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International business cycles and the relative price of investment goods*

Parantap Basu[†]
University of Durham

Christoph Thoenissen[‡]
University of St Andrews

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ABSTRACT

Is the relative price of investment goods a good proxy for investment frictions? 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. The paper argues that the one-to-one correspondence between investment friction 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. A regression experiment with major OECD countries provided empirical support of the fact that terms of trade effect on the relative price of investment is important.

JEL Classification: E22, E32, F41

Keywords: Investment frictions, investment specific technological progress, total factor productivity, relative price of investment goods terms of trade

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[†] Department of Economics, University of Durham, 23-26 Old Elvet, Durham DH1 3HY, UK. E-mail parantap.basu@durham.ac.uk.

[‡] Corresponding author: School of Economics and Finance, University of St Andrews, St Andrews, Fife, KY16 9AL, UK. E-mail: christoph.thoenissen@st-andrews.ac.uk.

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Abstract

Is the relative price of investment goods a good proxy for investment frictions? 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. The paper argues that the one-to-one correspondence between investment friction 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. A regression experiment with major OECD countries provided empirical support of the fact that terms of trade effect on the relative price of investment is important.

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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

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[†]Department of Economics, University of Durham, 23-26 Old Elvet, Durham DH1 3HY, UK. E-mail: parantap.basu@durham.ac.uk

[‡]Corresponding author: School of Economics and Finance, University of St Andrews, St Andrews, Fife, KY16 9AL, UK. E-mail: christoph.thoenissen@st-andrews.ac.uk

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 this 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 sets out the model and Section 3 describes the baseline calibration. Sections 4 and 5 analyze the dynamics of the model using impulse response analysis and second moments. Section 6 reports on a number of robustness checks. Section 7 puts forward empirical support for our key proposition that relative price of investment goods reflects more than just the IST shock. Finally, Section 8 concludes.

2 The model

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 (2008). 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.

2.1 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:

$$U_t^j = E_t \sum_{s=t}^{\infty} \beta^{s-t} (u(C_s^j - \gamma C_{s-1}^j), z(1 - h_s^j)) \quad (1)$$

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 .

International asset markets are assumed to be incomplete. 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. As in Benigno (2001), 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 :

$$P_t C_t^j + \frac{B_{H,t}^j}{(1+i_t)} + \frac{S_t B_{F,t}^j}{(1+i_t^*)\Theta\left(\frac{S_t B_{F,t}^j}{P_t}\right)} = B_{H,t-1}^j + S_t B_{F,t-1}^j + P_t w_t h_t^j + \Pi_t^j \quad (2)$$

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 $\Theta(\cdot)$ 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.¹

¹Here we follow Benigno (2001) in assuming that the cost function $\Theta(\cdot)$ assumes the value of 1 only when the

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 (1) subject to (2) 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:

$$L = E_t \sum_{s=t}^{\infty} \beta^{s-t} \left\{ \mu_s \left[\frac{B_{H,s-1}^j}{P_s} + \frac{S_s B_{F,s-1}^j}{P_s} + w_s h_s^j + \frac{\Pi_s^j}{P_s} - C_s^j - \frac{B_{H,s}^j}{P_s(1+i_s)} - \frac{S_s B_{F,s}^j}{P_s(1+i_s^*)\Theta\left(\frac{S_s B_{F,s}^j}{P_s}\right)} \right] \right\}$$

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

$$\frac{\partial L_t}{\partial C_t^j} : u_{C_s^j}(C_s^j - \gamma C_{s-1}) - \mu_t = 0 \quad (3)$$

$$\frac{\partial L}{\partial h_t^j} : \frac{z h_s^j (1 - h_s^j)}{u_{C_s^j}(C_s^j - \gamma C_{s-1})} = w_t \quad (4)$$

$$\frac{\partial L_t}{\partial B_{H,t}^j} : -\mu_t \frac{1}{P_t(1+i_t)} + \beta E_t \mu_{t+1} \frac{1}{P_{t+1}} = 0 \quad (5)$$

$$\frac{\partial L_t}{\partial B_{F,t}^j} : -\mu_t \frac{S_t}{P_t(1+i_t^*)\Theta\left(\frac{S_t B_{F,t}^j}{P_t}\right)} + \beta E_t \mu_{t+1} S_{t+1} \frac{1}{P_{t+1}} = 0 \quad (6)$$

where (5) is the optimality condition for the Home country's holding of home-currency denominated bonds. (6) is the optimality condition for the Home country's holdings of foreign-currency denominated bonds.

net foreign asset position is at its steady state level, ie $B_{F,t} = \bar{B}$, and is a differentiable decreasing function in the neighbourhood of \bar{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 \bar{B} . The expression for profits from financial intermediation is given by $K = \frac{B_{F,t}}{P_t^*(1+i_t^*)} \left[\frac{RS_t}{\Theta\left(\frac{S_t B_{F,t}}{P_t}\right)} - 1 \right]$.

