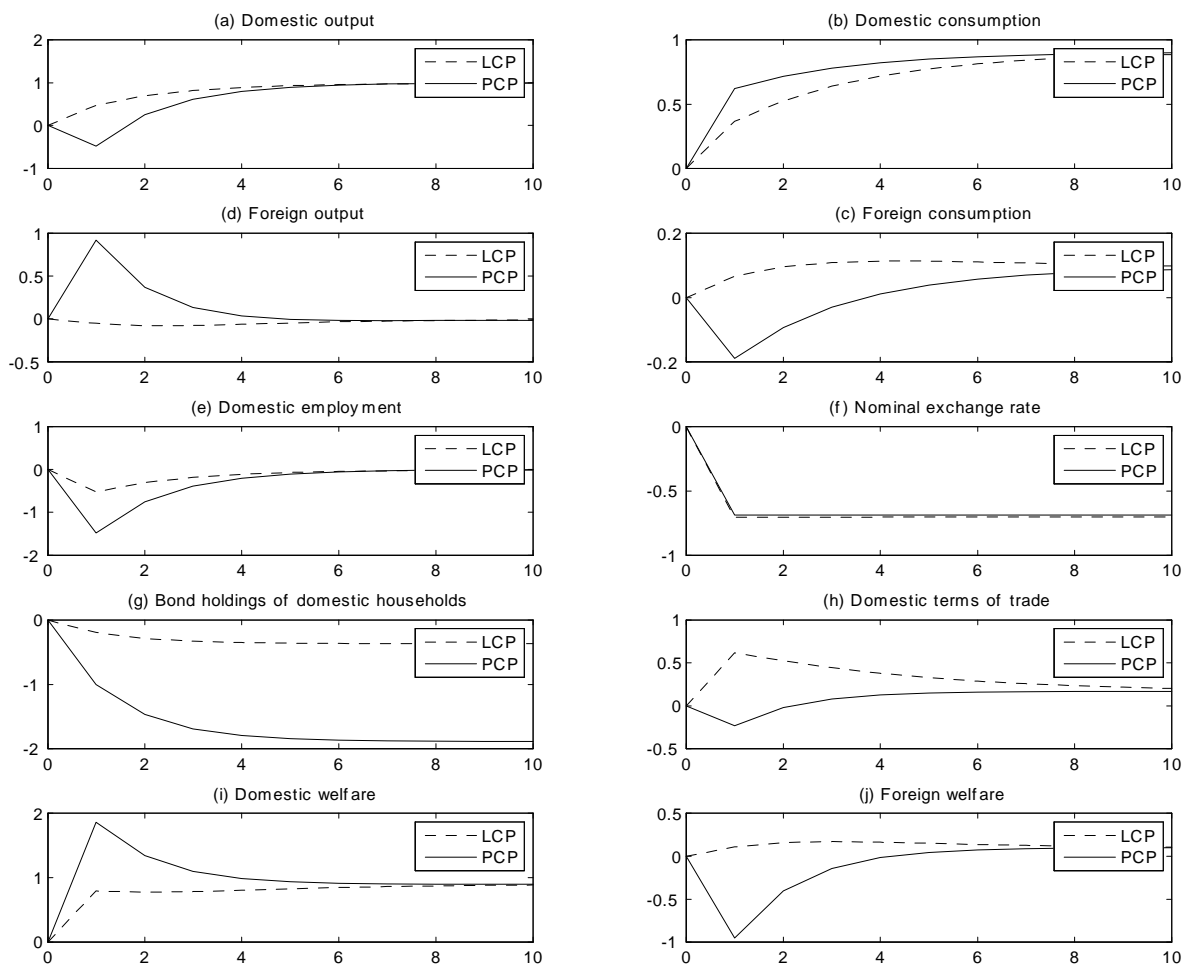
$$dU_t = \hat{C}_t - \bar{\ell}_0^2 \hat{\ell}_t.$$

As can be seen from Figure 1, a technology shock causes a sharp, if only short-lived, decline in domestic employment. In the case of LCP, the reason for the decline in employment is virtually the same as in the closed economy model of Galí (2003), notwithstanding the fact that the present model is an open economy model. A technology shock lowers the marginal costs of all domestic firms. In the short run, however, only a fraction of them have an opportunity to lower their prices. The aggregate price level starts to gradually adjust downward, increasing real balances and consequently aggregate demand. A technology shock therefore causes a gradual increase in domestic output. In the short run, the rise in output is smaller than that of labour productivity. The gap between the increase in labour productivity and the initial rise in output is reflected in a temporary fall in employment.

