International business cycles and the relative price of investment goods*

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Abstract

Is the relative price of investment goods a good proxy for investment specific technology? We model this relative price in a flexible price international economy with two fundamental shocks, namely the total factor productivity (TFP) shock and the investment specific technology (IST) shock. We show that the one-to-one correspondence between the IST shock and the relative price of investment goods breaks down in an international economy because of the short run correlation between the terms of trade and the relative price of investment goods. The data congruent negative correlation between the investment rate and the relative price of investment goods thus does not necessarily reflect decline in investment frictions (rise in IST) as suggested by many studies. A calibration experiment with the US data demonstrates that such an inverse relation between rate of investment and the relative price of investment goods basically reflects the positive effect of TFP on the terms of trade for a broad range of economies where the home bias in consumption exceeds investment and there is a sizable adjustment cost of investment.

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1 Introduction

The relative price of investment goods with respect to consumption goods has shown a remarkable decline during the 80s in the United States. At the same time, there has been a pronounced increase in the investment rate since the early 1990s (see Figure 1). A number of papers interpret this decline in the relative price of investment goods as evidence of a decline in capital market frictions. Greenwood et al (2000) use the relative price of equipment as a driver of investment specific technological (IST) change in their calibrated model. Chari, Kehoe and McGrattan (2005) similarly interpret investment friction as simply a tax on investment which raises its price relative to consumption. Fisher (2006) derives a long run identifying restriction that a positive IST shock means a concomitant negative shock to the real price of investment.

Recent empirical evidence by Justianiano, Primiceri and Tambalotti (JPT) (2009), Schmidt-Grohe and Uribe (2008) and Liu, Waggoner and Zha (2009) suggests that when identified by the relative price of investment goods, IST shocks play only a minor role in explaining US business cycles. JPT point out that linking IST shocks to the relative price of investment goods can be misleading if investment goods are produced in a non-competitive setting. In that case, the relative price depends on both the IST shock and the time varying mark-up.

The aim of our work is to show that identifying IST shocks with the relative price of investment goods is potentially not robust in an open economy setting. We argue that as soon as one extends the model to an open economy, the relative price of investment goods can become a misleading indicator of investment specific technological progress. To demonstrate this point, an international real business cycle model similar to Heathcote and Perri (2002) is set up, where final consumption and investment goods are produced with a combination of foreign and home-produced intermediate goods. The model is driven by shocks to total factor productivity located in the intermediate-goods producing sector and IST shocks located in the final investment goods producing sector. In this economy, the relative price of investment goods depends inversely on the IST shock *and* on the terms of trade, defined as the relative price of imports to exports. The link between the relative price of investment goods and the terms of trade depends on the degree of home bias in the final consumption good relative to that in the final investment good.

A consequence of the terms of trade affecting the relative price of investment goods is that one can no longer uniquely associate IST shocks with a negative correlation between the relative price of investment goods and the investment rate. Furthermore, we show that in our model, for a broad range of plausible parameter values, TFP shocks alone can generate a negative correlation between the relative price of investment goods and the investment rate, a co-movement usually associated with the presence of IST shocks.

The conclusion we draw from our analysis is that identifying IST shocks with the relative price of investment goods is not necessarily robust in an open economy environment.

The remainder of this paper is structured as follows. Section 2 describes the basic intuition of the elaborate model laid out later. Section 3 presents some stylized facts. Section 4 describes the dynamic model. and Section 5 describes the baseline calibration. Sections 6 and 7 analyze the dynamics of the model using impulse response analysis and second moments. Section 8 reports on a number of robustness checks. Finally, Section 9 concludes.

2 Basic Intuition

It is easy to see how the terms of trade can break the link between IST shock and the relative price of investment goods. Consider a simple environment where home final and investment goods are produced with the help of home and foreign produced intermediate goods. In other words, we have the two following CES aggregators for the home final consumption goods (C_t) and home final investment goods (x_t):

$$C_t = \left[v^{\frac{1}{\theta}} c_{Ht}^{\frac{\theta-1}{\theta}} + (1-v)^{\frac{1}{\theta}} c_{Ft}^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} \tag{1}$$

$$x_t = \varepsilon_t \left[\psi^{\frac{1}{\tau}} x_{H,t}^{\frac{\tau-1}{\tau}} + (1-\psi)^{\frac{1}{\tau}} x_{F,t}^{\frac{\tau-1}{\tau}} \right]^{\frac{\tau}{\tau-1}}. \tag{2}$$

where c_H and c_F are home and foreign-produced intermediate goods used to produce final consumption goods and x_H and x_F are the home and foreign-produced intermediate goods used to produce final investment goods. θ and τ are the elasticities of intratemporal substitution between home and foreign-produced intermediate goods in consumption and investment goods industries, v and ψ are the respective home biases, and finally, ε_t is an investment specific technological (IST) shock. This shock directly affects the amount of final investment goods that are produced from a given amount of intermediate goods. A rise in ε_t directly increases the quantity of final investment goods available in the economy. For the market in investment goods to clear, the relative price of investment goods must decline. An alternative location of the IST shock is inside the capital or investment adjustment cost function. JPT (2009) call this a marginal efficiency of investment shock. In this case a positive shock raises the amount of capital accumulation for a given amount of investment. As in our specification, a positive shock also requires the relative price of investment goods to decline to clear the market for final investment goods. Introducing the IST shock directly into equation (2) has the advantage of allowing us to establish a simple link between the relative price of investment goods and the terms of trade without laying out the basic dynamics.

Profit maximization by the producers of final consumption and final investment goods yields the following price aggregators for final consumption and investment:

$$P_t^{1-\theta} = [vP_{Ht}^{1-\theta} + (1-v)P_{Ft}^{1-\theta}] \tag{3}$$

$$P_{x,t}^{1-\tau} = \varepsilon_t^{\tau-1}\left[\psi P_{H,t}^{1-\tau} + (1-\psi)P_{F,t}^{1-\tau}\right] \tag{4}$$

The price of investment goods relative to the price of consumption goods, $\frac{P_{x,t}}{P_t}$ can be written as a log-linear approximation of the price index

$$\frac{P_{x,t}}{P_t} = \frac{P_{x,t}}{P_{H,t}}\frac{P_{H,t}}{P_t} \tag{5}$$

around its steady state value making use of the investment and consumption goods price indices.[1]

$$\begin{aligned}
\widehat{\frac{P_{x,t}}{P_t}} &= \widehat{\frac{P_{x,t}}{P_{H,t}}} + \widehat{\frac{P_{H,t}}{P_t}} \\
&= (1-\psi)\widehat{\frac{P_{F,t}}{P_{H,t}}} - \hat{\varepsilon}_t + (v-1)\widehat{\frac{P_{F,t}}{P_{H,t}}} \\
&= (1-\psi)\hat{T}_t - \hat{\varepsilon}_t + (v-1)\hat{T}_t \\
&= (v-\psi)\hat{T}_t - \hat{\varepsilon}_t
\end{aligned} \tag{6}$$

[1] We make use of the consumption and investment goods price indices and normalise the price of home-produced traded goods such that in the steady state $P_H = P_F$. Because the law of one price is assumed to hold, we can define the terms of trade as $T = P_F/P_H$

This shows that the log-deviation, denoted by a "^", of the price of investment goods from its steady state value is a linear function of both the IST shock and the log-deviation of the terms of trade from its steady state value.

The link between the relative price of investment goods and the terms of trade is a function of the degree of home bias in consumption relative to that in investment. If home-bias for consumption goods is stronger than for consumption goods ($v > \psi$) then the price of investment goods is positively related to the terms of trade, for a given IST shock. Assume the terms of trade, $\frac{P_{F,t}}{P_{H,t}}$ depreciate (rise), say due to a fall in the price of home-produced intermediate goods. If there is more home bias in consumption than investment, then there is a relative shortage of investment goods with respect to consumption goods basket. This means that the relative price of investment to consumption goods increases. This clearly shows that the value of $(v - \psi)$ is crucial for our results. It is crucial to note that in an international economy the terms of trade is endogenous and depends on economic fundamentals which includes the IST shock. The bottomline here is that changes in terms of trade driven by these fundamentals can break the close link between IST and the relative price of investment goods.

The relative price of investment goods uniquely identifies the IST shock if (i) the economy is closed, i.e. if the share of home produced intermediate goods in final consumption and investment is unity: $v = \psi = 1$, or (ii) if home-bias in consumption is the same as in investment, when the final investment and consumption goods are essentially the same product. When $v \neq \psi$, the relative price of investment goods is affected by all factors that cause the terms of trade to deviate from its steady state value.

An alternative way of breaking the link between the relative price of investment goods and an IST shocks is put forward by Justiniano et al. (2009) who show that sticky prices will further weaken the link between relative price of investment goods and investment specific technology shocks. For example, if consumption and investment goods producers set prices with a time varying mark-up over their marginal costs, then an additional term (which is the changes in the relative markups) will be added to (6). The aim of our paper is to highlight the open economy dimension of the problem.