2.2 Final consumption goods sector

Home and foreign agents consume a final consumption good. Home final consumption goods (C) are produced with the aid of home and foreign-produced intermediate goods (c_H and c_F) in the following manner:

$$C = \left[v^{\frac{1}{\theta}} c_H^{\frac{\theta-1}{\theta}} + (1-v)^{\frac{1}{\theta}} c_F^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} \quad (7)$$

where θ is the elasticity of intratemporal substitution between home and foreign-produced intermediate goods. Final goods producers maximize (8) subject to (7).

$$\max_{c_H, c_F} PC - P_H c_H - P_F c_F \quad (8)$$

This maximization yields the following input demand functions for the home economy (similar conditions hold for Foreign producers)

$$c_H = v \left(\frac{P_H}{P} \right)^{-\theta} C, \quad c_F = (1-v) \left(\frac{P_F}{P} \right)^{-\theta} C \quad (9)$$

The price index that corresponds to the previous demand function is defined as:

$$P^{1-\theta} = [v P_H^{1-\theta} + (1-v) P_F^{1-\theta}] \quad (10)$$

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.

2.3 Investment goods sector

Final investment goods (x) are produced by combining home and foreign-produced intermediate goods (x_H and x_F) in the following manner:

$$x_t = \varepsilon_t \left[\varphi^{\frac{1}{\tau}} x_{H,t}^{\frac{\tau-1}{\tau}} + (1-\varphi)^{\frac{1}{\tau}} x_{F,t}^{\frac{\tau-1}{\tau}} \right]^{\frac{\tau}{\tau-1}}, \quad (11)$$

where φ is the share of home-produced intermediate goods in the home final investment good and τ the elasticity of substitution between home and foreign intermediate inputs. Different from final consumption goods, we assume that the production technology (11), is subject to a stochastic shock process ε_t (IST shock) that affects the amount of final production goods that are produced from a given amount of intermediate goods. Investment goods producers maximize (12) subject to (11)

$$\max_{x_H, x_F} P_{x,t}x_t - P_{H,t}x_{H,t} - P_Fx_{F,t}. \quad (12)$$

The investment goods producer's maximization problem yields the following investment demand functions and price index:

$$x_{H,t} = \varphi \left(\frac{P_{H,t}}{P_{x,t}} \right)^{-\tau} x_t \varepsilon_t^{\tau-1}, \quad x_{F,t} = (1 - \varphi) \left(\frac{P_{F,t}}{P_{x,t}} \right)^{-\tau} x_t \varepsilon_t^{\tau-1} \quad (13)$$

$$P_{x,t}^{1-\tau} = \varepsilon_t^{\tau-1} \left[\varphi P_{H,t}^{1-\tau} + (1 - \varphi) P_{F,t}^{1-\tau} \right] \quad (14)$$

The investment goods price index 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. φ , 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 .

2.4 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:

$$y_t = A_t f(k_{t-1}, h_t) \quad (15)$$

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

$$\Pi_t = P_{H_t} A_t f(k_{t-1}, h_t) - P_t w_t h_t - P_{x,t} x_t \quad (16)$$

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:

$$k_t = (1 - \delta)k_{t-1} + F(x_t, x_{t-1}) \quad (17)$$

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 $s''(1) > 0$. An alternative location of the IST shock is in the function $F(x_t, x_{t-1})$. JPT (2009) call this a marginal efficiency of investment shock. Introducing such a shock in equation (17) complicates the identification of the TFP shock, since the capital stock is required to construct the Solow residual.

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:

$$J = E_t \sum_{s=t}^{\infty} \beta^{s-t} \mu_s \left\{ \frac{\Pi_s}{P_s} \right\} + E_t \sum_{s=t}^{\infty} \beta^{s-t} \lambda_s \left[(1 - \delta)k_{s-1} + (1 - s(\frac{x_s}{x_{s-1}}))x_s - k_s \right] \quad (18)$$