²See separate Appendix for more detailed information about the solution method and a description of the Matlab file that solves the model. The file is available to all readers.

³As typical in the literature, I neglect the utility derived from real balances.

Figure 1: The macroeconomic effects of an unexpected increase in domestic productivity



With full LCP, an exchange rate appreciation does not change relative prices. Money market equilibrium requires either a rise in relative consumption of the home country or a fall in the (relative) domestic nominal interest rate. Since exchange rate overshooting is extremely small, money market equilibrium implies an instant rise in relative domestic consumption.⁴ Thus, domestic households also raise current consumption by running a current account deficit. A permanent rise in output leads to a permanently higher level of consumption.

Due to the LCP assumption, the main economic effects of an exchange rate change are on the profits of firms. With import and domestic prices sticky, an exchange rate appreciation does not switch demand from domestic goods to foreign goods. An exchange rate change, instead, generates a distribution of income. When domestic firms price their exports in foreign currency, an exchange rate appreciation reduces their profits measured in terms of domestic currency [equation (13)]. An exchange rate appreciation raises the profits of foreign firms measured in foreign currency terms, however.

It is worth noting that, under LCP, the effect of a technology shock on domestic employment is almost the same as it would be in the closed economy ($n \rightarrow 1$). One main reason is that there is no expenditure switching effect as witnessed with a nominal exchange rate change. It is also worth observing that the effect of a technology shock on employment is positive, albeit small, in the long run. The home country runs a current account deficit and thus lower long run wealth leads to a small increase in the labour supply. The opposite change occurs in the foreign country. One should, however, not overstate this effect as it is weak. In the closed economy, a technology shock would not have an impact on the labour supply in the long run. (See also: Gali 2003).

Panel (d) of Figure 1 demonstrates that a domestic technology shock also has a positive effect on foreign consumption. This is due to three factors. Firstly, as mentioned, an exchange rate appreciation distributes income towards the foreign economy in the short run. Secondly, a domestic technology shock improves the foreign terms of trade. In the short run, under LCP, a domestic currency appreciation causes an improvement in the foreign country's terms of trade. In the long run, an increase in the supply of domestic goods decreases the relative price of domestic goods. So the change in the terms of trade raises foreign consumption in real terms. Thirdly, the accumulation of

⁴As in Betts and Devereux (2000), the nominal exchange rate overshoots its long run level if $\varepsilon > 1$. Because ε is close to 1, exchange rate overshooting is a negligible phenomenon.

external assets enables foreign households to increase their consumption.

Panels (i) and (j) illustrate the welfare effects of a technology shock. It is welfare enhancing in both countries in every period. The intuition behind this result is straightforward. An improvement in the level of technology allows domestic households to consume more without having to increase labour supply. On the contrary, labour supply is reduced in the short run. As mentioned, the accumulation of external assets and the improvement in the foreign terms of trade have a positive effect on foreign consumption.

3.3 The Expenditure Switching Effect and Employment

As emphasised by e.g. Obstfeld and Rogoff (2000b), the expenditure switching effect of a nominal exchange rate change is a key concept in the Keynesian approach to international macroeconomics. The traditional argument goes that, when a country's currency appreciates, it experiences an increase in the relative price of its exports and world consumption shifts away from its products. The authors present empirical evidence that supports the traditional framework and the assumption of PCP. They underline that the expenditure switching effect "should be a central feature of open economy models" (ibid, 127).

The first step deriving from the above assumption is to analyse the international transmission of technology shocks in the case where import prices move with the exchange rate. The solid lines in Figure 1 show the effects of the same unexpected increase in domestic technology, under full PCP ($b = 0$). Figure 1 illustrates that PCP has important implications for an economy's adjustment to a domestic technology shock in general and for output and employment dynamics in the short run in particular.

