Technology Shocks and Employment*

Fabrice Collard† and Harris Dellas‡

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Abstract

Recent empirical work has suggested that in response to a positive technology shock employment shows a persistent decline. This finding has raised doubts concerning the relevance of the real business cycle model. We show that the standard, open economy, flexible price model can generate a negative response of employment to a positive technology shock and can also match the negative conditional correlation between productivity and employment quite well if trade elasticities are low. In addition, the model has satisfactory overall empirical performance.

Keywords: Technological shocks, employment, open economy, flexible prices.
JEL Class: E32, E24.

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†GREMAQ-CNRS, Manufacture des Tabacs, bât. F., 21 allée de Brienne, 31000 Toulouse, France. Phone: (+335) 61–12–85–42, Fax: (+335) 61–22–55–63. Email: fabrice.collard@univ-tlse1.fr, Homepage: http://fabcol.free.fr
‡Department of Economics, University of Bern, CEPR and IMOP, Gesellschaftsstrasse 49, CH–3012 Bern, Switzerland. Phone: (+41) 31–631–3989, Fax: (+41) 31–631–3992. Email: harris.dellas@vwi.unibe.ch, Homepage: http://www-vwi.unibe.ch/amakro/dellas.htm
Introduction

The real business cycle model (RBC) model assigns a critical role to aggregate variations in technology as the driving force behind macroeconomic fluctuations. One of its key implications is that technology shocks lead to procyclical movements in employment, productivity and real wages of the type observed in the data.

The ability of the RBC model to account for business cycles has been questioned on the basis of recent evidence concerning the conditional relationship between productivity and employment. Galí [1999] and more recently Galí and Rabanal [2004], and Basu, Fernald and Kimball [1998] (henceforth BFK) have identified technology shocks based on plausible identification schemes and have found that in response to a positive technology shock, labor productivity rises more than output while employment shows a persistent decline. Hence, the empirical correlation between employment and productivity as well as that between employment and output conditional on technology shocks is negative. This finding has raised “... serious doubts not only about the relevance of the RBC model but more importantly about the quantitative significance of technology shocks as a source of aggregate fluctuations in industrialized economies...” (Galí [2000]). Moreover, as the standard Keynesian model with imperfect competition and sticky prices seems capable of generating a short run decline in employment in response to a positive technology shock, this stylized fact has provided support for models with nominal frictions.

There have been three lines of response to the findings of Galí and BFK. The first is to dispute the ability of the particular identification schemes used to truly identify technology shocks (see Bils [1998]) and also Christiano, Eichenbaum and Vigfusson [2004] and Chari, Kehoe and McGrattan [2003]). However, Francis and Ramey [2001] examine whether Galí’s constructed technology shocks behave like true technology shocks and conclude that this seems to be indeed the case.

The second response is more defensive and argues that the new Keynesian model is equally incapable of matching these stylized facts. Dotsey [1999] shows that a sufficiently procyclical monetary policy can induce a positive correlation between output and employment following a technology shock even under fixed prices.

The third response is to suggest plausible, flexible price models that can reproduce these stylized facts. It is easy to see what kind of modelling features are needed for this. In order to get a reduction in employment following a positive productivity shock, the increase in labor demand must be limited while the supply of labor must decrease. The latter can come about either by a strong wealth effect and/or by an intertemporal substitution effect that favors
future at the expense of current effort. Standard preferences with high risk aversion can make wealth effects large. Implementation lags in the adoption of new technology can make future productivity higher than current one, inducing a decrease in current labor supply (time-to-implement as in Hairault, Langot and Portier [1997], or time-to-plan as in Christiano and Todd [1996]). Implementation lags also work to restrain the increase in labor demand.

An alternative way of thinking about this is via aggregate demand and supply. If aggregate demand is sluggish in the short run then output will not expand much following a positive productivity shock. With more productive workers, fewer of them will be needed in order to produce a given level of output. Sluggishness in investment can be brought about by capital adjustment costs, in consumption by habit persistence (Francis and Ramey [2001]) and in exports by low trade elasticities.

In this paper we argue that the open economy dimension can greatly enhance the standard flexible price model’s ability to account for Galí’s stylized facts. And that it does so without compromising the ability of the model to account for other dimensions of the business cycle. This is an important consideration because specifications that are less standard (i.e. require “extreme” parameter values) may succeed in matching the conditional correlations singled out by Galí and BFK but tend to perform poorly in many other respects.

The mechanism we suggest relies on the degree of substitution between domestic and foreign goods. A positive domestic supply shock may reduce domestic employment if domestic and foreign goods are not good substitutes. Indeed, low substitutability means that the domestic terms of trade must worsen significantly in order to clear the market. The reduction in the relative price of the domestic good then discourages output expansion. Therefore, higher productivity combined with a small output expansion translates into lower employment.

An alternative but equivalent way of describing this is to say that in an open economy, if short run international trade substitution is low, domestic output cannot expand much unless it is accompanied by a comparable expansion in foreign output. Foreign output expands because of the improvement in the foreign term of trade. However, in the absence of strong contemporaneous international correlation of supply shocks this expansion may not be sufficient to boost domestic employment.

We show that an RBC model that contains a combination of three elements matches the aforementioned conditional correlations quite well. These elements are trade openness, low trade elasticities and sluggish capital adjustment. Using the standard open economy parameterization employed in the literature (e.g. Backus, Kehoe and Kydland [1992]) but with lower trade elasticities (for instance, using the values suggested by Taylor [1993] or those implicit
in the J–curve literature) we obtain negative, conditional comovement of output and employment. While the model does not generate enough unconditional volatility in employment the model’s overall implications are broadly consistent with those in the data. We conclude that the observation of a negative conditional correlation between employment and output (or productivity and employment) does not justify the rejection of the equilibrium model.

Note that the multi–country world used here is not much different from a multi sector economy. Hence, rather than thinking about multiple countries, one could instead think about multiple sectors within a single country. As long as the products of different industries are not good substitutes (in either consumption or production) and significant sector specific supply shocks exist, then similar patterns are expected. The main reasons we are focusing on the multi–country specification are that openness is a key feature of all economies and also that we have much more information about international rather than intersectoral trade so that the model can be calibrated and evaluated more easily.

The rest of the paper is organized as follows. Section 1 reproduces and extends the empirical analysis of Galí to an open economy. Section 2 contains the description of the model. In section 3 we discuss the parametrization of the model. Section 4 reports and discusses the main findings.

1 The Empirical Evidence

This section reports evidence on the conditional relationship between productivity and the labor input as well as on the effects of identified technology shocks on open economy variables. The analysis follows closely Galí [1999].