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

$$\frac{\partial J_t}{\partial h_t} : \frac{P_{H,t}}{P_t} A_t F_h(k_{t-1}, h_t) - w = 0 \quad (19)$$

$$\frac{\partial J_t}{\partial x_t} : q_t(1 - s(\frac{x_t}{x_{t-1}})) = q_t s'(\frac{x_t}{x_{t-1}}) \frac{x_t}{x_{t-1}} - \beta E_t q_{t+1} \frac{\mu_{t+1}}{\mu_t} s'(\frac{x_{t+1}}{x_t}) \frac{x_{t+1}}{x_t} \frac{x_{t+1}}{x_t} + \frac{P_{x,t}}{P_t} \quad (20)$$

$$\frac{\partial J_t}{\partial k_t} : \beta E_t \frac{\mu_{t+1}}{\mu_t} \left(\frac{P_{H,t+1}}{P_{t+1}} A_t F_{k_t}(k_t, h_{t+1}) + q_{t+1}(1 - \delta) \right) = q_t \quad (21)$$

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

2.5 The relative price of investment goods

In this two-country model, the price of investment goods relative to the price of consumption goods, $\frac{P_{x,t}}{P_t}$, is a function of the terms of trade and the IST shock. We can illustrate this by taking a log-linear approximation of the price index

$$\frac{P_{x,t}}{P_t} = \frac{P_{x,t}}{P_{H,t}} \frac{P_{H,t}}{P_t} \quad (22)$$

around its steady state value making use of the investment and consumption goods price indices.²

$$\begin{aligned} \widehat{\frac{P_{x,t}}{P_t}} &= \widehat{\frac{P_{x,t}}{P_{H,t}}} + \widehat{\frac{P_{H,t}}{P_t}} \\ &= (1 - \varphi) \widehat{\frac{P_{F,t}}{P_{H,t}}} - \hat{\varepsilon}_t + (v - 1) \widehat{\frac{P_{F,t}}{P_{H,t}}} \\ &= (v - \varphi) \hat{T}_t - \hat{\varepsilon}_t \end{aligned} \quad (23)$$

This shows that the log-deviation, denoted by a " $\hat{\cdot}$ ", 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 investment goods is stronger (weaker) than for consumption goods $v < \varphi$ ($v > \varphi$) then the price of investment goods is negatively (positively) related to the terms of trade. Assume the terms of trade depreciate

²We 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 holds, we can define the terms of trade as $T = P_F/P_H$

(rise), say due to a rise in the price of imported intermediate goods. If there is more home bias in consumption than investment ($v > \varphi$), the investment goods sector is more import intensive than consumption. This means that following a rise in the relative price of imported intermediate inputs, the relative price of investment goods with respect to consumption rises. This highlights the role of $(v - \varphi)$ for our results.

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: $v = \varphi = 1$, 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. This case is very common in the literature, see for instance Heathcote and Perri (2002), Backus et al (1994), or Corsetti et al's (2008) alternative calibration. When $v \neq \varphi$, the relative price of investment goods is affected by all factors that cause the terms of trade to deviate from its steady state value.

2.6 Tobin's q and the Relative Price of Capital

In this section, we analyze the link between Tobin's q and the relative price of investment goods. Taking a log-linear approximation of the first-order condition of the intermediate goods firm (20) yields the following relationship between deviations in Tobin's q and the relative price of investment goods:

$$\hat{q}_t = \left[(1 + \beta)s''(.)\hat{x}_t - s''(.)\hat{x}_{t-1} - s''(.)\beta\hat{x}_{t+1} + \frac{\widehat{P_{x,t}}}{P_t} \right] \quad (24)$$

$$\hat{q}_t = \left[(1 + \beta)s''(.)\hat{x}_t - s''(.)\hat{x}_{t-1} - s''(.)\beta\hat{x}_{t+1} + (v - \varphi)\hat{T}_t - \hat{\varepsilon}_t \right] \quad (25)$$

alternatively, if we abstract from adjustment costs, i.e. if $s''(.) = 0$

$$\hat{q}_t = \frac{\widehat{P_{x,t}}}{P_t} = (v - \varphi)\hat{T}_t - \hat{\varepsilon}_t. \quad (26)$$

Tobin's q is a function of the relative price of investment goods which is itself a function of the terms of trade as well as the IST shock.

2.7 Market Equilibrium

The solution to our model satisfies the following market equilibrium conditions must hold for the home and foreign country³:

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:

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

2.8 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.

2.9 Summary - IST shocks and the price of investment goods

Our international real business cycle model shows that IST shocks can not be uniquely identified by the relative price of investment goods. Modelling the production of final investment goods in much the same way as the production of final consumption goods, shows that the relative price of investment goods depends partly on the terms of trade. The link between the two relative prices

³Since we are characterizing a nominal model we need to specify a monetary policy rule. To obtain the flexible price allocation, we simply assume that the monetary authorities in both countries follow a strategy of setting producer price inflation equal to zero.

is determined by the degree of home bias in final consumption relative to that in final investment:

$$\widehat{\frac{P_{x,t}}{P_t}} = (v - \varphi)\hat{T}_t - \hat{\varepsilon}_t \quad (27)$$

In the following sections, we calibrate and solve the model to analyze whether or not the negative correlation between the investment rate and the relative price of investment observed in the data can be attributed to factors other than IST shocks.