3 Stylized Facts

Our basic story in this paper is that in an international setting, the terms of trade can break the link between relative price of investment goods and the IST shocks as long as home bias in consumption differs from home bias in investment. To motivate our analysis, we establish two sets of stylized facts for major OECD countries: (i) the home bias in consumption is systematically different than in investment; (ii) the relative price of investment goods is not independent of the terms of trade.

3.1 Home bias in consumption and investment

We use the stylized facts documented by Burstein, Neves and Rebelo (2004), Burstein, Eichenbaum and Rebelo (2005) as well as Claus and Li (2003). Using industry level input-output tables, Burstein et al. (2004, 2005) construct two measures of import content of consumption and investment goods. These measures are (i) direct import content which is the fraction of imported final consumption or investment goods (excluding distribution service) in total consumption or investment, (ii) total important content which is (i) plus the value of intermediate inputs to produce final consumption or investment goods as a fraction of total consumption or investment. The difference between (ii) and (i) comes closest to the import content of consumption or investment in our model. Tables 1 and 2 report the import content of consumption and investment goods respectively for overlapping countries in the studies of Burstein et al. Based on all three measures, one finds that the import content of investment goods exceeds the import content of consumption in all economies analysed.

Similar facts are established by Claus and Li (2003) who also use input-output tables to construct these home bias measures as Burstein et al. Tables 3 reports their findings.

Table 1: Import Content of Consumption Goods

	US	UK	Italy	Finland	Argentina	Mexico	Korea
Total Import content	9.1	20.9	16.2	24.0	10.5	10.9	20.6
Direct Import Content	4.7	12	6.6	13.1	4.3	4.7	6.6
Total minus Direct	4.4	8.9	9.6	10.9	6.2	6.2	14

Source: Burstein, et al (2005, JPE)

Both these studies provide robust evidence that home bias in consumption is higher than in

Table 2: Import Content of Investment Goods

	US	UK	Italy	Finland	Argentina	Mexico	Korea
Total Import content	18.4	35.1	21.8	34.2	22.6	26.2	27.5
Direct Import Content	10.4	2.4	10.2	16.7	14.7	15.9	12.4
Total minus Direct	8	11.1	11.6	17.5	7.9	10.3	15.1

Source: Burstein, et al (2004, JEEA)

Table 3: Consumption and Investment home bias II

	Australia	Belgium	Denmark	Germany	NZ	Norway	UK
Import content of							
Consumption	13.3	20.1	13.9	12.9	18.7	20.3	19.0
Investment	25.0	41.7	25.2	17.3	36.7	43.0	32.3

Source: Claus and Li (2003)

investment for major OECD countries.[2]

3.2 Terms of Trade and the Relative Price of Investment Goods

If one takes the reduced form relationship (6) seriously, one expects to see a relationship between relative price of investment and the terms of trade. How important is this link between the terms of trade and the relative price of investment goods empirically? To address this question, we compute the correlation between these two variables for 10 major OECD countries for which a reasonably long series for the terms of trade and relative price of investment goods are available. The relative price of investment is computed by taking the ratio of the price index of gross capital formation to the CPI. The terms of trade is the ratio of the import to export prices. Both relative prices are log- detrended to make it comparable to the log-linearized deviations from the steady state. Table 4 presents the correlations between these detrended terms of trade and the relative price of investment goods.

For majority of these countries this correlation is significant. Seven countries show positive correlations. In principle, both terms of trade and the relative price of investment are endogenously determined by economic fundamentals such as shocks to investment and production technologies.

[2] Burstein et al. (2005) also exploit this stylized fact to answer the puzzle why the devaluation pass through to the CPI is weak for many countries.

Table 4: Correlation between log detrended trerms of trade and the relative price of investment goods

US	UK	Italy	France	Sweden	Netherlands	Australia	Korea	Canada	NZ
0.75*	0.67*	0.71*	0.22**	0.26**	0.27**	-.02	.06	-.72*	-.45*

Data sources: OECD, DNBSA Deflator, seasonally adjusted. $\frac{P_{x,t}}{P_t} = \frac{P51\text{:gross fixed cap form.}}{P3\text{: final consumption exp.}}$, $\frac{P_F}{P_H} = \frac{P7\text{: imports}}{P8\text{:exports}}$

* significant at the 5% level. ** at the 12% level. Sample periods: US, UK and Aus 1960:1-2008:4; Italy 1981:1 - 2008:3; France 1978:1 - 2008:4; Sweden 1980:1 - 2008:3; NL 1988:1 - 2008:3; Kor 1970A1-2008Q3; Canada: 1961Q1-2008Q3 NZ: 1987Q2-2008Q3.

Thus the sign of this correlation does not say much about the magnitude of relative home bias. However the fact that there is a discernible relationship between terms of trade and relative price of investment goods motivates us to undertake a serious dynamic analysis how economic fundamentals can give rise to a co-movement between two relative prices. In the next section, we lay out a stochastic dynamic general equilibrium model to understand these linkages.

4 The model

Motivated by the stylized facts reported in the previous section, we set up a two-country, international real business cycle model where the terms of trade are endogenous and investment and consumption goods differ in terms of their import content.

Specifically, we propose an international real business cycle model with incomplete financial markets where each country produces one tradable intermediate good that forms part of the home as well as the foreign consumption and investment goods baskets. Examples of this kind of model are Heathcote and Perri (2002), Backus et al (1994) and Thoenissen (2010). This model is modified to incorporate some recent features put forward by Smets and Wouters (2003) and Christiano, Eichenbaum and Evans (2005). Specifically, investment adjustment costs and external habit formation in consumption are included. The dynamics of the model are driven by home and foreign shocks to total factor productivity (TFP) as well as investment specific technology (IST) shocks.

4.1 Consumer behavior

The world economy is populated by a continuum of agents on the interval $[0, 1]$. The population on the segment $[0, n)$ belongs to the country H (Home), while the segment $[n, 1]$ belongs to F

(Foreign). Preferences for a generic Home-consumer are described by the following utility function:

$$U_t^j = \mathrm{E}_t \sum_{s=t}^{\infty} \beta^{s-t} (u(C_s^j - \gamma C_{s-1}), z(1-h_s^j)) \tag{7}$$

where E_t denotes the expectation conditional on the information set at date t, while β is the intertemporal discount factor, with $0 < \beta < 1$. The Home consumer obtains utility from current consumption, C_s^j adjusted by the previous period's aggregate level of consumption and receives dis-utility from supplying labour, h^j.

We have a choice as to how to model the international asset market, either by assuming a complete or an incomplete asset market structure. We choose the latter, but the results of the paper are unaffected by this modelling choice. As in Benigno (2001), home residents are able to trade two nominal risk-less bonds denominated in the domestic and foreign currency. These bonds are issued by residents in both countries in order to finance their consumption expenditure. Home bonds are only traded nationally. Foreign residents can only allocate their wealth in bonds denominated in the foreign currency. This asymmetry in the financial market structure is made for simplicity. The results would not change if one allows home bonds to be traded internationally, this would, however, require a further arbitrage condition. Home households face a cost (i.e. transaction cost) when they take a position in the foreign bond market. This cost depends on the net foreign asset position of the home economy as in Benigno (2001). Consumer j faces the following budget constraint in each period t:

$$P_t C_t^j + \frac{B_{H,t}^j}{(1+i_t)} + \frac{S_t B_{F,t}^j}{(1+i_t^*)\Theta\left(\frac{S_t B_{F,t}}{P_t}\right)} = B_{H,t-1}^j + S_t B_{F,t-1}^j + P_t w_t h_t^j + \Pi_t^j \tag{8}$$

where $B_{H,t}^j$ and $B_{F,t}^j$ are the individual's holdings of domestic and foreign nominal risk-less bonds denominated in the local currency. i_t is the Home country nominal interest rate and i_t^* is the Foreign country nominal interest rate. S_t is the nominal exchange rate expressed as units of domestic currency needed to buy one unit of foreign currency, P_t is the consumer price level and w_t is the real wage. Π_t^j are dividends from holding a share in the equity of domestic firms obtained by agent j. All domestic firms are wholly owned by domestic agents and equity holding within these firms is evenly divided between domestic agents.

The cost function $\Theta(.)$ drives a wedge between the return on foreign-currency denominated bonds received by domestic and by foreign residents. Benigno (2001) rationalizes this cost by the existence of foreign-owned intermediaries in the foreign asset market who apply a spread over the risk-free rate of interest when borrowing or lending to home agents in foreign currency. This spread depends on the net foreign asset position of the home economy. Profits from this activity in the foreign asset market are distributed equally among foreign residents.[3]

As in Benigno (2001), all individuals belonging to the same country have the same level of initial wealth. This assumption, along with the fact that all individuals face the same labour demand and own an equal share of all firms, implies that within the same country all individuals face the same budget constraint. Thus they will choose identical paths for consumption. As a result, we can drop the j superscript and focus on a representative individual for each country.