In the case of PCP, the expenditure switching effect of a nominal exchange rate change is to blame for a remarkable fall in domestic output. Under PCP, the relative consumption change increases the relative demand for domestic money. This requires an appreciation of the domestic currency. Due to the assumption of PCP, there is a one-to-one pass-through of exchange rate changes to import prices. The nominal exchange rate appreciation increases the relative price of domestic exports, shifting foreign demand toward foreign goods away from domestic goods. At the same time, the exchange rate appreciation implies that domestic goods become more expensive relative to foreign goods in the home country. Thus, domestic demand also shifts towards foreign goods. These expenditure switching effects imply that the exchange rate appreciation causes a fall in domestic output and a rise in

foreign output in the short run. Since the impact of a technology shock on the nominal exchange rate is strong and prices are relatively sticky, the expenditure switching effect is also strong. Thus, a technology shock causes a significant fall in domestic output and a significant rise in foreign output in the short run. When domestic firms have an opportunity to reset their prices, domestic goods become cheaper relative to foreign goods and the expenditure switching effect gradually peters out.

Panel (e) in Figure 1 shows that, in the case of PCP, a technology shock causes a more persistent and significant decline in domestic employment than in the LCP benchmark. As before, the gap between the increase in output and the increase in technology is reflected in a decline in employment. The expenditure switching effect, accounts for the added decline in employment. As mentioned, the effect of a technology shock in the LCP case is almost the same as in a closed economy model. Thus, one can also conclude that the expenditure switching effect causes an additional decline in employment compared to the closed economy case.

Complete exchange rate pass-through to import prices has the opposite effect on domestic and foreign consumption in the short run. The exchange rate appreciation lowers the domestic price level, increasing domestic consumption in real terms. The exchange rate change increases the foreign price level, reducing foreign consumption in real terms in the short run. In the long run, the accumulation of external assets and the improvement in foreign terms of trade have a positive effect on foreign consumption.

Panel (h) illustrates how a technology shock induces an improvement in the domestic terms of trade in the case of PCP in the short run. A domestic currency appreciation lowers import prices measured in terms of domestic currency. In the short run this "exchange rate effect" implies an improvement in the terms of trade. An increase in the supply of domestic goods implies a decrease in the relative price of domestic goods, however. As a result the terms of trade deteriorate in the long run.

Panel (j) shows that, in the case of PCP, a technology shock has a "beggarthy-neighbour" effect in the short run. Foreign consumption falls and employment increases in the short run. The spillover effect of a domestic technology shock is therefore a reduction of foreign welfare in the short run. This negative welfare spillover is soon reversed, due to the changes in the paths of foreign consumption and employment (output).

Since the effect of a technology shock on employment depends on the strength of the expenditure switching effect, it is reasonable to ask whether the nominal exchange rate appreciates following a technology shock. A number of empirical studies have analysed the effect of technology shocks on the real exchange rate (see, e.g., MacDonald 1998). If one adopts the view of

Mussa (1986), these provide indirect evidence of the effect of a technology shock on the nominal exchange rate. Mussa (1986) shows that nominal exchange rate changes are the driving force behind real exchange rate changes and that nominal exchange rate fluctuations alter the real exchange rate almost on a one-to-one basis.

Empirical literature provides mixed evidence on the effects of technology shocks on the exchange rate. Using a structural VAR approach Clarida and Gali (1994) find that a supply shock appreciates the real exchange rate. The effect is, however, relatively weak. There is, however, some evidence showing that productivity differentials can cause substantial real exchange rate changes. Alquist and Chinn (2002) find that an increase in the US-Euro area productivity differential causes a strong real appreciation of the dollar. Alexius (2005) shows that real exchange rates appreciate significantly in response to increases in relative productivity both in the short-run and the long-run.

Basu et al. (2004) find that a US technology shock depreciates the nominal and the real exchange rate. They also show that the time path of the real exchange rate change is virtually identical to that of the nominal exchange rate, consistent with the view of Mussa (1986). The long-run change in the nominal exchange rate is, however, somewhat smaller than that of the real exchange rate. A depreciation of the nominal exchange rate suggest that it is possible that a technology shock causes the expenditure switching effect whose sign is different than in this model.