3 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 utility:

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

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, $\varphi = (1 - \varphi^*) = 1$. This rather extreme assumption that $\varphi = 1$ is nevertheless also made in the baseline calibrations in Corsetti et al (2008) and Benigno and Thoenissen (2008). Section 6, performs sensitivity analysis letting φ 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 6 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.

Table 1: Baseline calibration

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

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 1 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.

4 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, the terms of trade and Tobin's q .

Assuming complete home bias in final investment goods, i.e. $\varphi = 1$, results in a positive correlation between the investment rate and the relative price of investment goods following a positive TFP shock. 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 (23) shows that the relative price of investment goods declines as the terms of trade depreciate, as long as $\varphi > v$. 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 factors that determine consumption home bias may not apply in equal measure to investment goods. Based on equation (23), the relationship between the relative price of investment goods and the terms of trade changes sign when $v > \varphi$. 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 $\varphi = 0.5$. Here, the response of the terms of trade remains the same as in the case where $\varphi = 1$. 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.⁴

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 always result in a negative correlation, regardless of the relative degree of home bias. Table 2 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 $\varphi = 1$ and $\varphi = 0.5$ calibration:

Table 2: Summary of Impulse Responses		
	A_t	IST_t
$\varphi = 1$	$x/y \downarrow, T \uparrow, P_x/P \downarrow$	$x/y \uparrow, T \uparrow, P_x/P \downarrow$
$\varphi = 0.5$	$x/y \downarrow, T \uparrow, P_x/P \uparrow$	$x/y \uparrow, T \uparrow, P_x/P \downarrow$

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

5 Second Moments

Following the impulse response analysis, this section analyzes a selection of second moments generated by the calibrated model. The selected second moments presented in Table 3 are constructed using actual data, as well as artificial model economy data. Both types of data are of quarterly frequency, logged and Hodrick-Prescott filtered with a smoothing parameter set to 1600. The

⁴The qualitative results do not change when we vary φ . The impulse response corresponds to a calibration where $\varphi = 0.75$.

sample period for the data is 1960:1 - 2006:4. We refer the reader to the appendix for details of data sources.

Table 3: Second moments: baseline model

	<i>Data</i>	<i>Model</i>						
		<i>high adjustment costs</i>			<i>low adjustment costs</i>			<i>IST</i>
<i>Correlations</i>		$\varphi = 1$	$\varphi = 0.5$	$\varphi = 0.75$	$\varphi = 1$	$\varphi = 0.5$	$\varphi = 0.75$	$\varphi = 0.75$
$\text{Corr}(\frac{P_x}{P}, \frac{x}{y})$	-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
<i>Std dev.</i>								
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 key finding of Section 4 is reflected in the second moments generated by the model, as reported in Table 3. 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 $\varphi > v$, and yields a negative correlation if φ is less than v .

The model generates a standard deviation of GDP, σ_y , somewhat in excess of the data⁵, and for the ‘high adjustment cost’ scenario, which corresponds to the baseline calibration, under predicts

⁵It 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.

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 impulse response analysis suggests that the adjustment cost parameter, $s''(.)$ plays a key role in determining the initial response of the investment rate to TFP shocks. To analyze the role of this parameter, Table 3 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 $\varphi > v$ and positive when $\varphi < v$, the exact opposite of the ‘high adjustment cost’ scenario. This exercise also shows that for small adjustment costs and $\varphi \neq 1$, the current account is counter-cyclical and more volatile than in the ‘high adjustment’ cost case. The next section analyses the joint role of adjustment costs and home bias in investment in more detail.

The column headed ‘IST’ reports the second moments generated by our model when all the dynamics are driven by IST shocks. As the impulse response analysis suggest, this version of the model generates a negative correlation between the relative price of investment and the investment rate. 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.

6 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 φ for a given v) and the extent of adjustment costs. This section, analyzes how the correlation responds to changes in both φ 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 φ and the adjustment cost parameter, thus the terms of trade always rise (depreciate) following a positive TFP shock.

6.1 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 φ 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 $\varphi > v$ the correlation is negative for small values of the adjustment cost parameter and rises as $s''(.)$ increases; and (ii) for $\varphi < v$ the correlation is positive for small values of the adjustment cost parameter and declines as $s''(.)$ rises.