We estimate a four variable VAR model which includes, besides labor productivity, \( x \), and labor input, \( h \), the real exchange rate, RER, and the trade balance, TB. We use U.S. quarterly data from 1970:1–2001:4. Hours per capita are taken from Prescott and Ueberfeldt [2003]. Labor productivity is constructed by dividing GDP (obtained from the NIPA) by total hours worked. The real exchange rate is computed according to the standard formula (an increase in this variable represents a US currency real depreciation):

\[
\text{REER}_t = \sum_{i \in I} \omega_i e_{i,t} \frac{CPI_{i,t}}{CPI_{US,t}}
\]

where \( \omega_i \) is the share of country \( i \)'s trade in total US trade, \( e_{i,t} \) is the nominal exchange rate between the \( i \)-th country’s currency and the US dollar and \( CPI_{i,t} \) is the consumption price.

\[1\] King and Rebelo [2000] and Francis and Ramey [2001] have suggested that production complementarities may help the flexible price model account for Galí’s stylized facts.
index in country \( i \). Both series are obtained from the IFS database. The set of countries consists of the main EU trading partners of the US: Belgium, France, Germany, Netherlands and the United Kingdom (they together account for more than 80% of EU trade with the US). The trade balance is constructed using data from the IMF’s direction of trade statistics. It is computed as

\[
TB_t = \frac{\sum_{i \in I} EXP_{i,t}}{\sum_{i \in I} IMP_{i,t}}
\]

where \( EXP \) and \( IMP \) denote, respectively, US exports to and imports from country \( i \) denominated in US dollars. As \( TB_t \) was found to exhibit a strong seasonal component we seasonally adjusted it using the CENSUS X–12 procedure.

The VAR is run in the rate of growth of productivity, hours worked per capita, the log of the real exchange rate and the log of the trade balance index. The latter two series are found to be stationary. Regarding hours worked we follow Galí [1999] in using two alternative methods for rendering the data stationary: (i) hours were detrended using a linear trend and (ii) hours were taken in first difference. In both cases a likelihood ratio test suggested a model with 5 lags. As in Galí [1999] the technology shock is identified through the assumption that it is the only one that has a long run effect on labor productivity.

Table 1: Correlation with productivity

<table>
<thead>
<tr>
<th></th>
<th>ΔHours</th>
<th>REER</th>
<th>TB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unconditional</td>
<td>-0.25**</td>
<td>-0.05</td>
<td>-0.02</td>
</tr>
<tr>
<td></td>
<td>(0.08)</td>
<td>(0.08)</td>
<td>(0.07)</td>
</tr>
<tr>
<td>Techno.</td>
<td>-0.81**</td>
<td>0.33**</td>
<td>-0.27**</td>
</tr>
<tr>
<td></td>
<td>(0.10)</td>
<td>(0.09)</td>
<td>(0.07)</td>
</tr>
<tr>
<td>Non–Techno.</td>
<td>-0.13**</td>
<td>-0.01</td>
<td>-0.00</td>
</tr>
<tr>
<td></td>
<td>(0.07)</td>
<td>(0.01)</td>
<td>(0.01)</td>
</tr>
<tr>
<td>Linearly Detrended</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unconditional</td>
<td>-0.25</td>
<td>-0.05</td>
<td>-0.02</td>
</tr>
<tr>
<td></td>
<td>(0.08)</td>
<td>(0.08)</td>
<td>(0.07)</td>
</tr>
<tr>
<td>Techno.</td>
<td>-0.70**</td>
<td>0.21*</td>
<td>-0.16**</td>
</tr>
<tr>
<td></td>
<td>(0.13)</td>
<td>(0.11)</td>
<td>(0.08)</td>
</tr>
<tr>
<td>Non–Techno.</td>
<td>-0.12*</td>
<td>0.00</td>
<td>-0.01</td>
</tr>
<tr>
<td></td>
<td>(0.06)</td>
<td>(0.02)</td>
<td>(0.01)</td>
</tr>
</tbody>
</table>

Note: Standard errors (obtained by Monte Carlo simulations using 1000 draws) into parenthesis. Significance is indicated by one asterisk (10–percent level) or two asterisks (5–percent level).

Figure (1) reports the impulse response functions of output, productivity and hours to a one standard deviation, positive technological shock. The shaded area corresponds to the 95%
Figure 1: Impulse Response to a Technology Shock

(a) Hours in difference

(b) Linearly detrended hours

Note: The shaded area is the 95% confidence interval, obtained by Monte Carlo simulation using 1000 draws.
confidence interval, computed using a Monte Carlo method to sample from the estimated asymptotic distribution of the VAR coefficients and the covariance matrix. The results are similar to those obtained by Galí [1999].\(^2\) In response to a one standard deviation positive shock to technology, labor productivity rises on impact by 0.4% when hours are used in the first difference form. The impact effect of the technology shock is about the same when hours are linearly detrended. Labor productivity eventually reaches a permanently higher level in the long run. Likewise, output experiences a permanent increase. As in Galí, the gap between the impact effects of the technology shock on labor productivity and output is reflected in a persistent decrease in the labor input. This pattern obtains whether hours are in first difference or in deviations from a linear trend. A direct consequence of this result is that the conditional correlation between changes in labor productivity and changes in hours worked is negative. For instance, as reported in Table 1, the conditional correlation between changes in labor productivity and hours is -0.81 when hours are taken in differences, and -0.70 when they are linearly detrended. The unconditional correlation is weaker (-0.25). These results are in line with Galí’s findings, suggesting that trade openness does not affect fundamentally the stylized facts.\(^3\)

Table 2: Correlation with output

<table>
<thead>
<tr>
<th></th>
<th>ΔHours</th>
<th>REER</th>
<th>TB</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Difference</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unconditional</td>
<td>0.62**</td>
<td>-0.19*</td>
<td>-0.20*</td>
</tr>
<tr>
<td></td>
<td>(0.07)</td>
<td>(0.10)</td>
<td>(0.10)</td>
</tr>
<tr>
<td>Techno.</td>
<td>0.05</td>
<td>0.37**</td>
<td>-0.22**</td>
</tr>
<tr>
<td></td>
<td>(0.19)</td>
<td>(0.14)</td>
<td>(0.09)</td>
</tr>
<tr>
<td>Non–Techno.</td>
<td>0.73**</td>
<td>-0.24**</td>
<td>-0.21**</td>
</tr>
<tr>
<td></td>
<td>(0.04)</td>
<td>(0.04)</td>
<td>(0.02)</td>
</tr>
<tr>
<td><strong>Linearly Detrended</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unconditional</td>
<td>0.62</td>
<td>-0.19</td>
<td>-0.20</td>
</tr>
<tr>
<td>Techno.</td>
<td>-0.12</td>
<td>0.40*</td>
<td>-0.33**</td>
</tr>
<tr>
<td></td>
<td>(0.14)</td>
<td>(0.23)</td>
<td>(0.09)</td>
</tr>
<tr>
<td>Non–Techno.</td>
<td>0.79**</td>
<td>-0.31**</td>
<td>-0.28**</td>
</tr>
<tr>
<td></td>
<td>(0.03)</td>
<td>(0.02)</td>
<td>(0.02)</td>
</tr>
</tbody>
</table>

Note: Standard errors (obtained by Monte Carlo simulations using 1000 draws) into parenthesis. Significance is indicated by one asterisk (10–percent level) or two asterisks (5–percent level).

Figure 2 reports the impulse response functions of the real exchange rate and the trade balance

\(^2\)We also run Galí’s bivariate VAR model using the updated sample and found results similar to his.