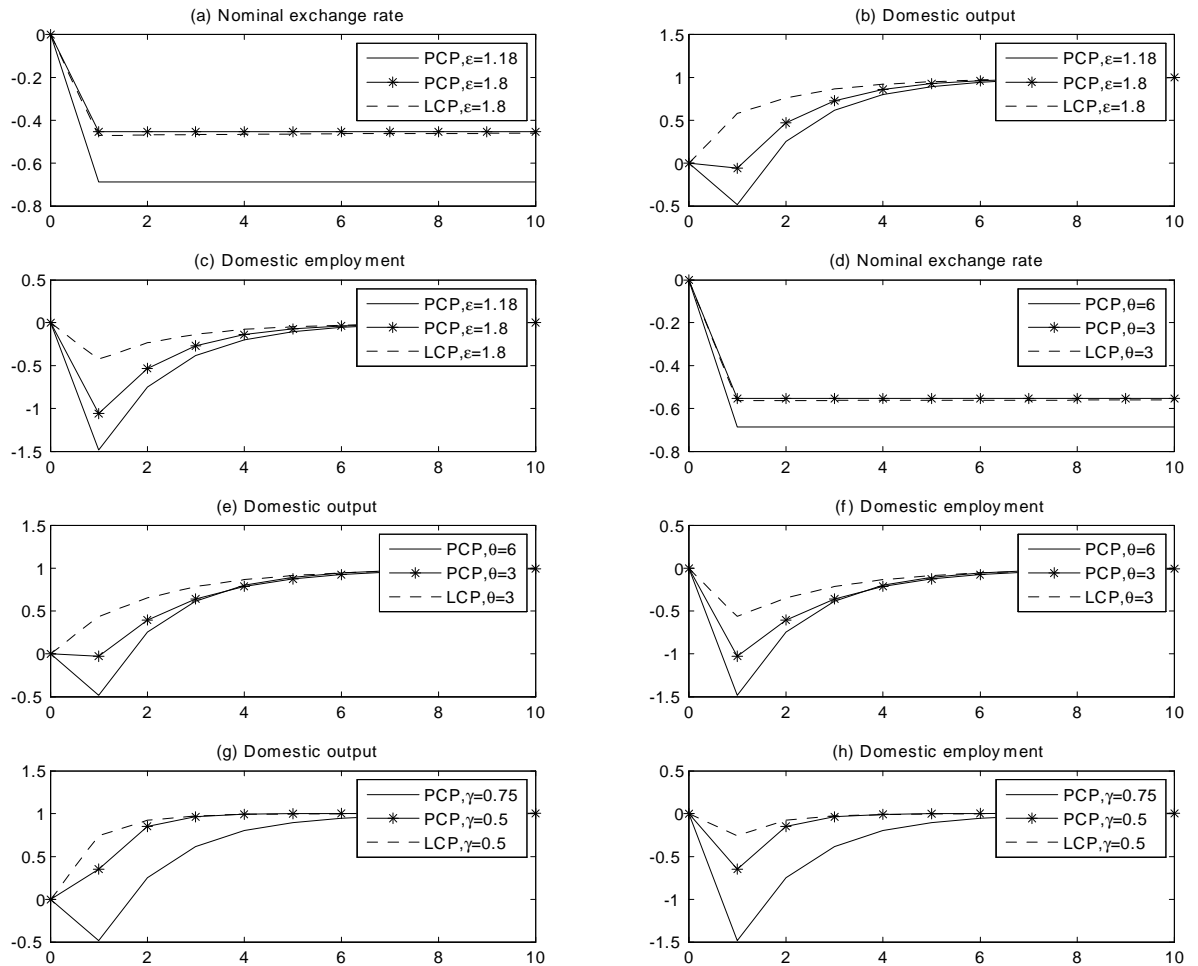
3.4 Technology Shocks and Employment: Varying Key Parameter Values

In this section I implement a sensitivity analysis to assess how responsive the effects of technology shocks on employment are to changes in key parameter values. The above discussion suggests that the behaviour of employment is dependent on the strength of the expenditure switching effect. Thus, I study how sensitive the results are to changes in the consumption elasticity of money demand, the elasticity of substitution between domestic and foreign goods and the speed of price adjustment.