The maximization problem of the Home individual consists of maximizing (7) subject to (8) in determining the optimal profile of consumption and bond holdings and the labour supply schedule.

The Lagrange multiplier corresponding to agent j's maximization problem is:

$$L = \mathrm{E}_t \sum_{s=t}^{\infty} \beta^{s-t} \left\{ \begin{array}{c} (u(C_s^j - \gamma C_{s-1}) + z(1-h_s^j)) + \\ \mu_s \left[\frac{B_{H,s-1}^j}{P_s} + \frac{S_s B_{F,s-1}^j}{P_s} + w_s h_s^j + \frac{\Pi_s^j}{P_s} - C_s^j - \frac{B_{H,s}^j}{P_s(1+i_s)} - \frac{S_s B_{F,s}^j}{P_s(1+i_s^*)\Theta\left(\frac{S_s B_{F,s}}{P_s}\right)} \right] \end{array} \right\}$$

The domestic households' first order conditions are described by the following equations:

$$u_{C_s^j}(C_s^j - \gamma C_{s-1}) - \mu_t = 0 \tag{9}$$

$$\frac{z_{h_s^j}(1-h_s^j))}{u_{C_s^j}(C_s^j - \gamma C_{s-1})} = w_t \tag{10}$$

[3] Here we follow Benigno (2001) in assuming that the cost function $\Theta(.)$ assumes the value of 1 only when the net foreign asset position is at its steady state level, ie $B_{F,t} = \overline{B}$, and is a differentiable decreasing function in the neighbourhood of $\overline{B}$. This cost function is convenient because it allows us to log-linearise our economy properly since in steady state the desired amount of net foreign assets is always a constant $\overline{B}$. The expression for profits from financial intermediation is given by $K = \frac{B_{F,t}}{P_t^*(1+i_t^*)}\left[\frac{RS_t}{\Theta\left(\frac{S_t B_{F,t}}{P_t}\right)} - 1\right]$.

$$-\mu_t \frac{1}{P_t(1+i_t)} + \beta \mathrm{E}_t \mu_{t+1} \frac{1}{P_{t+1}} = 0 \tag{11}$$

$$-\mu_t \frac{S_t}{P_t(1+i_t^*)\Theta\left(\frac{S_t B_{F,t}}{P_t}\right)} + \beta \mathrm{E}_t \mu_{t+1} S_{t+1} \frac{1}{P_{t+1}} = 0 \tag{12}$$

where (11) is the optimality condition for the Home country's holding of home-currency denominated bonds. (12) is the optimality condition for the Home country's holdings of foreign-currency denominated bonds.

4.2 Final consumption goods sector

As described in Section 2, producers of final consumption goods combine home and foreign-produced intermediate goods according to a CES technology. Assuming that the intratemporal elasticity of substitution between home and foreign produced goods, θ, is less than infinite ensures that the terms of trade are endogenous in our model. The final goods producer solves the following profit maxmimization problem:

$$\max_{c_H, c_F} PC - P_H c_H - P_F c_F \tag{13}$$

subject to (1). This yields the following input demand functions for the home economy (similar conditions hold for Foreign producers)

$$c_H = v \left(\frac{P_H}{P}\right)^{-\theta} C \ , \quad c_F = (1-v) \left(\frac{P_F}{P}\right)^{-\theta} C \tag{14}$$

and the price index (3) described in section 2.

The foreign final goods producing sector is symmetric, with the exception that v^* the share of home-produced intermediate goods in the foreign final consumption good is less than v. This assumption captures consumption home bias.

4.3 Investment goods sector

Analogous to final consumption goods producers, investment goods (x) producers maximize

$$\max_{x_H, x_F} P_{x,t}x_t - P_{H,t}x_{H,t} - P_F x_{F,t}. \tag{15}$$

subject to

$$x_t = \varepsilon_t \left[\psi^{\frac{1}{\tau}} x_{H,t}^{\frac{\tau-1}{\tau}} + (1-\psi)^{\frac{1}{\tau}} x_{F,t}^{\frac{\tau-1}{\tau}} \right]^{\frac{\tau}{\tau-1}}. \tag{16}$$

This yields the following investment demand functions:

$$x_{H,t} = \psi \left(\frac{P_{H,t}}{P_{x,t}} \right)^{-\tau} x_t \varepsilon_t^{\tau-1}, \quad x_{F,t} = (1-\psi) \left(\frac{P_{F,t}}{P_{x,t}} \right)^{-\tau} x_t \varepsilon_t^{\tau-1} \tag{17}$$

and the price aggregator (4) discussed in section 2.

The investment goods price index (4) is a function of the price of home and foreign-produced intermediate goods prices, as well as the IST shock. It differs from the consumption goods price index due to different substitution elasticities, different degrees of consumption and investment home biases and due to the presence of an IST shock. ψ, the share of home-produced intermediate goods in the home final investment good can differ from v, the share of home-produced intermediate goods in the final consumption good. Unlike in Greenwood, et al (2000), $\frac{P_{x,t}}{P_t}$, the relative price of investment goods in terms of the consumption goods basket is an endogenous relative price, that responds to exogenous shocks such as changes in total factor productivity (TFP) or investment specific technology shocks, ε_t.

4.4 Intermediate goods sectors

Firms in the intermediate goods sector produce output, y_t, that is used in the production of the final consumption and investment goods at home and abroad, using capital and labour services employing the following constant returns to scale production function:

$$y_t = A_t f(k_{t-1}, h_t) \tag{18}$$

where A_t is total factor productivity. The cash flow of this typical firm in the intermediate goods producing sector is:

$$\Pi_t = P_{H_t} A_t f(k_{t-1}, h_t) - P_t w_t h_t - P_{x,t} x_t \tag{19}$$

where w_t is the real wage, P_{H_t} is the price of home-produced intermediate goods and P_t and $P_{x,t}$ are the consumption and investment goods deflators, respectively. The firm faces the following capital accumulation constraint:

$$k_t = (1-\delta)k_{t-1} + F(x_t, x_{t-1}) \tag{20}$$

where δ is the rate of depreciation of the capital stock and $F(x_t, x_{t-1})$ captures investment adjustment costs as proposed by Christiano et al (2005), i.e. it summarizes the technology which transforms current and past investment into installed capital for use in the following period. We assume that $F(x_t, x_{t-1}) = (1 - s(\frac{x_t}{x_{t-1}}))x_t$ and that the function s has the following properties: $s(1) = s'(1) = 0$ and $s''(1) > 0$.

The firm maximizes shareholder's value using the household's intertemporal marginal rate of substitution as the stochastic discount factor. The Lagrangian corresponding to the maximization problem of the representative domestic intermediate goods firm is thus:

$$J = E_t \sum_{s=t}^{\infty} \beta^{s-t} \mu_s \left\{ \frac{\Pi_s}{P_s} \right\} + E_t \sum_{s=t}^{\infty} \beta^{s-t} \lambda_s \left[(1-\delta)k_{s-1} + (1 - s(\frac{x_s}{x_{s-1}}))x_s - k_s \right] \tag{21}$$

The first-order conditions for the choice of labour input, investment and capital stock in period t are:

$$\frac{P_{H,t}}{P_t} A_t F_h(k_{t-1}, h_t) - w_t = 0 \tag{22}$$

$$q_t(1 - s(\frac{x_t}{x_{t-1}})) = q_t s'(\frac{x_t}{x_{t-1}}) \frac{x_t}{x_{t-1}} - \beta \mathrm{E}_t q_{t+1} \frac{\mu_{t+1}}{\mu_t} s'(\frac{x_{t+1}}{x_t}) \frac{x_{t+1}}{x_t} \frac{x_{t+1}}{x_t} + \frac{P_{x,t}}{P_t} \tag{23}$$

$$\beta \mathrm{E}_t \frac{\mu_{t+1}}{\mu_t} \left(\frac{P_{H,t+1}}{P_{t+1}} A_t F_{k_t}(k_t, h_{t+1}) + q_{t+1}(1-\delta) \right) = q_t \tag{24}$$

where we define Tobin's q as: $q_t \equiv \frac{\lambda_t}{\mu_t}$.

4.5 Market Equilibrium

The solution to our model satisfies the following market equilibrium conditions must hold for the home and foreign country:

1. Home-produced intermediate goods market clears:

$$y_t = c_{H_t} + c^*_{H_t} + x_{H_t} + x^*_{H_t}$$

2. Foreign-produced intermediate goods market clears:

$$y^*_t = c_{F_t} + c^*_{F_t} + x_{F_t} + x^*_{F_t}$$

3. Bond Market clears:

$$\frac{S_t B_{F,t}}{P_t(1+i^*_t)\Theta\left(\frac{S_t B_{F,t}}{P_t}\right)} - \frac{S_t B_{F,t-1}}{P_t} = \frac{P_{H_t}}{P_t}\left(c^*_{H,t} + x^*_{H,t}\right) - \frac{P_{F,t}}{P_t}\left(c_{F,t} + x_{F,t}\right)$$

4.6 Solution technique

Before solving our model, we log-linearize around the steady state to obtain a set of equations describing the equilibrium fluctuations of the model. We solve this system using the King and Watson (1998) solution algorithm.