\(^3\)However, as it will be emphasized below, openness may be play a crucial role in the interpretation of these stylized facts.
Figure 2: Impulse Response to a Technology Shock
(a) Hours in difference

(b) Linearly detrended hours

Note: The shaded area is the 95% confidence interval, obtained by Monte Carlo simulation using 1000 draws.
following a one standard deviation, technological shock. The real exchange rate depreciates on impact (the US traded goods become less expensive) while the trade balance follows a J–curve type of path. Namely, it deteriorates in the short run and then reverses course going back to its initial steady state level of zero. There is a positive conditional —on the technology shock— correlation between the real exchange rate and changes in productivity (0.33 in the difference case, and 0.25 in the linear trend case) and a negative correlation between productivity and the trade balance (-0.27 in the difference case, and -0.16 in the linear trend case). Table 2 reports the correlations between —changes in— output and the real exchange rate and the trade balance. The unconditional correlation between output and the real exchange rate is slightly negative (-0.19 under either detrending method) whereas it is positive (about 0.40) when only technological shocks are taken into account. Most of the negative unconditional correlation is therefore due to other shocks. The pattern is different for the trade balance where both the conditional and unconditional correlation are negative.

2 The model

This section develops an open economy model with the goal of accounting for the stylized facts described in the previous section. The models consists of two large countries. Each country is populated by a large number of identical agents and specializes in the production of a distinct, traded good. Asset markets are complete and there are no impediments to international transactions. Labor is not mobile.

2.1 Domestic Household

Household preferences are characterized by the lifetime utility function:

$$
\mathbb{E}_t \sum_{\tau=0}^{\infty} \beta^\tau U \left( C_{t+\tau}, \frac{M_{t+\tau}}{P_{t+\tau}}, \ell_{t+\tau} \right)
$$

where $0 < \beta^* < 1$ is a constant discount factor, $C$ denotes the domestic consumption bundle, $M/P$ is real balances and $\ell$ is the quantity of leisure enjoyed by the representative household. The utility function $U \left( C, \frac{M}{P}, \ell \right) : \mathbb{R}_+ \times \mathbb{R}_+ \times [0,1] \rightarrow \mathbb{R}$ is increasing and concave in its arguments.

The household is subject to the following time constraint

$$
\ell_t + h_t = 1
$$

where $h$ denotes hours worked. The total time endowment is normalized to unity.
The representative household faces a budget constraint of the form

\[
\int P^b(s) B_{t+1}(s) ds + M_t \leq B_t + P_t z_t K_t + W_t h_t + \Pi_t + M_{t-1} + N_t - P_t (C_t + I_t + T_t)
\]

where \(P^b(s)\) is the period \(t\) price of a contingent claim that pays one unit of the home currency in period \(t + 1\) if the particular state \(s\) occurs and 0 otherwise. \(B_{t+1}(s)\) is the number of contingent claims owned by the domestic household at the beginning of period \(t\); \(W_t\) is the nominal wage; \(P_t\) is the nominal price of the domestic final good; \(C_t\) is consumption and \(I_t\) is investment expenditure; \(K_t\) is the amount of physical capital owned by the household and leased to the firms at the real rental rate \(z_t\). \(M_{t-1}\) is the amount of money that the household brings into period \(t\), \(M_t\) is the end of period \(t\) money and \(N_t\) is a nominal lump-sum transfer received from the monetary authority; \(T_t\) is the real lump–sum taxes paid to the government and used to finance government consumption.

Capital accumulates according to the law of motion

\[
K_{t+1} = \Phi \left( \frac{I_t}{K_t} \right) K_t + (1 - \delta) K_t
\]

where \(\delta \in [0, 1]\) denotes the rate of depreciation. The concave function \(\Phi(\cdot)\) reflects the presence of adjustment costs to investment. It is assumed to be twice differentiable and homogeneous of degree 0. Furthermore, without loss of generality, we impose two assumptions that guarantee the absence of adjustment costs in the steady state: \(\Phi(\gamma + \delta - 1) = \gamma + \delta - 1\) and \(\Phi'(\gamma + \delta - 1) = 1\), where \(\gamma\) denotes the deterministic rate of growth of the economy. We will also assume that physical capital is not internationally mobile, that is, once it is in place it cannot be transported to the other country. Nonetheless, foreign goods can be indirectly used to augment the domestic capital stock through trade in intermediated goods.

The domestic household decides on its optimal plans by maximizing the utility function (1) subject to (2), (3) and (4).

It is useful for later purposes to report the labor supply decision

\[
u_\ell(c_t, M_t/P_t, \ell_t) = \frac{W_t}{P_t} u_c(c_t, M_t/P_t, \ell_t)
\]

where \(u_x(\cdot)\) denotes the partial derivative of \(u(\cdot)\) with respect to \(x\). Note that the labor supply depends on the real wage expressed in terms of the domestic final (consumption) good, \(W_t/P_t\).

The behavior of the foreign household is similar.\(^4\)

\(^4\)Note, however, that since contingent claims are denominated in terms of the domestic currency, the foreign
2.1.1 Final goods sector

The economy consists of two sectors. One produces final goods that are not traded. The other produces intermediate goods that are internationally traded.

The domestic final good, \( Y \), is produced by combining domestic \((X^d)\) and foreign \((X^f)\) intermediate goods. Final good production at home is described by

\[
Y_t = \left( \omega^{1-\rho} X_t^{d\rho} + (1 - \omega)^{1-\rho} X_t^{f\rho} \right)^{\frac{1}{\rho}}
\]

where \( \omega \in (0, 1) \) and \( \rho \in (-\infty, 1) \). \( X^d \) and \( X^f \) are themselves combinations of the domestic and foreign intermediate goods according to

\[
X_t^d = \left( \int_0^1 X_t^d(i)^{\theta} \, di \right)^{\frac{1}{\theta}} \quad \text{and} \quad X_t^f = \left( \int_0^1 X_t^f(i)^{\theta} \, di \right)^{\frac{1}{\theta}}
\]

where \( \theta \in (-\infty, 1) \). Note that \( \rho \) determines the elasticity of substitution between the foreign and the domestic bundle of goods, while \( \theta \) determines the elasticity of substitution between the goods in the domestic and foreign bundles. The producers of the final goods behave competitively and determine their demand for each intermediate good \( X_t^d(i) \) and \( X_t^f(i) \), \( i \in (0, 1) \) by maximizing the static profit equation

\[
\max_{\{X_t^d(i), X_t^f(i)\}_{i \in (0, 1)}} P_t Y_t - \int_0^1 P_{xt}(i) X_t^d(i) \, di - \int_0^1 e_t P_{xt}(i) X_t^f(i) \, di
\]

subject to (6), where \( P_{xt}(i) \) and \( P_{xt}^*(i) \) denote the price of each domestic and foreign intermediate good respectively, denominated in terms of the currency of the seller. \( e_t \) is the nominal exchange rate. This yields demand functions of the form:

\[
X_t^d(i) = \left( \frac{P_{xt}(i)}{P_{xt}} \right)^{\frac{1}{\rho-1}} \left( \frac{P_{xt}}{P_t} \right)^{\frac{1}{\rho-1}} \omega Y_t
\]

and

\[
X_t^f(i) = \left( \frac{e_t P_{xt}^*(i)}{e_t P_{xt}^*} \right)^{\frac{1}{\theta-1}} \left( \frac{e_t P_{xt}^*}{P_t} \right)^{\frac{1}{\theta-1}} (1 - \omega) Y_t
\]

and the following general price indexes

\[
P_{xt} = \left( \int_0^1 P_{xt}(i)^{\theta} \, di \right)^{\frac{\theta-1}{\theta}} \quad \text{and} \quad P_{xt}^* = \left( \int_0^1 P_{xt}^*(i)^{\theta} \, di \right)^{\frac{\theta-1}{\theta}}
\]

\[
P_t = \left( \omega P_{xt}^{\frac{\rho-1}{\rho}} + (1 - \omega)(e_t P_{xt}^*)^{\frac{\theta-1}{\theta}} \right)^{\frac{\rho}{\rho-1}}
\]