Helliwell et al. (1990) estimated that the consumption elasticity of M1 is 0.85 ($\varepsilon = 1.18$) for the U.S., while the corresponding figure for Japan was found to be 0.55 ($\varepsilon = 1.8$). Panels (a) through (c) in Figure 2 show the consequences of varying the consumption elasticity of money demand. The solid lines show the PCP baseline case which is analysed in the previous section. The dashed lines illustrate the LCP case where $\varepsilon = 1.8$ and the solid

lines with stars show the PCP case where $\varepsilon = 1.8$.

Figure 2: The effects of varying key parameter values



In the case of PCP, a lower consumption elasticity of money demand implies that the relative demand for domestic money increases by less than in the baseline case ($\varepsilon = 1.18$). Thus, the exchange rate also depreciates by less. In this case, the exchange rate movement causes a smaller change in the international price ratio. The expenditure switching effect is thus weaker and the decline in employment is smaller than in the PCP baseline case. However, a shift in world demand implies that the decline in employment is still greater and more persistent than in the LCP case.

Another important parameter is the elasticity of substitution between domestic and foreign goods for two reasons. As shown by Obstfeld and Rogoff (1995, 1996), it is a key variable in determining the exchange rate response and it also governs the strength of the reallocation in world demand. Panels (d) through (f) illustrate the effects of varying the elasticity of substitution between goods. Now the solid lines with stars show the PCP case where $\theta = 3$ ($\varepsilon = 1.18$ as in the baseline case) and the dashed lines show the corresponding LCP case. Panel (d) illustrates that the lower the elasticity of substitution between goods, the smaller the exchange rate effect of a technology shock. This and the fact that domestic and foreign goods are now poorer substitutes imply that the exchange rate change leads to a smaller shift in world demand with sticky prices. The expenditure switching effect implies that the decline in employment is higher and more persistent than in the LCP case.

Panels (g) and (h) in Figure 2 illustrate the consequences of varying the degree of price inertia. The solid line with stars indicate the PCP case where the fraction of firms setting a new price in each period is increased to 0.5 ($\theta = 6$, $\varepsilon = 1.18$). This implies an average delay of 2 periods between price adjustments. This is consistent with Bils and Klenow (2004) who find that prices change twice a year. As prices become more flexible, the expenditure switching effect becomes weaker and it peters out faster.

One general lesson from this section is that the effect of a technology shock on domestic output and employment greatly depends on the strength of the expenditure switching effect. In the case of PCP, a technology shock can have a positive or negative effect on output depending on parameter values. However, in the PCP case the expenditure switching effect induces a larger decrease in domestic employment than in the LCP case. This effect is independent of parameter values. The stronger the expenditure switching effect, the stronger the decline in domestic employment.

3.5 Technology Shocks and Employment

As mentioned in the introduction, the empirical literature has shown that a technology shock causes a temporary and significant decline in employment. After the initial response, employment and output gradually increase. In the long run, employment levels rise close to the pre-shock level and output reaches a permanently higher level.

Gali (1999) introduced a nominal explanation to explain why the response of employment to a technology shock is negative in the short run. In his model, insufficient aggregate demand due to sticky prices, accounts for the negative response of employment to a technology shock.

This paper shows that the open economy dimension can enhance the abil-

ity of sticky price models to account for the empirical evidence. The reason for this is that there is an additional factor causing a decline in employment and output in the short run in open economies: the expenditure switching effect of a nominal exchange rate change. In the case of PCP, a shift in world demand causes an additional decline in domestic employment in the short run. The decline in employment is therefore sharper and more persistent in open economies. The model also matches empirical findings quite well. Perhaps, however, the baseline calibration with relatively sticky prices and the fact that the steady state import share is 50 percent overemphasises the role of the expenditure switching effect.

Collard and Deltas (2004, 2007) develop a two-country flexible-price RBC model to show that a technology shock can cause a decline in employment if the elasticity of substitution between domestic and foreign goods is very low.⁵ In their framework, sufficiently low substitutability implies that a technology shock induces a significant deterioration of the terms of trade. This deterioration discourages domestic output expansion and employment may decline because the level of output increases less than proportionately to the increase in productivity.