5 Calibration

The calibration assumes that countries Home and Foreign are of the same size and are symmetric in terms of their deep structural parameters. The following functional form is specified for preferences:

$$U_t = E_t \sum_{s=t}^{\infty} \beta^{s-t} \left[\frac{(C^j_s - \gamma C_{s-1})^{1-\rho}}{1-\rho} + \chi \frac{(1-h^j_s)^{1-\eta}}{1-\eta} \right],$$

where β is the subjective discount factor, ρ and η are the constant relative risk aversion parameters (inverse of the intertemporal elasticity of substitution) associated with consumption and leisure, respectively. Christiano et al (2005) suggest a value of γ, the parameter determining the degree of habits in consumption, of around 0.6 for the US economy. A moderate amount of consumption home-bias is assumed, $v = (1 - v^*) = 0.85$, which corresponds to a 15% share of imports in US final consumption and is similar to the value assumed by Enders and Müller (2008). Initially, complete specialization in the production of the final investment good is assumed, $\psi = (1 - \psi^*) = 1$. This rather extreme assumption that $\psi = 1$ is nevertheless also made in the baseline calibrations in Corsetti et al (2008) and Benigno and Thoenissen (2008). Section 8 performs sensitivity analysis letting ψ vary from 0.5 to 1. Following Benigno and Thoenissen (2008), the intratemporal elasticity of substitution between home and foreign-produced intermediate goods in consumption, θ, is set to 2, whereas τ, the intertemporal elasticity of substitution between home and foreign intermediate goods in investment goods is set to 1. Section 8 analyzes the effect of different values of this parameter. As is common in the literature, the share of labour in production is 0.64 and the capital stock depreciates by 2.5% per quarter. Following Benigno (2001), a bond holding cost is introduced to eliminate the otherwise arising unit root in foreign bond holdings. This cost can be very small, and thus a 10 basis point spread of the domestic interest rate on foreign assets over the foreign rate is chosen, such that $\xi \equiv -\Theta'(\bar{b})\bar{C} = 0.001$. Christiano et al's (2005) estimate the curvature of the investment adjustment cost function for US data and suggest a value of $s''(.)$ of 2.5. It turns out that this value is important in determining the correlation between the relative price of investment goods and the investment rate. Hence, we report extensive sensitivity analysis for this parameter value.

The stochastic processes for total factor productivity and investment specific technological change are taken from Boileau (2002), whose model structure is similar and consistent with ours. The investment specific productivity shock calculated by Boileau (2002) is price-based and calculated using G7 data on the relative price of a new unit of equipment relative to final goods output. The home country in this calibration is the United States. Matrix $V[\mu]$ in Table 5 shows the variance-covariance matrix of the shock processes, and matrix Ω their first-order autocorrelation coefficients. The upper left hand quadrant of matrices $V[\mu]$ and Ω contain the TFP shocks, while the lower right hand quadrant contain the investment specific technology shocks.

Table 5: Baseline calibration

Preferences	$\beta = 1/1.01, \rho = 1, \eta = 0.25, \bar{h} = 1/3, \gamma = 0.6$
Final goods tech	$\upsilon = (1 - \upsilon^*) = 0.85,\ \theta = 2,\ \tau = 1,\ \psi = (1-\psi^*) = 0.5, 0.75, 1.0$
Intermediate goods tech	$\alpha = 0.64,\ \delta = 0.025,\ s''(.) = 2.5$
Financial markets	$\xi = 0.001$
Shocks	$\Omega = \begin{bmatrix} 0.906 & 0.088 & 0 & 0 \\ 0.088 & 0.906 & 0 & 0 \\ 0 & 0 & 0.553 & 0.027 \\ 0 & 0 & 0.027 & 0.553 \end{bmatrix}$
	$V[\mu] = 10^{-4} \begin{bmatrix} 0.726 & 0.187 & 0 & 0 \\ 0.187 & 0.726 & 0 & 0 \\ 0 & 0 & 1.687 & 0.582 \\ 0 & 0 & 0.582 & 1.687 \end{bmatrix}$

6 Impulse Response Analysis

This section uses impulse response analysis to examine the effects of IST and TFP shocks on the investment rate, its relative price, and the terms of trade. In particular, we are interested in the co-movement between the investment rate and the relative price of investment goods. A negative correlation between these two variables is usually associated with IST shocks.

Assuming complete home bias in final investment goods, i.e. $\psi = 1$, results in a positive correlation between the investment rate and the relative price of investment goods following a positive TFP shock (see Figure 2). A rise in TFP raises output of home intermediate goods. In order for the market for home-produced intermediate goods to clear their international relative price must fall which causes the terms of trade (P_F/P_H) to depreciate (rise). This depreciation leads to a positive wealth effect abroad, raising foreign demand for home-produced intermediate goods. Equation (6) shows that the relative price of investment goods declines as the terms of trade depreciate, as long as $\psi > \upsilon$. This parameter restriction implies that final investment goods are more biased towards home-produced intermediate goods than are final consumption goods. As a result, the relative price of final investment to consumption goods falls when the price of home-produced intermediate goods declines.

Given the size of adjustment costs in our baseline calibration, the investment rate initially falls, as output rises by more than investment. Adjustment costs that penalize rapid changes in the rate of investment cause investment to rise more gradually in response to a TFP shock. Given that both the investment rate and the relative price decline on impact, the correlation between the two will be positive.

So far, the calibration assumes that all investment goods are home produced. Next, we assume that producers of final investment goods have no home-bias at all. This assumption is not unreasonable, as the the data presented in Section 2 suggests. Based on equation (6), the relationship between the relative price of investment goods and the terms of trade changes sign when $v > \psi$. A terms of trade depreciation is now associated with a rise in the relative price of investment goods. Assume there is a decline in the relative price of home produced intermediate goods causing the terms of trade to depreciate (rise). If final investment goods are less intensive in home-produced intermediate goods than consumption goods, their price index will fall by less than the price index of final consumption, causing the relative price of investment goods to increase.

Figure 3, analyzes the response of the model to a TFP shock when $\psi = 0.5$. Here, the response of the terms of trade remains the same as in the case where $\psi = 1$. However, since the relative price of investment goods is now positively correlated with the terms of trade, a depreciation raises the relative price of investment goods, thus further lowering the investment response. The result is a negative correlation between the investment rate and the relative price of investment goods.

Figure 4 shows the response of the model to a positive IST shock. The relative price of investment goods declines, whereas the investment rate rises. IST shocks result in a negative correlation between the relative price of investment goods and the investment rate.

The impulse response analysis suggests that TFP shocks can lead to both a negative as well as a positive correlation between the relative price of investment and the investment rate, depending on the relative degree of home-bias in investment. IST shocks analysed in this section always result in a negative correlation, regardless of the relative degree of home bias.[4] Table 6 summarizes the impact effects of positive TFP and IST shocks on the investment rate, the terms of trade and the relative price of investment goods for the $\psi = 1$ and $\psi = 0.5$ calibration:

[4] The Figure 4 does not change in a qualitative way if we vary ψ, we therefore only report the impulse response corresponding to the median value of ψ.

Table 6: Summary of Impulse Responses

	A_t	IST_t
$\psi = 1$	$x/y \downarrow$, $T \uparrow$, $P_x/P \downarrow$	$x/y \uparrow$, $T \uparrow$, $P_x/P \downarrow$
$\psi = 0.5$	$x/y \downarrow$, $T \uparrow$, $P_x/P \uparrow$	$x/y \uparrow$, $T \uparrow$, $P_x/P \downarrow$

The next section analyzes a selection of second moments generated by our model for the $\psi = 1$, $\psi = 0.5$ and $\psi = 0.75$ case.

7 Second Moments

Following the impulse response analysis, this section analyzes the correlation between the relative price of investment goods and the investment rate, and the correlation between the relative price of investment goods and the terms of trade generated by the calibrated model. The correlations presented in Table 7 are constructed using actual data, as well as artificial model economy data. Both types of data are of quarterly frequency, logged and Hodrick-Presocott filtered with a smoothing parameter set to 1600. The sample period for the data is 1960:1 - 2006:4. In the appendix, we report a wider set of second moments generated by our model, as well as details of data sources.

Table 7: Correlations between the relative price of investment goods, the investment rate and the terms of trade.