The household’s budget constraint takes the form

\[
\int P^k(s) \frac{B_{t+1}(s)}{e_t} + M_t^* \leq \frac{B_t(s)}{e_t} + M_{t-1}^* + N_t^* + \Pi_t^* + P_t^* W_t^* h_t^* + P_t^* z_t^* K_t^* - P_t^* (C_t^* + I_t^* + T_t^*)
\]

where \( \ast \) denotes the foreign economy and \( e_t \) is the nominal exchange rate.
The final good can be used for domestic private and public consumption as well as for investment purposes.

The behavior of the foreign final goods producers is similar.\footnote{Note that the general price index in the foreign economy is}

### 2.1.2 Intermediate goods producers

Each intermediate firm \( i, i \in (0,1) \), produces an intermediate good by means of capital and labor according to a constant returns-to-scale technology, represented by the production function

\[
X_t(i) \geq A_t K_t(i)^{\alpha} (\Gamma_t h_t(i))^{1-\alpha} \quad \text{with} \quad \alpha \in (0,1)
\]

where \( K_t(i) \) and \( h_t(i) \) respectively denote the physical capital and the labor input used by firm \( i \) in the production process.\footnote{We have also experimented with a version that allows for variable capital utilization. This modification does not matter for the ability of the model to match the conditional correlation of output and employment.} \( \Gamma_t \) represents Harrod neutral, deterministic, technical progress evolving according to \( \Gamma_t = \gamma \Gamma_{t-1} \), where \( \gamma \geq 1 \) is the deterministic rate of growth. \( A_t \) is an exogenous stationary stochastic technological shock, whose properties will be defined later. Assuming that each firm \( i \) operates under perfect competition in the input markets, the firm determines its production plan so as to minimize its total cost

\[
\min_{\{K_t(i), h_t(i)\}} W_t h_t(i) + P_t z_t K_t(i)
\]

subject to (12). This yields to the following expression for total costs:

\[
P_t C_{mt} X_t(i)
\]

where the real marginal cost, \( C_{mt} \), is given by \( \left( \frac{W_t}{P_t} \right)^{1-\alpha} \frac{\chi}{\alpha A_t \Gamma_t^{1-\alpha}} \) with \( \chi = \alpha^\alpha (1-\alpha)^{1-\alpha} \)

Intermediate goods producers are monopolistically competitive.\footnote{We assume imperfect competition so that the firms can have price setting power in the sticky price version of the model we solve.} The demand for labor is described by

\[
\theta(1-\alpha) \frac{X_t(i)}{h_t(i)} = \frac{W_t}{P_{xt}}
\]

It is worth noting that labor demand depends on the real wage expressed in terms of the intermediate rather than the final good. Hence, the relevant price for labor demand is different
from that for labor supply. This feature will prove very important for the ability of the flexible price version of the model to match the facts reported above. In particular, the labor market equilibrium is described by

\[
\frac{U_t(C_t, M_t/P_t, \ell_t)}{U_c(C_t, M_t/P_t, \ell_t)} = \theta(1 - \alpha) \frac{X_t(i)}{h_t(i)} \times \frac{P_{st}}{P_t}
\]

so, unlike the closed economy version of the model, the labor market equilibrium includes a terms of trade effect.

2.1.3 The monetary authorities

The behavior of the monetary authorities is similar to that postulated by Galí [1999]. Namely, the supply of money evolves according to the rule:

\[
M_t = g_{mt} M_{t-1}
\]

where \( g_{mt} > 1 \) is the gross rate of growth of nominal balances, which is assumed to follow an exogenous stochastic process. A similar process is assumed in the foreign country.

2.1.4 The government

The government finances government expenditure on the domestic final good using lump sum taxes. The stationary component of government expenditures is assumed to follow an exogenous stochastic process, whose properties will be defined later.

3 Calibration

The model is calibrated using post–WWII data for the US and Europe\(^9\). In setting the parameters, we draw heavily on previous calibration exercises by Backus, Kehoe and Kydland [1995], Cooley and Prescott [1995], Chari et al. [2003], Collard and Dellas [2002]. The parameters are reported in Table 3.

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\(^8\)While the monetary policy rule does not matter under flexible prices, it can make a big difference under fixed prices. Dotsey [1999] shows that a sufficiently procyclical monetary policy can induce a positive correlation between output and employment following a technology shock.

\(^9\)Europe consists of the five countries that are the main trade partners of the US: Belgium, France, Germany, the Netherlands and the UK. We also considered France and Germany separately. This pair actually represents a more favorable environment for the flexible price model because it contains very open economies and the estimated trade elasticities for Germany are close to zero.
As far as preferences are concerned, the instantaneous utility function takes the following form.

\[ U\left(C_t, M_t, \ell_t\right) = \frac{1}{1-\sigma} \left[ \left( C_t^\eta + \zeta M_t \frac{\eta}{\ell_t} \right)^{\frac{\nu \eta}{\ell_t^{1-\nu}}} - 1 \right] \]

The parameter ruling the elasticity of substitution between consumption and real balances, \( \eta \), and the weight assigned to real balances are borrowed from Chari et al. [2003] who estimated it from the money demand function. They find an interest rate elasticity of money demand of \(-0.39\) implying that \( \eta = -1.5641 \) and the estimated weight assigned to money in preferences implies that \( \zeta = 0.0638 \). \( \sigma \) is set to 2.5 in our study. We also ran the model assuming different values for \( \sigma \). The results are qualitatively the same, therefore we retained this value which is widely used in the literature. \( \nu \) is set such that the model generates a total fraction of time devoted to market activities of 31%. Finally the household is assumed to discount the future at a 4% annual rate, implying \( \beta = 0.988 \).