In region (i), where $\varphi > v$ 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 (23) without the IST shock: $\widehat{\frac{P_{x,t}}{P_t}} = (v - \varphi)\hat{T}_t$. 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

⁶We 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. 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 investment relative to output declines, so that the investment rate eventually falls, along with the relative price of investment goods, resulting in a positive correlation.

In region (ii), where $\varphi < v$, there is a positive relationship between the relative price of investment goods and the terms of trade. 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 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 φ and $s''(.)$ (keeping all other parameters constant). Without taking a stand on the likelihood of either φ or $s''(.)$ taking a particular value, what is the most likely value of the correlation? Assuming that φ 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.

6.2 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:

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

where $\phi(\cdot)$ 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). Figures 7 and 8 show 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.

6.3 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 9, 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 10 analyzes the role of the labor supply elasticity, η . In the baseline calibration, $\eta = 0.25$, Figure 10 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 10 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 4 reports the average correlation of further selected robustness checks.

Table 4: 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.

6.4 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 $\varphi < v$) 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 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.

7 Empirical connections

The upshot of this analysis is that in an international economy the fluctuation of the relative price of investment goods has an international component captured by the terms of trade term in (23). The short run fluctuation of the terms of trade can be driven by both TFP and IST shocks. Impulse responses analyzed in Section 4 show that the terms of trade positively covaries with both IST and TFP shocks regardless of the relative home bias. This makes the identification of the IST shock in

terms of the relative price of investment goods potentially difficult in an open economy, except for the special case when the home bias in consumption equals the home bias in investment.

How important empirically is this *terms of trade effect* on the relative price of investment goods? To address this question, we examine the relationship between these two relative prices for 10 major OECD countries. The relative price of investment is computed by taking the ratio of the deflator of gross capital formation to the deflator for private consumption expenditure. The terms of trade is the ratio of the import to export deflators. Both relative prices are log- detrended to make it comparable to the log-linearized deviations from the steady state. Table 5 presents the Newey-West autocorrelation adjusted regression coefficients of the terms of trade for all these countries. Except for Australia and Korea, they are all significant at no less than 88% levels of significance. For USA, UK, Canada and Italy the international effect is quite substantial represented by the R^2 . About 50% of the variation of the relative price of investment is attributed to the movement of the international terms of trade. ⁷

Table 5: Regression of relative price of investment goods on the terms of trade

	$\widehat{\frac{P_{x,t}}{P_t}}$										
	US	UK	CAN	ITA	France	CH	NL	NZ	Kor	Aus	Pooled
\hat{T}_t	0.594*	0.901*	-0.672*	0.267*	0.138**	0.280**	0.570**	-0.293*	.03	0.001	0.08*
St. err	0.067	0.139	0.0907	0.046	0.073	0.172	0.355	0.065	.06	0.035	0.01
R^2	0.566	0.455	0.523	0.505	0.052	0.068	0.073	0.209	.004	0.001	0.49

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 95%, ** significant at 88%. Sample periods: US, UK and Aus 1960:1-2008:4;

Canada 1961:1-2008:3, Italy 1981:1 - 2008:3; France 1978:1 - 2008:4; CH 1980:1 - 2008:3; NL 1988:1 - 2008:3;

Kor 1970:1-2008:3; NZ 1987:2 - 2008:3, Pooled regression 1988:1 - 2008:3

Table 5 also reports the results of a balanced pooled regression for all 10 countries after allowing for a country fixed effect and a fixed time effect. The terms of trade has a significantly positive effect on the relative price of investment as well as a reasonably high R^2 statistic suggesting that the international effect on the relative price of investment goods cannot be ignored. These regression experiments do not necessarily establish any causal relationship between the relative price of invest-

⁷ The regression coefficients basically reflect the relative home bias of consumption with respect to investment. For majority of these countries the home bias in consumption exceeds the home bias in investment.

ment and the terms of trade because both these relative prices are determined by the fundamental shocks, namely TFP and IST. However, it does strengthen our point that identifying IST shocks by the relative price of investment goods is not robust in an open economy setting.

8 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.

A regression exercise using OECD data suggests that the terms of trade effect on the relative price of investment goods may be important. This exercise suggests 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.