		Data	*Model*					
			$s''(.) = 2.5$			$s''(.) = 0.1$		
			ψ= 1	ψ= 0.5	ψ= 0.75	ψ= 1	ψ= 0.5	ψ= 0.75
TFP shocks	Corr($\frac{P_x}{P}$, $\frac{x}{y}$)	-0.22	0.09	-0.24	-0.15	-0.24	0.08	0.32
	Corr($\frac{P_x}{P}$, t)	0.75	-1.00	1.00	1.00	-1.00	1.00	1.00
IST shocks	Corr($\frac{P_x}{P}$, $\frac{x}{y}$)	-0.22	-0.64	-0.61	-0.62	-0.88	-0.72	-0.85
	Corr($\frac{P_x}{P}$, t)	0.75	-0.11	0.09	-0.04	0.46	0.10	0.49

Notation: $\frac{P_x}{P}$=relative price of investment goods, x=investment, y=GDP

The key finding of Section 6 is reflected in the second moments generated by the model, as reported in Table 7. Given the baseline calibration, the international real business cycle model driven solely by TFP shocks, yields a positive correlation between the investment rate and the relative price of investment goods when the share of home-produced intermediate goods in final investment goods exceeds that in final consumption goods, i.e. if $\psi > v$, and yields a negative correlation if ψ is less than v. Likewise, a model driven only by TFP shocks can generate a data congruent positive correlation between the relative price of investment goods and the terms of trade as long as $\psi < v$, as the evidence in Section 2 suggests.

When TFP is the main driver of technical change, the size of the adjustment cost interacts with the relative home bias in determining the sign of the correlation between relative price of investment and the rate of investment. To show this, Table 7 reports a version of the model where $s''(.) = 0.1$. With very small adjustment costs, most investment takes place in the period of the shock and responds by more than output so that the investment rate rises following a positive shock to TFP. As a result, the correlation between the investment rate and the relative price of investment goods is negative when $\psi > v$ and positive when $\psi < v$. The exact opposite happens in the 'high adjustment cost' scenario. The next section analyses the joint role of adjustment costs and home bias in investment in more detail.

The rows headed 'IST shocks' report the correlation generated by our model when all the dynamics are driven by IST shocks. As the impulse response analysis suggests, this version of the model generates a negative correlation between the relative price of investment and the investment rate. This happens because the direct effect of the IST shock on P_x/P always outweighs the indirect effect working through terms of trade.[5] Low adjustment cost economy makes this negative correlation stronger because of faster response of investment to IST shock. Note that the correlation between the relative price of investment goods and the terms of trade can be both negative as well as positive, depending on the parameters of the model.

[5] It is easy to decompose the direct and indirect effect of IST applying chain rule to (6). $\frac{\partial \widehat{\frac{P_{x,t}}{P_t}}}{\partial \hat{\varepsilon}_t} = (v - \psi)\frac{\partial \widehat{T_t}}{\partial \hat{\varepsilon}_t} - 1$. The direct effect is the second term, -1 and the indirect effect is the first term. In the present version of the model, absolute value of the first term is always less than unity.

8 Sensitivity Analysis

The previous section shows that under TFP shocks, the sign of the correlation between the relative price of investment goods and the investment rate depends on both the relative degree of home bias in investment (the value of ψ for a given v) and the extent of adjustment costs. This section analyzes how the correlation responds to changes in both ψ and the degree of adjustment costs. To gain a better understanding of the factors that determine the correlation between the relative price of investment goods and the investment rate, it is helpful to first determine how the terms of trade react to a TFP shock in the model. A rise in TFP always raises output. Therefore, by looking at the cross-correlation between GDP and the terms of trade, one can determine how the terms of trade respond to a TFP shock. Figure 5 shows that the terms of trade are pro-cyclical for all values of ψ and the adjustment cost parameter, thus the terms of trade always rise (depreciate) following a positive TFP shock.

8.1 The baseline model

Figure 6 shows the H-P filtered correlation generated by the model when driven by TFP shocks.[6] The surface plot shows the correlation corresponding to values of ψ between 0.5 (no home-bias) to 1.0 (complete home-bias) for values of the adjustment cost parameter $s''(.)$ between near zero and 3.5. The latter range encompasses Christiano et al's estimate as well as smaller and larger values used in the literature. Figure 6 shows a surface divided into two distinct regions: (i) for $\psi > v$ the correlation is negative for small values of the adjustment cost parameter and rises as $s''(.)$ increases; and (ii) for $\psi < v$ the correlation is positive for small values of the adjustment cost parameter and declines as $s''(.)$ rises.

In region (i), where $\psi > v$ such that investment home bias exceeds consumption home bias, there is a negative relationship between the relative price of investment goods and the terms of trade, see equation (6) without the IST shock: $\widehat{\frac{P_{x,t}}{P_t}} = (v - \psi)\hat{T}_t$. Since the terms of trade always depreciate (rise) following a positive TFP shock, the relative price of investment goods declines. Given that the relative price declines for all values of $s''(.)$ analyzed, the correlation depends on the

[6] We do not report sensitivity analysis for the model driven by IST shocks, as the negative correlation between the relative price and the investment rate is found to be robust to all alternative parameter choices analysed in this section.

response of the investment rate. For low values of the adjustment cost parameter the investment rate rises on impact following a positive TFP shock. The initial response of investment is greater than the initial response of output, such that on impact the investment rate (investment relative to output) rises. The result is a negative correlation between the relative price of investment and the investment rate.

Raising the adjustment cost parameter, such that increasing the flow of investment incurs a cost, slows down investment and leads to a 'hump' shaped profile in the impulse response function. The greater are investment adjustment costs, the more pronounced is the 'hump' shape in investment and the smaller is the initial response of investment relative to that of output. Thus, as $s''(.)$ rises the initial response of output exceed that of investment, so that the log of the investment rate eventually falls, along with the relative price of investment goods, resulting in a positive correlation.

In region (ii), where $\psi < v$, there is a positive relationship between the relative price of investment goods and the terms of trade. This finding is supported by our stylized facts put forward in Section 3. The relative price of investment goods rises in response to a positive TFP shock in this region of the parameter space. The sign of the correlation thus depends on the response of the investment rate. As in region (i), following a positive TFP shock, the investment rate rises for very low values of $s''(.)$, which in region (ii) results in a positive correlation. As $s''(.)$ increases and the the response of the investment rate to a positive TFP shock declines, the correlation between the relative price of investment goods and the investment rate becomes negative.

Figure 6 clearly shows that the correlation can be both positive as well as negative depending on the value of ψ and $s''(.)$ (keeping all other parameters constant). Without taking a stand on the likelihood of either ψ or $s''(.)$ taking a particular value, what is the most likely value of the correlation? Assuming that ψ and $s''(.)$ are uniformly distributed across the parameter range, the average of the observations that make up the surface plot of Figure 6 is -0.07 with a median of -0.1.

8.2 Capital adjustment costs

The previous section highlights the importance of adjustment costs in the investment process. Adjustment costs slow down the initial response of investment. The model uses a form of investment adjustment costs put forward by Christiano et al (2005). This section analyzes whether the results obtained so far are sensitive to the specific form of investment adjustment costs chosen. As an alternative, let capital adjustment costs take on the following form:

$$k_t = (1-\delta)k_{t-1} + \phi(\frac{x_t}{k_{t-1}})k_{t-1}$$

where $\phi(.)$ is strictly concave and when evaluated at the steady state has the following properties: $\phi(\frac{x}{k}) = \frac{x}{k} = \delta$, $\phi'(\frac{x}{k}) = 1$ and $\phi''(\frac{x}{k}) < 0$. This adjustment cost function is used amongst others in Nolan and Thoenissen (2009). Figure 7 shows the surface plot of correlations for the model with capital adjustment costs. The results are broadly similar to those in Figure 6. As a summary statistic, the average correlation in Figure 7 is -0.05.

8.3 Some deep parameters

The dynamics of consumption in the model are characterized by external consumption habits. The behavior of consumption does of course affect the dynamics of output, although not as much in an open economy than in a closed one. In Figure 8, the parameter determining the share of past aggregate consumption in the utility function, γ, is set to zero. The result is a more pronounced version of Figure 6. Regions of the parameter space where the baseline model generates negative correlations are now even more negative, and regions where the model generates positive correlations are now more positive. The average correlation is -0.15.

Figure 9 analyzes the role of the labor supply elasticity, η. In the baseline calibration, $\eta = 0.25$, Figure 9 examines the case where $\eta = \rho = 1$. The correlation surface suggests that the basic results are robust to the choice of η. Our summary statistic, the average of the observations plotted in Figure 9 is -0.1.

As further robustness checks, we carried out experiments on all key parameters of the model, but did not find a combination of parameters that overturns the basic result summarized in Figure 6. Table 8 reports the average correlation of further selected robustness checks.

Table 8: More sensitivity analysis

	Autarky	$\tau = 25$	$\tau = 0.5$	$\rho = 6$	$\theta = 0.5$	$\theta = 25$	$\rho = 6, \gamma = 0$
Ave. corr	-0.106	-0.103	-0.066	-0.18	-0.065	-0.094	-0.244

Raising the bond holding cost to such a level where domestic agents are unwilling to hold foreign-currency denominated bonds allows the model to reproduce the financial autarky allocation. The average correlation of -0.106 reflects a correlation surface that is not much different from that corresponding to the baseline calibration. The same holds for changes in to elasticity of substitution between home and foreign-produced intermediate goods in the production of investment (τ) and consumption (θ) goods. Raising the CRRA coefficient from 1.0 to 6.0, a value commonly used in the finance literature, significantly lowers the average correlation. The average correlation can be further reduced by 'turning off' consumption habits.