Table 3: Calibration

<table>
<thead>
<tr>
<th>Utility</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Discount factor</td>
<td>( \beta )</td>
</tr>
<tr>
<td>Relative risk aversion</td>
<td>( \sigma )</td>
</tr>
<tr>
<td>CES weight in utility function</td>
<td>( \nu )</td>
</tr>
<tr>
<td>Parameter of CES in utility function</td>
<td>( \eta )</td>
</tr>
<tr>
<td>Weight of money in the utility function</td>
<td>( \zeta )</td>
</tr>
<tr>
<td>Import share</td>
<td>( 1 - \omega )</td>
</tr>
<tr>
<td>Elasticity of substitution</td>
<td>( 1/(\rho - 1) )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technology</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate of growth</td>
<td>( \gamma )</td>
</tr>
<tr>
<td>Depreciation rate</td>
<td>( \delta )</td>
</tr>
<tr>
<td>Labor share</td>
<td>( wh/\text{py} )</td>
</tr>
<tr>
<td>Markup parameter</td>
<td>( \theta )</td>
</tr>
<tr>
<td>Capital adjustments costs (marginal elasticity)</td>
<td>( \varphi )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shocks</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Persistence of technology shock</td>
<td>( \rho_a )</td>
</tr>
<tr>
<td>Spillover of technology shock</td>
<td>( \rho_a^* )</td>
</tr>
<tr>
<td>Standard deviation of technology shock</td>
<td>( \sigma_a )</td>
</tr>
<tr>
<td>Correlation between foreign and domestic shocks</td>
<td>( \psi )</td>
</tr>
<tr>
<td>Persistence of government spending shock</td>
<td>( \rho_g )</td>
</tr>
<tr>
<td>Volatility of government spending shock</td>
<td>( \sigma_g )</td>
</tr>
<tr>
<td>Money supply gross rate of growth</td>
<td>( \mu )</td>
</tr>
<tr>
<td>Persistence of money supply shock</td>
<td>( \rho_m )</td>
</tr>
<tr>
<td>Volatility of money supply shock</td>
<td>( \sigma_m )</td>
</tr>
</tbody>
</table>
The rate of growth of the economy, $\gamma$, is calibrated such that the model reproduces the US rate of growth of real per capita output and the rate of population growth, respectively equal to 0.012 and 0.0156 on an annual basis. $\theta$ is set such that markups in the economy are 20%. $\alpha$, the elasticity of the production function to physical capital is set such that the labor share in the economy is $2/3$, which corresponds to the average labor share other the period. The technology shocks are specified as follows:

$$a_t = \log(A_t/A)$$

$$a^\star_t = \log(A^\star_t/A^\star)$$

are assumed to follow a stationary VAR(1) process of the form

$$\begin{pmatrix} a_t \\ a^\star_t \end{pmatrix} = \begin{pmatrix} \rho_a & \rho_a^\star \\ \rho_a^\star & \rho_a \end{pmatrix} \begin{pmatrix} a_{t-1} \\ a^\star_{t-1} \end{pmatrix} + \begin{pmatrix} \varepsilon_{a,t} \\ \varepsilon^\star_{a,t} \end{pmatrix}$$

with $|\rho_a + \rho_a^\star| < 1$ and $|\rho_a - \rho_a^\star| < 1$ for the sake of stationarity and

$$\begin{pmatrix} \varepsilon_{a,t} \\ \varepsilon^\star_{a,t} \end{pmatrix} \sim N\left( \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \sigma_a^2 \begin{pmatrix} 1 & \psi \\ \psi & 1 \end{pmatrix} \right)$$

We follow Backus et al. [1995] and set $\rho_a = 0.906$, $\rho_a^\star = 0.088$, $\sigma_a = 0.0085$ and $\psi = 0.258$.

The government spending shock is assumed to follow an AR(1) process

$$\log(g_t) = \rho_g \log(g_{t-1}) + (1 - \rho_g) \log(\bar{g}) + \varepsilon_{g,t}$$

with $|\rho_g| < 1$ and $\varepsilon_{g,t} \sim N(0, \sigma_g^2)$. $\rho_g$ and $\sigma_g$ are set at their empirical counterpart, namely, $\rho_g = 0.97$ and $\sigma_g = 0.02$.

Likewise, the money supply shock is assumed to follow an AR(1) process

$$\log(g_{mt}) = \rho_m \log(g_{mt-1}) + (1 - \rho_m) \log(\bar{g}_m) + \varepsilon_{m,t}$$

with $|\rho_m| < 1$ and $\varepsilon_{m,t} \sim N(0, \sigma_m^2)$. $\rho_m$ is set to 0.49, while $\sigma_g = 0.009$. The nominal growth of the economy, $\bar{g}_m$, is set equal to 6.8% per year.

$\omega$, the parameter representing the weight of domestic intermediate goods in the final good bundle is set so as to match the import share. Note that in our model economy, the whole world consists of only two countries so that bilateral and total trade coincide. We have used a common import share of 10%, implying a value of 0.90 for $\omega$. $\rho$ is related to the elasticity of substitution between domestic and foreign intermediate goods in the final good bundle and also determines the price elasticity of the import demand function. We consider two

---

10 While technology in Galí is an I(1) process, an I(1) specification cannot be used in an open economy, except under quite uninteresting circumstances. The reason is that if technology in each country has a country specific random walk component then it leads with probability one to a situation where one of the two economies becomes infinitely large relative to the other one. This can be prevented only if the shocks are perfectly correlated across countries or if preferences are logarithmic so that the ratio of incomes of the two countries is constant. In either case the real exchange rate is left unaffected by a technology shock.

11 We have also carried out the analysis with a higher import share (20%). With this value the results are even more favorable to the flexible price, low elasticity model. See 3 below.
alternative values for $\rho$. The first one, $\rho = 1/3$ (henceforth labelled the high elasticity case) corresponds to the value commonly used in the RBC literature (see e.g. Backus et al. [1995], Chari et al. [2003]). It implies an elasticity of substitution of 1.5 in the Armington aggregator, as reported in Whalley [1985]. There actually exists no consensus on this parameter and the literature reports a wide range of values for trade elasticities. In a recent study, Hooper, Johnson and Marquez [2000] estimate trade elasticities for the G7 countries. Their results suggest that the price channel plays a weak role in the determination of imports and exports. They report a short–run trade elasticity of 0.6 for the US, and values ranging between 0 and 0.6 for the other G7 countries. Earlier studies by Houthakker and Magee [1969] and Marquez [1990] also suggest trade elasticities between 0 and 1. In his study, Taylor [1993] estimates an import demand equation for the US and finds a short–run trade elasticity of 0.22 and a long–run trade elasticity of 0.39. All these estimates are consistent with the trade elasticity pessimism view that emerged originally in the 40s in the context of the Marshall–Lerner conditions but has remained the dominant view among trade economists since. We set $\rho$ such that the trade elasticity is close to the upper bound of these estimates. We assume that $\rho = -1$, implying a trade elasticity of 0.5.\footnote{Using the lower value suggested by Taylor strengthens the ability of the RBC model to match the conditional correlation of employment and output.}

We also set the parameters characterizing the capital accumulation process. We first set the depreciation rate, $\delta$, at 0.025, which amounts to a 10% annual depreciation of physical capital. Since capital adjustment costs are assumed to be zero in the steady state, we cannot determine the benchmark value for the capital adjustment cost parameter, $\varphi \equiv (i/k)\Phi''(i/k)/\Phi'(i/k)$ by using long–run averages. We therefore set $\varphi$ such that the model reproduces the relative standard deviation of HP–filtered investment ($\sigma_i/\sigma_y$) in the model with a low trade elasticity. This led to a value of -0.169.