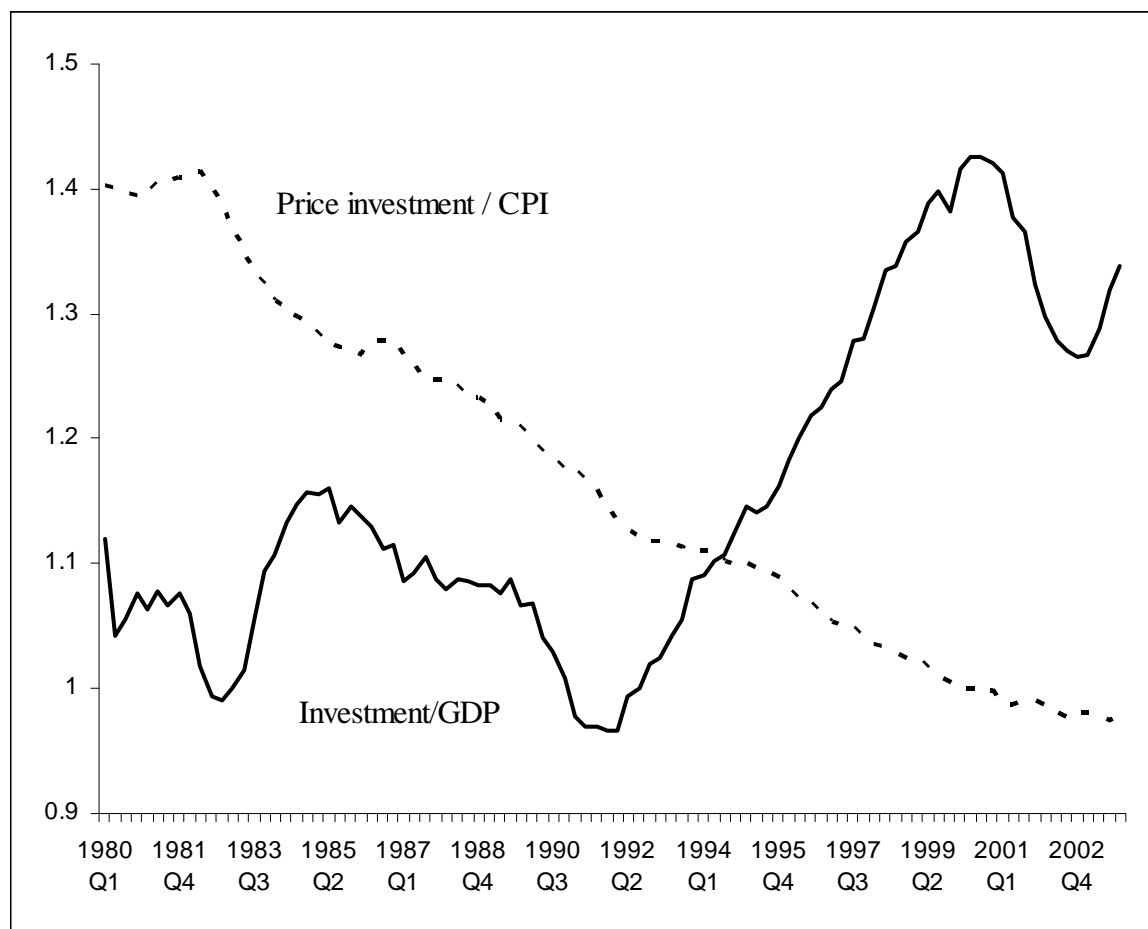


Figure 1: The relative price of investment goods and the investment to GDP ratio.

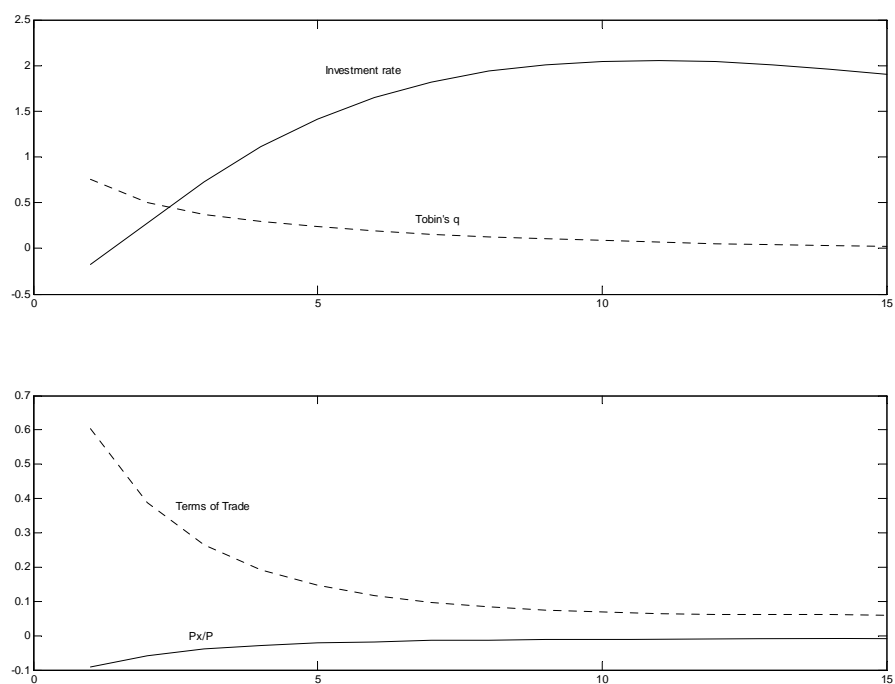


Figure 2 Impulse response function following a unit TFP shock, when $\phi = 1$.