8.4 Summary - correlation between the investment rate and $\frac{P_{x,t}}{P_t}$

An international real business cycle model driven only by TFP shocks can generate a negative correlation between the investment rate and the relative price of investment goods. Important factors in determining the sign of the correlation are the degree of home bias in investment (for a given home bias in consumption) and the size of adjustment costs. The former determines the impact response of the relative price of investment goods to a TFP shock of, via the terms of trade, and the latter the impact response of the investment rate. Our preferred calibration ($s''(.) = 2.5$ and $\psi < v$) yields a negative correlation, even under TFP shocks.

The conclusion we draw is that a negative correlation between the investment rate and the relative price of investment goods that one observes in the data can be attributed to both IST as well as TFP shock. Thus, identifying IST shocks with the relative price of investment goods is not necessarily robust in an open economy environment.

9 Conclusion

This paper shows that the conventional mode of identifying investment specific technology shocks in terms of the inverse of the relative price of investment goods is not robust in an open economy environment. In a simple calibrated international real business cycle model augmented by IST and TFP shocks, we find that the changes in the relative price of investment goods are associated with changes in terms of trade as well as with IST shocks. The one-to-one mapping between IST shock and the relative price of investment goods thus breaks down in an international economy except for a special case where the home bias in consumption equals the home bias in investment.

The model also shows that a data congruent inverse relationship between the investment rate and the relative price of investment goods is compatible with both IST and TFP shocks for a wide parameter range. Our results suggest that in an open economy context, researchers should make a serious effort to identify the relative contributions of TFP and IST to understand the observed negative relationship between investment rate and the relative price of investment goods and the volatility of other relevant open economy aggregates.

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A The data

Our data are of quarterly frequency and come from two main sources: the *US Department of Commerce: Bureau of Economic Analysis* (BEA) and *US Department of Labor: Bureau of Labor Statistics* (BLS) and span the sample period 1960:1 to 2006:4.

1. GDP referred to in table 3 is real GDP per capita from BEA's NIPA table 7.1. 'Selected Per Capita Product and Income Series in Current and Chained Dollars', seasonally adjusted. The series was logged and H-P filtered.

2. Consumption referred to in table 3 is total consumption expenditures deflated by the relevant GDP deflator, both from BEA's NIPA tables 2.3.5 and 1.1.9.

3. Investment referred to in table 3 is real fixed investment per capita from BEA's NIPA table 5.3.3. Real Private Fixed Investment by Type. Population is from NIPA table 7.1.

4. Hours referred to in table 3 is per capita hours worked in non-farm businesses, from BLS, series code PRS85006033. Population is from NIPA table 7.1.

5. Real wage referred to in table 3 is real hourly compensation from BLS, series code PRS85006153.

6. Exchange rate, terms of trade and current account data are taken from OECD.

B Further second moments

Table 9: Second moments: baseline model

	Data	*Model*						
		$s''(.) = 2.5$			$s''(.) = 0.1$			*IST*
Correlations		ψ= 1	ψ= 0.5	ψ= 0.75	ψ= 1	ψ= 0.5	ψ= 0.75	ψ= 0.75
$\text{Corr}(\frac{P_x}{P}, \frac{x}{y})$	-0.22	0.09	-0.24	-0.15	-0.24	0.08	0.32	-0.62
$\text{Corr}(c, y)$	0.86	0.82	0.81	0.81	0.22	0.34	0.32	-0.65
$\text{Corr}(x, y)$	0.89	0.83	0.77	0.81	0.97	0.94	0.96	0.48
$\text{Corr}(h, y)$	0.88	0.94	0.93	0.94	0.99	0.97	0.99	0.95
$\text{Corr}(w, y)$	0.26	0.76	0.77	0.77	0.83	0.77	0.82	-0.44
$\text{Corr}(t, y)$	0.14	0.44	0.48	0.47	0.40	0.39	0.44	-0.02
$\text{Corr}(\frac{ca}{c}, y)$	-0.42	0.14	0.06	0.03	0.22	-0.29	-0.42	-0.32
$\text{Corr}(c, c^*)$	0.51	0.34	0.23	0.29	0.63	-0.22	0.21	0.83
$\text{Corr}(y, y^*)$	0.66	0.47	0.50	0.50	0.44	0.67	0.54	0.65
Std dev.								
σ_y	1.57	1.78	1.76	1.76	2.37	2.20	2.29	0.18
σ_c/σ_y	0.78	0.74	0.77	0.76	0.31	0.49	0.377	1.55
σ_x/σ_y	3.18	2.42	2.35	2.39	3.75	3.71	3.95	10.25
σ_t/σ_y	1.60	0.49	0.53	0.52	0.17	0.44	0.32	0.38
σ_{rs}/σ_y	3.04	0.34	0.37	0.36	0.12	0.30	0.22	0.26
σ_{ca}/σ_y	0.22	0.10	0.13	0.15	0.04	0.28	0.30	0.84

Notation: $\frac{P_x}{P}$=relative price of investment goods, w=real wage, x=investment, c=consumption, y=GDP h=hours worked, t=terms of trade, ca=current account, rs=real exchange rate

The model generates a standard deviation of GDP, σ_y, somewhat in excess of the data[7], and for the 'high adjustment cost' scenario, which corresponds to the baseline calibration, under predicts the relative volatility of investment to GDP, σ_x/σ_y. In common with most of the literature, this type of model fails to match the standard deviation of the terms of trade and the real exchange rate relative to GDP (σ_t/σ_y and σ_{rs}/σ_y) and generates a pro-cyclical current account. Unlike the standard international real business cycle model, this model generates a series for consumption that is less highly correlated across countries than is GDP. This result arises from the introduction of external habit persistence, which lowers the cross-country correlation of consumption.

The column headed 'IST' shows the filtered second moments for a model driven only by IST

[7] It is worth noting that the shock process for home and foreign TFP used is taken from Backus et al (1994) and therefor does not capture the reduction in output volatility observed in recent years.

shocks. Following an IST shock, there is a large response in investment, which is 10 times as volatile as output. Agents respond to the demand for investment goods by reducing consumption and raising imports. The result is a counter-cyclical series for consumption as well as the current account. The current account is also more volatile than under TFP shocks. IST shocks alone are not able to account for the volatility of output, indeed the model under predicts GDP by a factor of 9. JPT (2009) put forward an interesting interpretation of IST shocks. Since IST shocks affect the way savings are transformed into capital stock, via investment, one could interpret them as reflecting the efficiency of financial intermediation. Indeed, our model's response to an IST shock is similar to that of a financial efficiency shock identified by Nolan and Thoenissen (2009), in particular with regards to the response of consumption and investment.