For comparative purposes, we have also solved a fixed price version of the model. Price stickiness is modelled with Calvo price setting. The probability of price resetting in that version of the model was set equal to 0.25, which amounts to assume that —on average— firm reset their price every year.

4 The results

This section reports the results. We first evaluate the ability of the model to account for the basic stylized facts reported in Section 1. We then assess its ability to account for a broader set of stylized facts reported in the international business cycle literature.
4.1 Dynamic Properties

In the flexible price economy, the impact effect of a technology shock on employment depends mostly on three parameters: The marginal elasticity of capital with regard to investment (the capital adjustment cost parameter), the trade elasticity and the degree of openness. The first parameter is important because it determines the degree to which investment — and hence aggregate demand — responds to a technological shock. With a small increase in aggregate demand, a given capital stock and improved technology, labor may have to decrease.\(^\text{13}\)

The second parameter can also play a crucial role. When domestic and foreign goods are not good substitutes, a positive supply shock deteriorates the terms of trade for the economy that experiences the shock. The reduction in the relative price of the domestic good discourages output expansion. Therefore, as the mild expansion in output is accompanied with a higher level of total factor productivity, and because capital is predetermined, less labor may be needed. Hours worked can drop. Moreover, the greater the degree of trade openness (the larger the import share) the larger the potential role of this mechanism.

This intuition is summarized in Figure 3, which reports the loci of points for which the contemporaneous response of employment to a technology shock is zero \((dh/dA = 0)\) as a function of these parameters. Points below a curve correspond to \(dh/dA < 0\). We report two combinations. The first one, depicted in the left hand side panel, plots the size of capital adjustment costs required to get a negative response of hours worked for a given level of the elasticity of substitution between foreign and domestic goods. The figure makes it clear

\(^{13}\)An alternative way of limiting changes in aggregate demand is to use habit persistence.
that when foreign and domestic goods are substitutable, the level of capital adjustment costs required to get a negative response of hours is very high. In the case of an import share of 10%, a value of $\varphi = -0.6$ is needed which is much higher than that assumed in the benchmark calibration (-0.169). When goods are highly substitutable, the terms of trade are less responsive to shocks, and hence they cannot act as a major barrier to output expansion. Therefore, a drop in hours can only occur when demand is very unresponsive, which is achieved by having very large capital adjustment costs. Since the volatility of the terms of trade is decreasing in the degree of openness, the required capital adjustment costs tend to increase ($\varphi$ becomes more negative) as the import share increases. An unsatisfactory implication of such a high level of capital adjustment costs is that the model generates a relative standard deviation of investment that is close to zero. Conversely, when the trade elasticity is low, say 0.5, then the required level of capital adjustment costs is low (-0.145) and consistent with that in the data (at least as far as investment volatility is concerned).

The second panel in the right hand side of the figure plots again the combination of the elasticity of substitution between foreign and domestic goods, the degree of openness and the capital adjustment costs parameter that is required for a negative response of hours to a positive technological shock. Again, points below a curve correspond to $dh/dA < 0$. The figure suggests that such a response is not too difficult to get if it is costly to adjust capital, domestic and foreign goods are not good substitutes and the degree of openness is sufficiently — but not unrealistically — high. As expected, a low degree of substitutability can support a negative response of hours even when capital adjustment costs are mild. The figure also illustrates that when capital adjustment costs are large enough — i.e. when aggregate demand is less responsive — a negative response of hours worked may obtain even in situations where foreign and domestic goods are good substitutes. Note however that, as discussed above, this obtains at the price of having excessively smooth investment.

Table 4 and Figure 4–6 report the impact and dynamic effects of technological shocks in the flexible economies under the two alternative values of the trade elasticity: High, -1.5 and low -0.5. The signs of the impact effects and the dynamics of the main macroeconomic variables are as predicted by theory.

The main difference across the two trade elasticity values regards the response of hours. It is negative when the elasticity is low and positive when it is high. In Figure 5, we compare

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14 Note that beyond a certain threshold, the phenomenon reverses.
15 Figures reporting the impulse response functions to the other shocks are reproduced in the appendix.
16 Under the same calibration, a sticky price version of the model with Calvo type contracts gives a negative and considerably larger effect: -1.26 as compared to -0.06 in the flexible price case. However, it also predicts negative response of output to a technology shock. The complete results from the sticky price version are available from the authors.
Table 4: Elasticities (Flexible Prices, Low Elasticity)

<table>
<thead>
<tr>
<th></th>
<th>$\epsilon_a$</th>
<th>$\epsilon_a^*$</th>
<th>$\epsilon_g$</th>
<th>$\epsilon_g^*$</th>
<th>$\epsilon_m$</th>
<th>$\epsilon_m^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low Elasticity Case</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>0.971</td>
<td>-0.045</td>
<td>0.162</td>
<td>-0.026</td>
<td>-0.024</td>
<td>0.001</td>
</tr>
<tr>
<td>$h$</td>
<td>-0.019</td>
<td>-0.074</td>
<td>0.158</td>
<td>0.012</td>
<td>-0.027</td>
<td>-0.001</td>
</tr>
<tr>
<td>W</td>
<td>0.875</td>
<td>0.144</td>
<td>-0.013</td>
<td>-0.021</td>
<td>0.006</td>
<td>-0.000</td>
</tr>
<tr>
<td>$\pi$</td>
<td>-0.953</td>
<td>-0.072</td>
<td>0.112</td>
<td>0.030</td>
<td>1.820</td>
<td>-0.001</td>
</tr>
<tr>
<td>$e$</td>
<td>0.148</td>
<td>-0.148</td>
<td>-0.070</td>
<td>0.070</td>
<td>1.818</td>
<td>-1.818</td>
</tr>
<tr>
<td>RER</td>
<td>1.030</td>
<td>-1.030</td>
<td>-0.151</td>
<td>0.151</td>
<td>-0.003</td>
<td>0.003</td>
</tr>
<tr>
<td>ToT</td>
<td>1.287</td>
<td>-1.287</td>
<td>-0.189</td>
<td>0.189</td>
<td>-0.004</td>
<td>0.004</td>
</tr>
<tr>
<td>TB</td>
<td>-0.143</td>
<td>0.143</td>
<td>0.358</td>
<td>-0.358</td>
<td>-0.021</td>
<td>0.021</td>
</tr>
<tr>
<td><strong>High Elasticity Case</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>0.903</td>
<td>0.023</td>
<td>0.166</td>
<td>-0.030</td>
<td>-0.023</td>
<td>0.001</td>
</tr>
<tr>
<td>$h$</td>
<td>0.099</td>
<td>-0.192</td>
<td>0.137</td>
<td>0.033</td>
<td>-0.027</td>
<td>-0.001</td>
</tr>
<tr>
<td>W</td>
<td>0.882</td>
<td>0.136</td>
<td>-0.014</td>
<td>-0.020</td>
<td>0.006</td>
<td>-0.000</td>
</tr>
<tr>
<td>$\pi$</td>
<td>-0.865</td>
<td>-0.160</td>
<td>0.100</td>
<td>0.041</td>
<td>1.820</td>
<td>-0.001</td>
</tr>
<tr>
<td>$e$</td>
<td>0.077</td>
<td>-0.077</td>
<td>-0.050</td>
<td>0.050</td>
<td>1.818</td>
<td>-1.818</td>
</tr>
<tr>
<td>RER</td>
<td>0.783</td>
<td>-0.783</td>
<td>-0.109</td>
<td>0.109</td>
<td>-0.003</td>
<td>0.003</td>
</tr>
<tr>
<td>ToT</td>
<td>0.979</td>
<td>-0.979</td>
<td>-0.137</td>
<td>0.137</td>
<td>-0.003</td>
<td>0.003</td>
</tr>
<tr>
<td>TB</td>
<td>-1.762</td>
<td>1.762</td>
<td>0.566</td>
<td>-0.566</td>
<td>-0.016</td>
<td>0.016</td>
</tr>
</tbody>
</table>