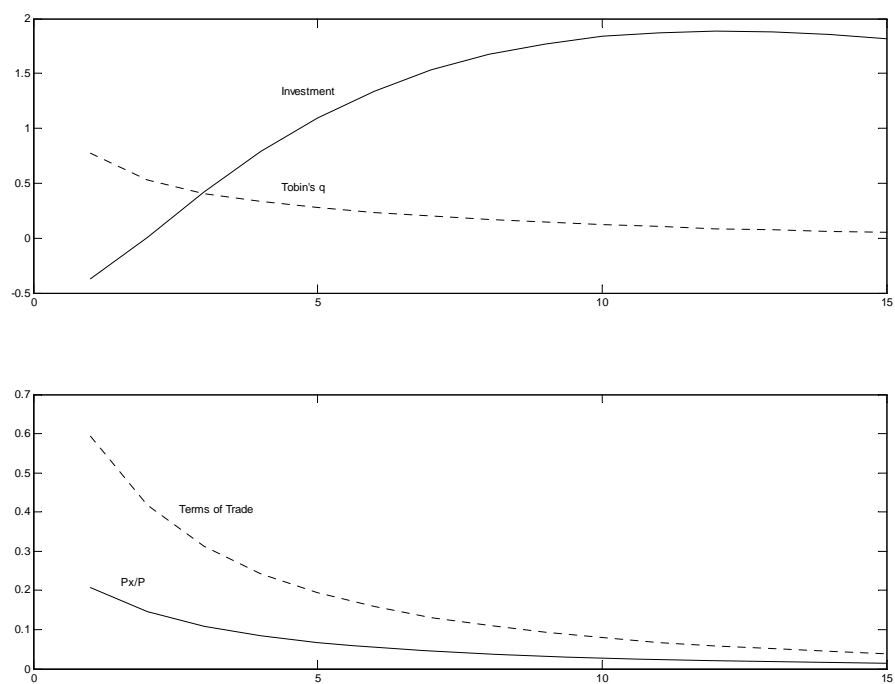


Figure 3 Impulse response function following a unit TFP shock, when $\phi = 0.5$.

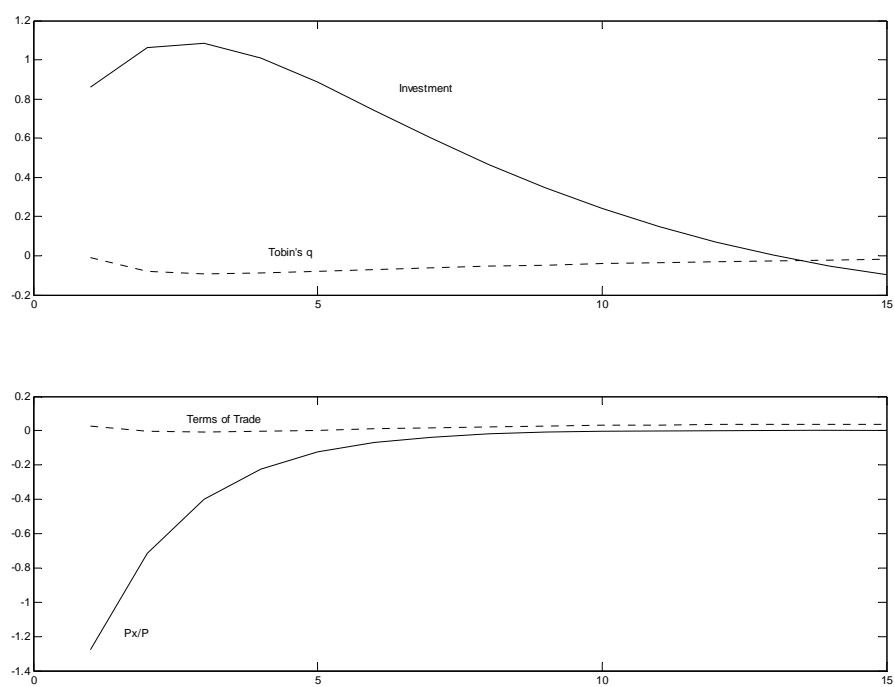


Figure 4 Impulse response function following a unit IST shock, when $\phi = 0.75$