The findings of this paper are different to those of Collard and Deltas (2004, 2007) in the PCP case. With sticky prices, a high elasticity of substitution between domestic and foreign goods implies that the expenditure switching effect is powerful. Hence, the higher the elasticity of substitution between domestic and foreign goods, the more a technology shock decreases domestic employment.

The new open economy macroeconomics (NOEM) literature has also analysed the effects of technology shocks. A limitation of many NOEM models (including the one by Obstfeld and Rogoff, 1996) is that technology shocks are modelled as shocks to the parameter that captures the disutility of labour.⁶ This is more a change in preferences (a labour supply shock) than a technology shock, as already noted by Obstfeld and Rogoff (1996, 699). In this type of a technology shock, households increase their labour supply immediately.

Corsetti and Pesenti (2005) develop a NOEM model, in which technology shocks are modelled as shocks to production technology, to analyse how the effects of a technology shock depend on the currency of export pricing. In their framework, the assumption of unitary elasticity of substitution between

⁵In Collard and Deltas (2004) employment declines if the elasticity is less than one.

⁶NOEM models in which model technology shocks are modeled as shocks to the production technology include, but are not limited to, Benigno and Thoenissen (2003), Corsetti, Dedola and Leduc (2004), Evers (2006), Ortega and Rebei (2006), Rabanal and Tuesta (2006).

domestic and foreign goods implies that technology shocks do not have an effect on the nominal exchange rate. Hence, the international transmission of technology shocks is completely independent of the currency of export pricing. A technology shock causes a decline in domestic employment, exactly as in the closed economy case (Corsetti and Pesenti 2005, Section 6.2). In this paper, it is demonstrated that if the elasticity of substitution between domestic and foreign goods is not equal to one, the currency of export pricing matters for the response of employment to a technology shock.

3.6 Monetary Policy

A limitation of the present model is that of neglecting the role of monetary policy. It is worth remembering, however, that the effect of any economic shock (including a technology shock) on employment (or any other endogenous variable) is not independent of monetary policy. Dotsey (2002), Gali (1999), (2003) and Gali and Rabanal (2004) show that monetary policy can significantly influence the response of employment to a technology shock. To highlight the potential limitations of neglecting the role of monetary policy, I briefly survey the previous literature that studies how monetary policy affects the response of employment following a technology shock. This literature suggests that if monetary policy was sufficiently accommodative, employment could rise in this model after a technology shock .

Gali (1999) and (2003) shows that when technology improves, employment declines unless the central bank expands the money supply at least in proportion to the improvement in technology. Dotsey (2002) extends the analysis of Gali (1999) by introducing Taylor-type monetary policy rules. He finds that if the central bank follows the monetary policy rule estimated by Clarida et al. (2000)⁷ or by Taylor (1993), monetary policy is very accommodative and consequently the large increase in output implies an increase in employment in the short run. Gali and Rabanal (2004) analyse the effect of technology shocks using a model where monetary policy is characterised by an interest rate rule similar to Taylor (1993). The central bank responds to output or its deviations from trend, not to the output gap. They find that in this case the impact of a technology shock on employment can be positive or negative, depending on parameter values. They, however, conclude that employment is likely to decline "under a broad range of reasonable parameter values" (Gali and Rabanal 2004, 258).

⁷The central bank responds to both expected deviations of inflation from target and expected deviations of current output from its potential level.

4 Conclusions

In recent years, the empirical literature has shown that technological improvements cause temporary and significant declines in employment. This paper presents a model which illustrates that the open economy dimension can enhance the ability of sticky price models to account for this empirical finding. In this paper, it is shown that the expenditure switching effect can be one reason why technology shocks have a negative effect on employment in the short run.

This analysis focuses on a simple case and assumes no home bias in consumption, a simple production function without capital, perfectly competitive labour markets and a monetary authority that does not respond to technology shocks. One can think of numerous variants of and extensions to the model. It may be worth analysing how the results of this model change e.g. if one assumed more general preferences, imperfectly competitive labour markets or introduced capital into the production function. An interesting extension to the model would be the introduction of a monetary policy rule. Attempts to extend the model are simple and welcome: the Matlab code that solves the model is available to all readers. Further research could investigate the robustness of the results presented here. In addition, the model can easily be used to study a number of questions related to the international transmission of technology shocks.

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