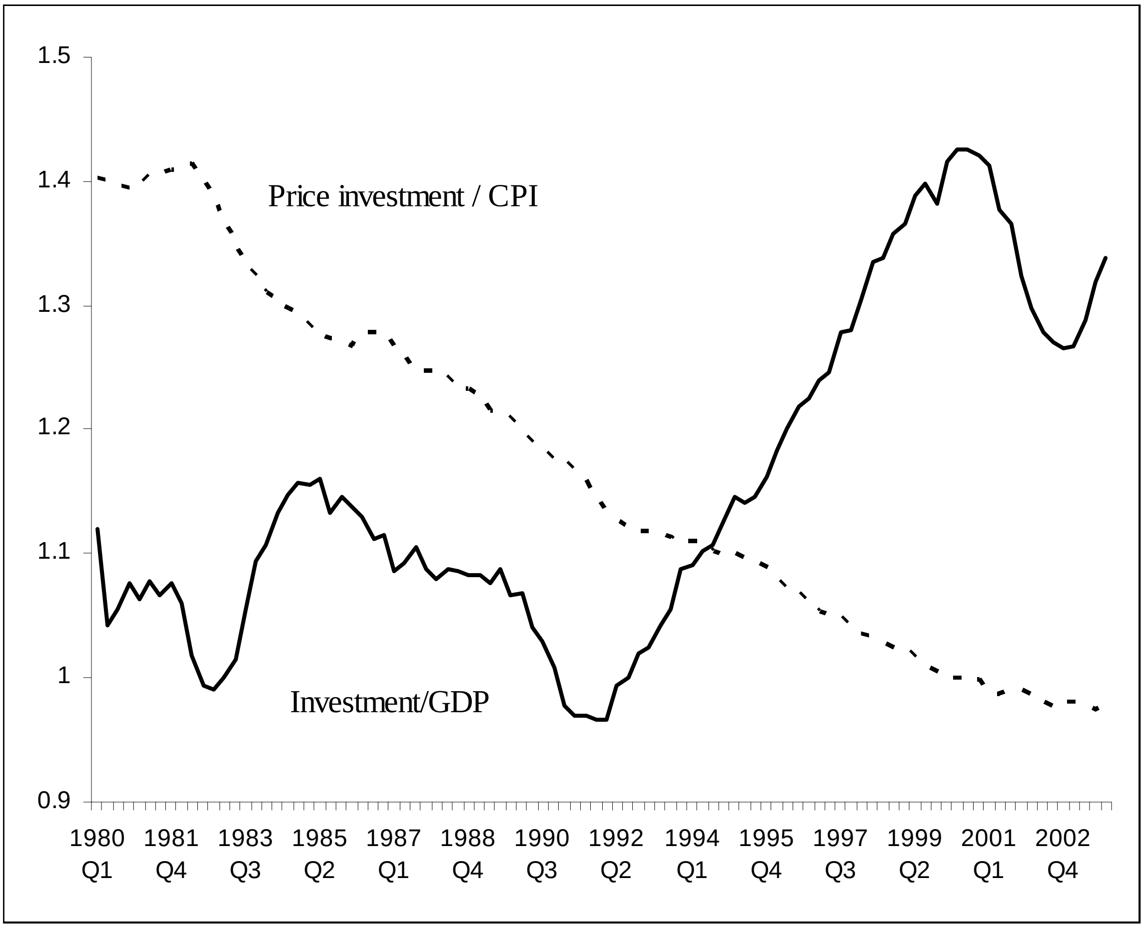

Figure 1: The relative price of investment goods and the investment to GDP ratio.

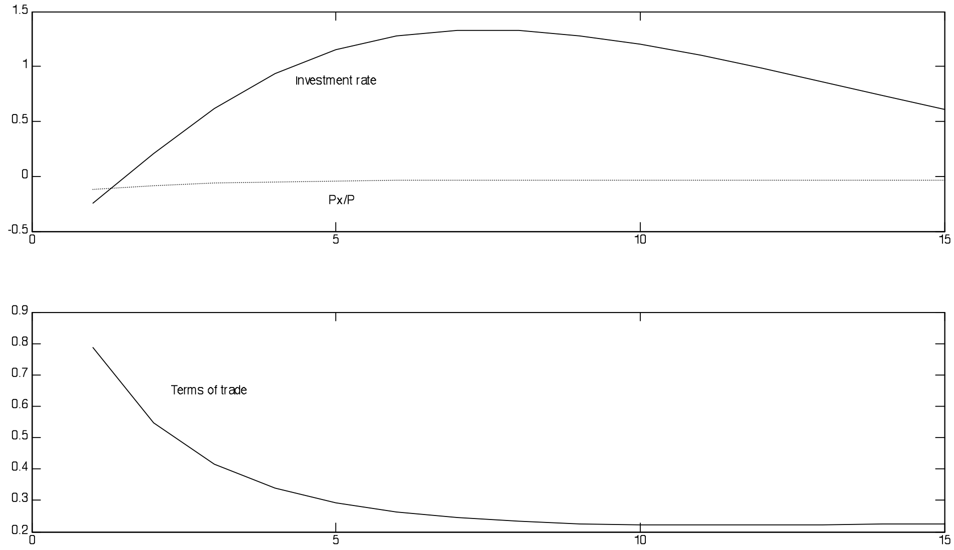

Figure 2 Impulse response function following a unit TFP shock, when ψ= 1.

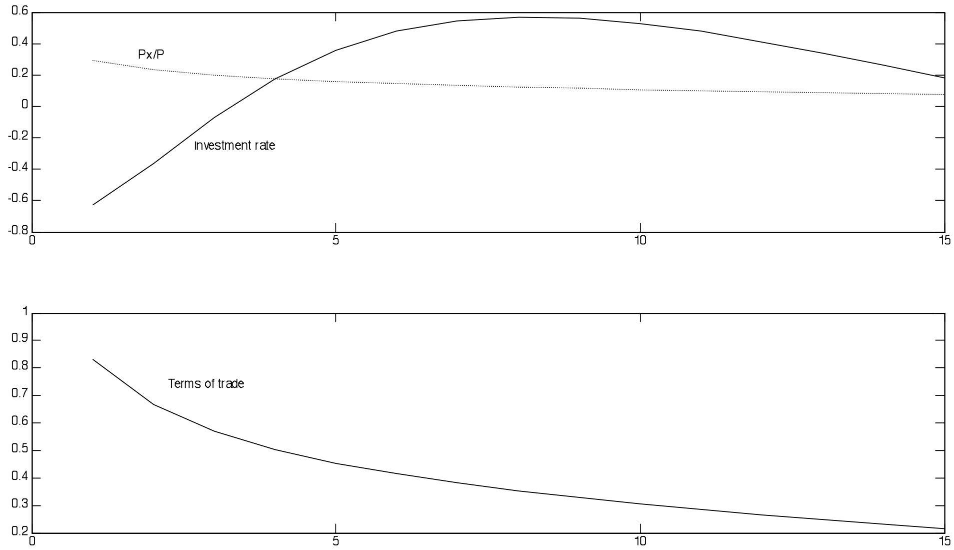

Figure 3 Impulse response function following a unit TFP shock, when ψ = 0.5.

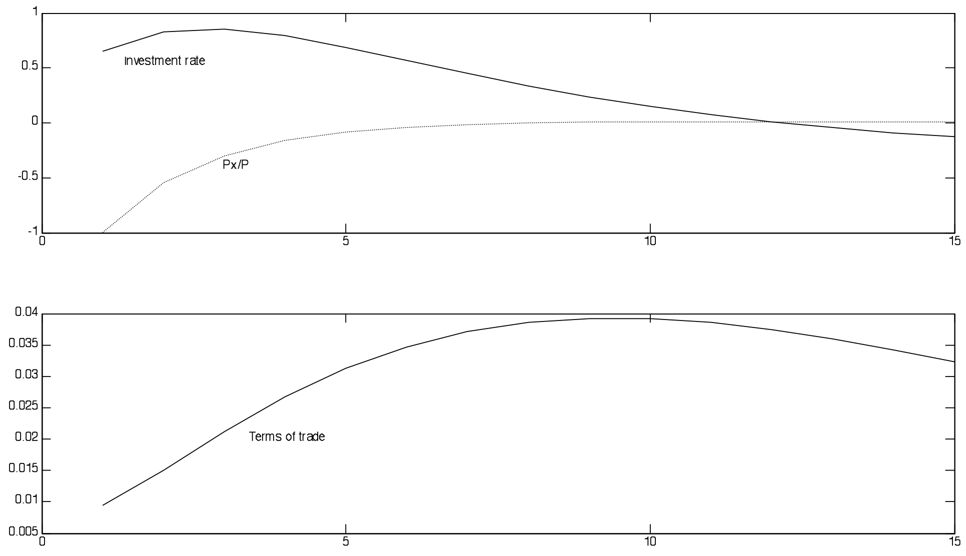

Figure 4 Impulse response function following a unit IST shock, when ψ = 0.75

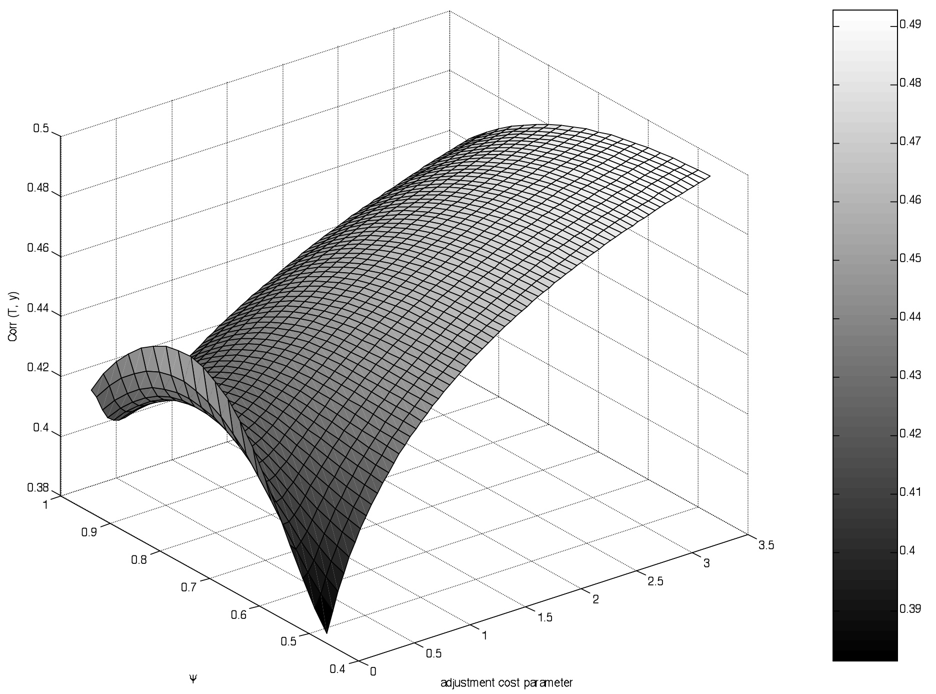

Figure 5 The correlation between the terms of trade and output for various values of ψ and the adjustment cost parameter.