Note: $\epsilon_j$, $j = a, m, g$ denote respectively the supply, money and fiscal shock respectively. A star denotes the foreign country. $e$, RER, ToT and TB respectively denote the nominal exchange rate, the real exchange rate, the terms of trade and the trade balance.

Figure 4: IRF to a positive technological shock: Domestic Variables
the model predicted IRFs of output, hours and productivity to their empirical counterparts. The shaded area corresponds to the 95% confidence interval.\footnote{The empirical IRFs are obtained from the VAR specification with linearly detrended hours worked. This avoids the criticism of Christiano et al. [2004] that hours should not be differenced.}

Figure 5: Impulse Response Function to a 1 s.d. technological shock

The middle panel of the figure shows that the model with a low trade elasticity can statistically account for the empirical IRF of hours with regard of a technology shock. The theoretical IRF lies within the 95% confidence interval. However, output is excessively responsive, as the impact effect of the technological shock is above the upper limit of the confidence interval. As a result, the model fails to statistically account for the very short–run dynamics of labor productivity.

Turning to correlations one can see how well the low trade elasticity version of the flexible price model performs in terms of conditional correlations. In Table 5, we report the correlation between changes in hours and changes in productivity, both unconditional and conditional. The low trade elasticity version of the model generates an unconditional correlation of -0.10, when the data indicate that this correlation is -0.25. Likewise, the correlation conditional on technology shocks is -0.42 in the model while that in the data is about -0.70 or -0.81, depending on the way hours worked are made stationary. The model also does a good job in accounting for the correlation conditional on the other shocks. It is slightly negative in the data (about -0.1) while the model generates zero correlation. In this respect, a sticky price version of the model would outperform qualitatively the flexible price version, but it would do much worse quantitatively as it generates a correlation of -0.96. Note also that because the model fails to account for the hump–shaped pattern of actual output it cannot generate the low conditional correlation between changes in hours and changes in output observed
(0.05 or -0.12 in the data versus -0.34 in the model).\textsuperscript{18}

Table 5: Conditional Correlations

<table>
<thead>
<tr>
<th>Corr(\cdot, \Delta y/h)</th>
<th>Corr(\cdot, \Delta y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>\Delta h RER NX</td>
<td>\Delta h RER NX</td>
</tr>
<tr>
<td>All</td>
<td>-0.094 0.110 0.035</td>
</tr>
<tr>
<td>Flexible, low elasticity</td>
<td></td>
</tr>
<tr>
<td>Techno.</td>
<td>-0.415 0.153 0.013</td>
</tr>
<tr>
<td>Other</td>
<td>0.029 -0.154 0.150</td>
</tr>
<tr>
<td>Flexible, high elasticity</td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>0.048 0.060 -0.013</td>
</tr>
<tr>
<td>Flexible, high elasticity</td>
<td></td>
</tr>
<tr>
<td>Techno.</td>
<td>0.042 0.106 -0.093</td>
</tr>
<tr>
<td>Other</td>
<td>0.189 -0.177 0.174</td>
</tr>
</tbody>
</table>

We now turn to the behavior of the real exchange rate and the trade balance (see Figure 6). As shown by Backus et al. [1992], the properties of the open economy variables are quite sensitive to the size of the trade elasticity. Our model is quite similar to theirs, so it has similar properties. In particular, we face the trade off noted by Backus et al. [1992]: A lower elasticity of substitution between foreign and domestic goods amplifies the response of the nominal and real exchange rates and of the terms of trade, but dampens that of the trade balance. We see that in the low trade elasticity, the impact effect of a positive technology shock on the real exchange rate is 30% larger than that in the high trade elasticity (1.03 versus 0.78). But the impact effect of a unit, positive, technology shock on the trade balance is only -0.14 in the low trade case as compared with -1.77 in the high trade elasticity case. The intuition for these findings is that offered by Backus et al. [1992]. Hence, this model (as well as its sticky price version) does not escape the price anomaly.

As shown in Figure 7, the model has no difficulty accounting for the dynamics of the real exchange rate following a positive technological shock, irrespective of the value of the trade elasticity. The IRF generated by the model lies within the 95% confidence band. But it is less successful in capturing the short–run dynamics of the trade balance. In particular, while it does a good qualitative job (it predicts a worsening of the trade balance) it cannot generate a large enough response on impact. Note that the high trade elasticity version of the model does better in this regard.\textsuperscript{19}

These findings also show up in the correlation coefficients. The model cannot fully account for

\textsuperscript{18}The sticky price version of the model gives a positive conditional correlation of 0.11.
\textsuperscript{19}The sticky price version of the model fails too to account for the dynamics of trade balance since it also exhibits the price anomaly.
Figure 6: IRF to a positive technological shock: International variables

Nominal Exchange Rate

Real Exchange Rate

Terms of Trade

Trade Balance

Figure 7: Impulse Response Function to a 1 s.d. technological shock
the conditional correlation between the real exchange rate and changes in productivity. This correlation is about 0.33 in the data but 0.15 in the model. It is, however, worth noting that the low trade elasticity version of the model outperforms the high trade elasticity version, where the correlation is even lower (0.10). Likewise the correlation between the real exchange rate and changes in output is underestimated by the model (0.16 versus 0.40 in the data). The same difficulties obtain regarding the trade balance. The conditional correlation is all versions of the model is about zero while that in the data is -0.2. 20

4.2 Business Cycle Properties

The previous section has demonstrated that the standard, flexible price model can reproduce the negative conditional correlation between hours and productivity as long as one is prepared to accept low trade elasticities. It also showed that it has good qualitative properties as far as the real exchange rate and to a lesser extend the trade balance are concerned. Following a technology shock, both of them move in the right direction. In this section we investigate whether this success carries a cost in terms of overall model fit. In particular, we examine its ability to account for the broader set of stylized fact typically considered in the literature. In contrast to the previous section, and in order to adhere to the common practice in the international business cycle literature we consider moments of HP–filtered series.