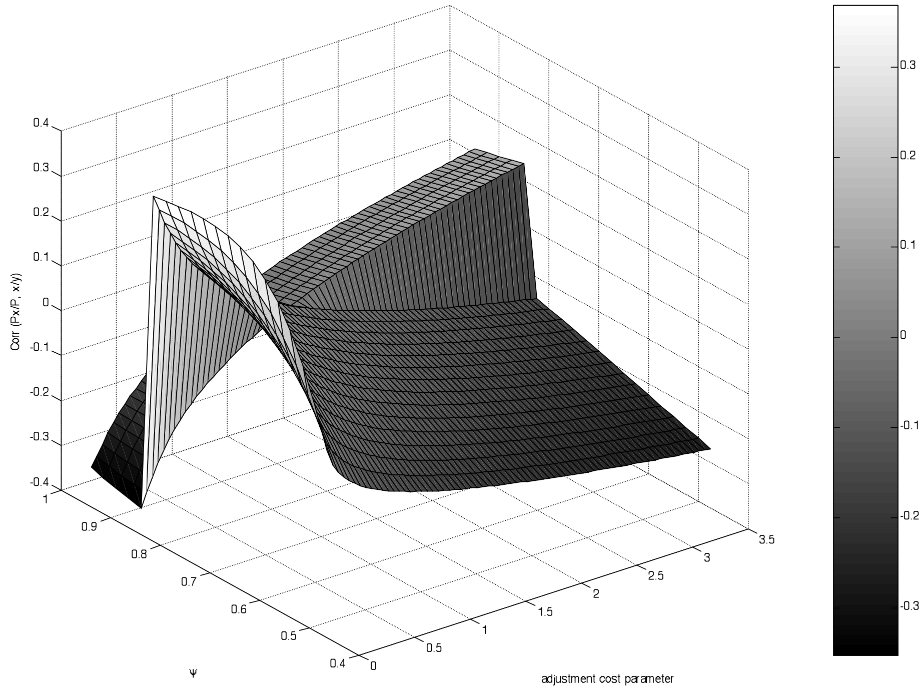

Figure 6 Investment adjustment costs a la Christiano et al (2005). Average correlation: -0.07

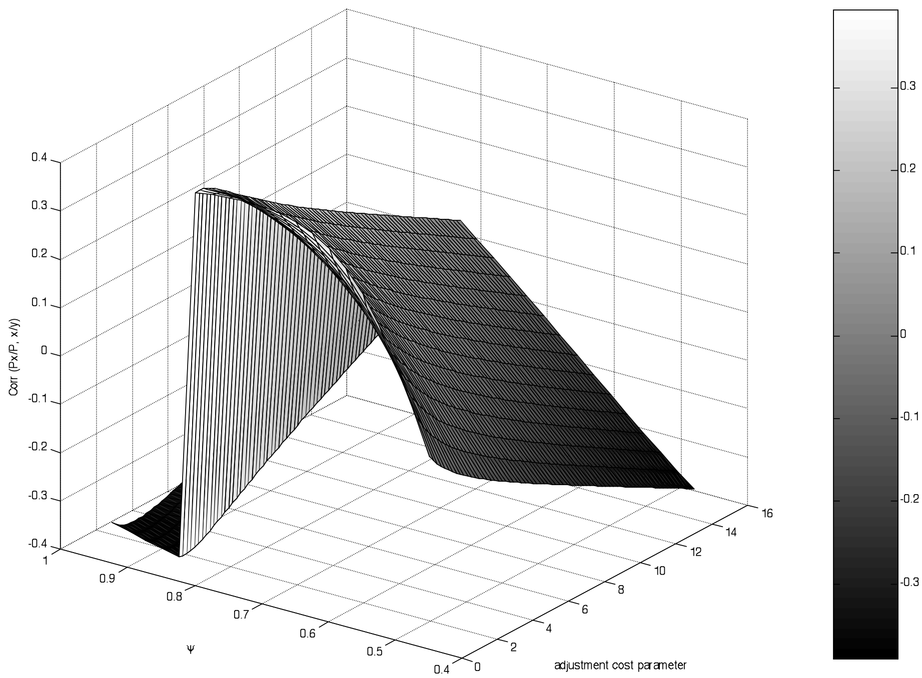

Figure 7 Quadratic capital adjustment costs, a la Hayashi (1982). Average correlation: -0.05

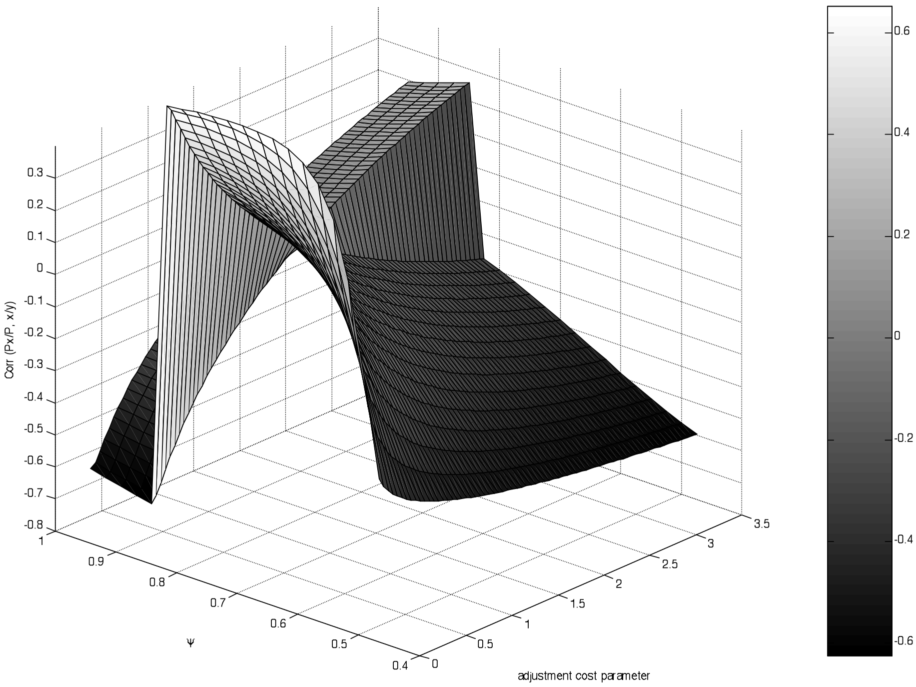

Figure 8 No consumption habits. Average correlation: -0.15

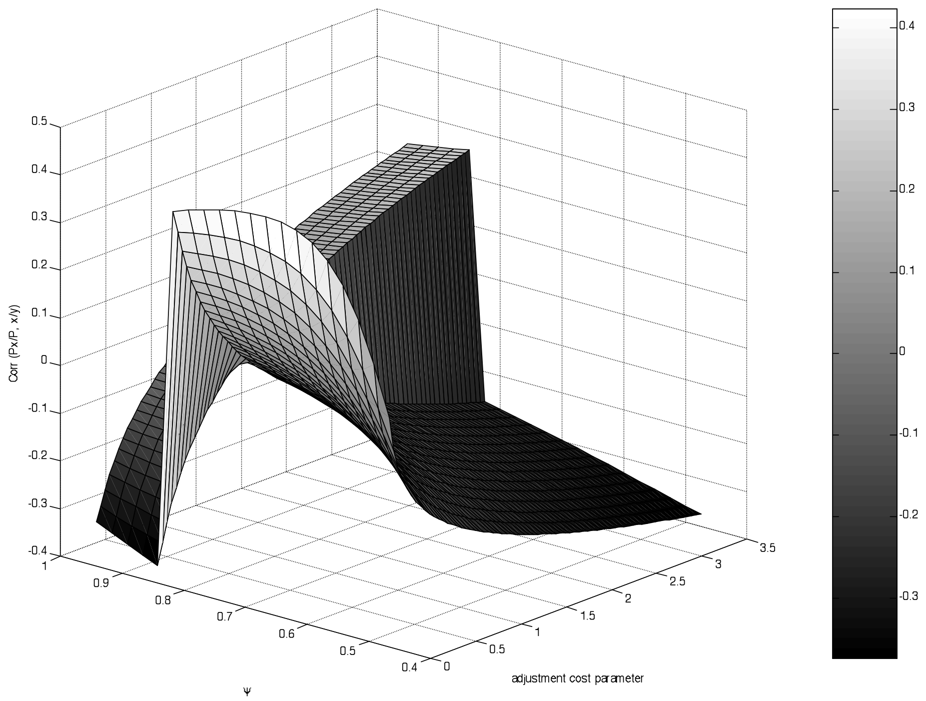

Figure 9 Investment adjustment costs, η = ρ. Average correlation: -0.1