Tables 6 and 7 report the findings. All standard deviations — except that of output — are expressed in relative terms (with regard to that of output). No clear, overall winner emerges from the comparison of the low elasticity, flexible price model with the two standard models in the literature, the high elasticity flexible and fixed price models. The model with a low trade elasticity tends to under–predict the standard deviation of hours worked, while it generates too much volatility in labor productivity and too low a correlation between hours and output. The fixed price version gives a correlation of 0.88 but it overestimates the relative standard deviation of hours and also fails to account for the positive correlation between output and productivity (-0.33).

The lower part of table 6 confirms the patterns documented by Backus et al. [1995]. A lower trade elasticity enhances the ability of the model to account for relative price volatility but this comes at the expense of lower volatility for net exports. All three versions exhibit the price anomaly and also underestimate the volatility of net exports.

A similar conclusion emerges from the evaluation of the models in terms of cross country

20The conditional correlations between the real exchange rate and changes in productivity and output in the sticky price version of the model are -0.01 and 0.10 respectively. And -0.21 and -0.13 for the trade balance.
Table 6: Second order moments

<table>
<thead>
<tr>
<th></th>
<th>Data</th>
<th>Flexible prices (Low elasticity)</th>
<th>Flexible prices (High elasticity)</th>
<th>Fixed prices (High elasticity)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>1.62</td>
<td>1.00</td>
<td>1.04</td>
<td>1.00</td>
</tr>
<tr>
<td>C</td>
<td>0.83</td>
<td>0.87</td>
<td>0.93</td>
<td>0.78</td>
</tr>
<tr>
<td>I</td>
<td>2.73</td>
<td>0.94</td>
<td>2.73</td>
<td>0.84</td>
</tr>
<tr>
<td>h</td>
<td>0.90</td>
<td>0.89</td>
<td>0.36</td>
<td>0.17</td>
</tr>
<tr>
<td>y/h</td>
<td>0.46</td>
<td>0.44</td>
<td>1.01</td>
<td>0.93</td>
</tr>
<tr>
<td>π</td>
<td>0.35</td>
<td>0.38</td>
<td>1.67</td>
<td>-0.16</td>
</tr>
</tbody>
</table>

Open economy dimension

<table>
<thead>
<tr>
<th></th>
<th>e</th>
<th>RER</th>
<th>ToT</th>
<th>NX</th>
</tr>
</thead>
<tbody>
<tr>
<td>e</td>
<td>4.54</td>
<td>0.07</td>
<td>2.90</td>
<td>0.02</td>
</tr>
<tr>
<td>RER</td>
<td>4.08</td>
<td>0.07</td>
<td>1.01</td>
<td>0.35</td>
</tr>
<tr>
<td>ToT</td>
<td>–</td>
<td>–</td>
<td>1.68</td>
<td>0.35</td>
</tr>
<tr>
<td>NX</td>
<td>5.20</td>
<td>-0.36</td>
<td>1.19</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Note: All standard deviations (except output) are relative to the standard deviation of output. The moments are derived from HP–filtered data. e is the nominal exchange rate, RER is the real exchange rate and ToT denotes the terms of trade (import price/export price). NX is a measure of the trade balance computed as the log of the ratio of exports to imports. The variables are from the OECD quarterly National Accounts, and the sample runs from 1970:1 to 1999:3.

Table 7: Cross-Country Correlations

<table>
<thead>
<tr>
<th></th>
<th>Data</th>
<th>Flexible prices (Low elasticity)</th>
<th>Flexible prices (High elasticity)</th>
<th>Fixed prices (High elasticity)</th>
</tr>
</thead>
<tbody>
<tr>
<td>y,y*</td>
<td>0.61</td>
<td>0.22</td>
<td>0.31</td>
<td>0.32</td>
</tr>
<tr>
<td>c,c*</td>
<td>0.43</td>
<td>0.77</td>
<td>0.82</td>
<td>0.41</td>
</tr>
<tr>
<td>h,h*</td>
<td>0.39</td>
<td>0.37</td>
<td>0.28</td>
<td>0.20</td>
</tr>
<tr>
<td>rer,nx</td>
<td>0.16</td>
<td>-0.50</td>
<td>-0.90</td>
<td>-0.83</td>
</tr>
</tbody>
</table>
correlations. All versions exhibit the quantity anomaly (they predict higher correlations for consumption than for output), but the model with fixed price less so. This finding is common to much of the literature, and unless the model is modified to allow for lower international risk sharing, non-traded goods and so on, the flexible price model cannot account for this stylized facts. The strength of the low trade elasticity, flexible price model is found in its better matching of the cross–country correlation in hours worked. Note also that all models fail to account for the positive, although weak, correlation between net exports and the real exchange rate (another widespread weakness in the literature). The flexible price, low elasticity model does relatively better regarding this fact but still not well enough.

Before concluding this section let us briefly comment on the role played by the other parameters of the model. The parameters whose values have some quantitative influence on the conditional correlation between employment and output, are: The intertemporal elasticity of substitution, the mark up and the depreciation rate. In general, the ability of the flexible price model to match the conditional correlation between employment and output is enhanced by smaller intertemporal substitution (because of the smaller wealth effect on the supply of labor) and higher values for the markup (because of the higher ”tax” on labor demand, to use the terminology of King and Goodfriend) and the depreciation rate (because of the lower return on investment and hence less responsive investment and aggregate demand). Labor indivisibility and variable capital utilization, on the other hand, were not found to have a quantitatively significant effect on this conditional correlation.

**Summary and conclusions**

The empirical evidence indicates that in response to an –empirically identified– positive technology shock, labor productivity rises more than output while employment shows a persistent decline. Technology shocks are almost synonymous with the RBC model, yet the standard RBC model does not seem capable of accounting for this important stylized fact. This finding has led many to doubt not only the relevance of the RBC model. Moreover, as the standard Keynesian model with imperfect competition and sticky prices typically generates a short run decline in employment in response to a positive technology shock, this stylized fact has provided support for models with nominal frictions.

In this paper we have argued that the standard RBC model can plausibly generate a negative, conditional correlation between productivity and employment if the model allows for international trade. If trade elasticities fall below unity — a quite realistic case — then the flexible price model can match this correlation satisfactorily. Moreover, under these circum-
stances, it can also broadly account for the observed response of the real exchange rate to a technological shock.

Our conclusion is that it may be premature to claim that there is unreconcilable contradiction between the observation of a countercyclical employment response to a supply shock and the belief that prices are flexible. It must be acknowledged, though, that there exists at present no model (with fixed or flexible prices) that can fully account for the empirical patterns discussed in section 1 (the Galí facts as well as their open economy extensions) and also for the stylized facts presented in section 4. The present paper has identified and highlighted the limits of existing models and may thus offer the basis for building models with better properties.

References


A IRF to a Domestic Fiscal Shock

Figure 8: Domestic Variables

- Output
- Hours
- Productivity

Figure 9: International Variables

- Nominal Exchange Rate
- Real Exchange Rate

- Terms of Trade
- Trade Balance
B  IRF to a Domestic Money Supply Shock

Figure 10: Domestic Variables

- Output
- Hours
- Productivity

Figure 11: International Variables

- Nominal Exchange Rate
- Real Exchange Rate
- Terms of Trade
- Trade Balance