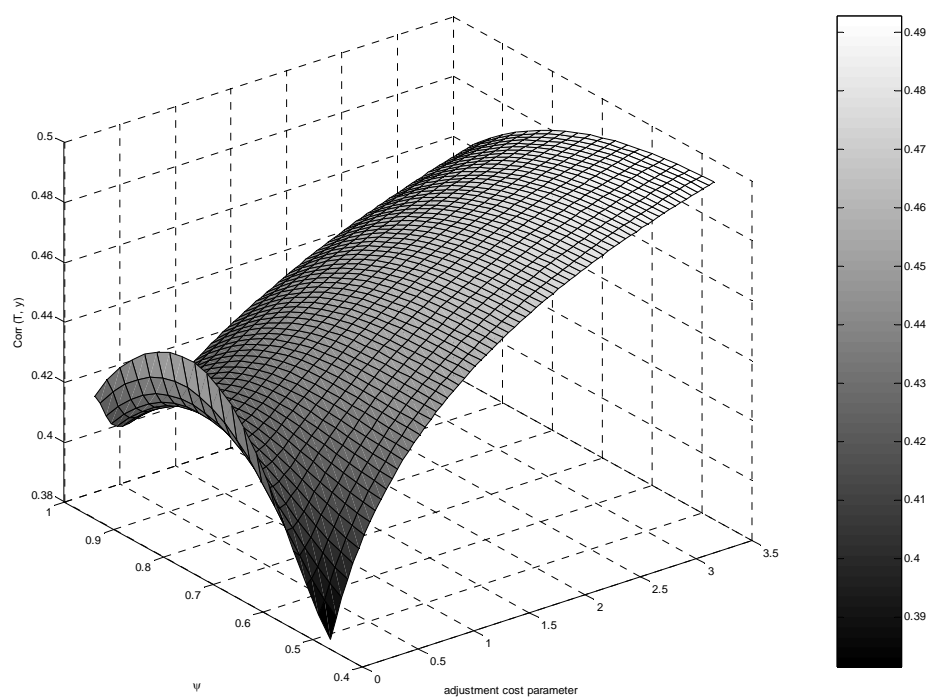


Figure 5 The correlation between the terms of trade and output for various values of ϕ and the adjustment cost parameter.

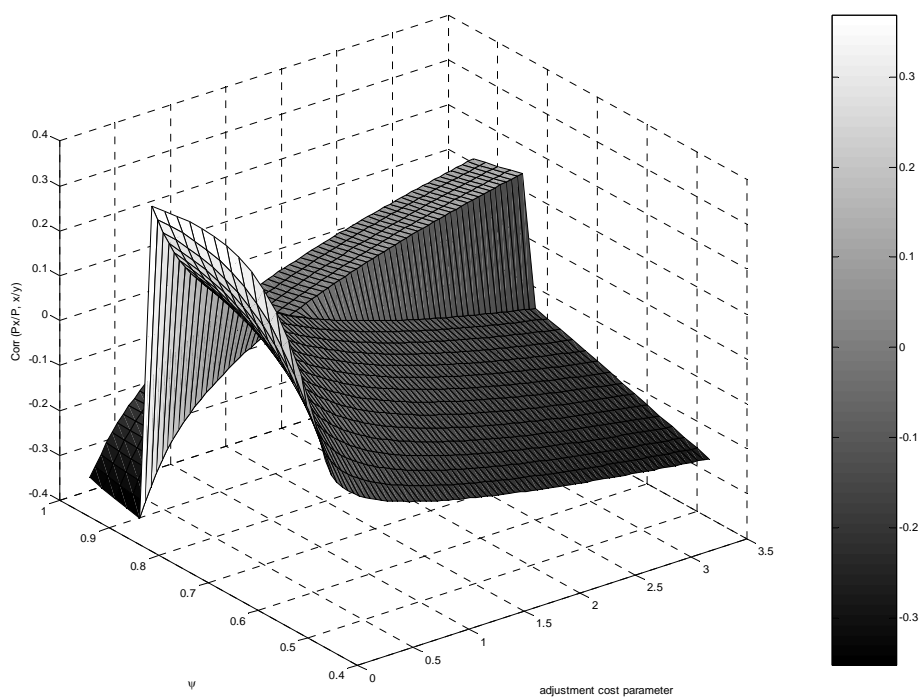


Figure 6 Investment adjustment costs a la Christiano et al (2005). Average correlation: -0.07

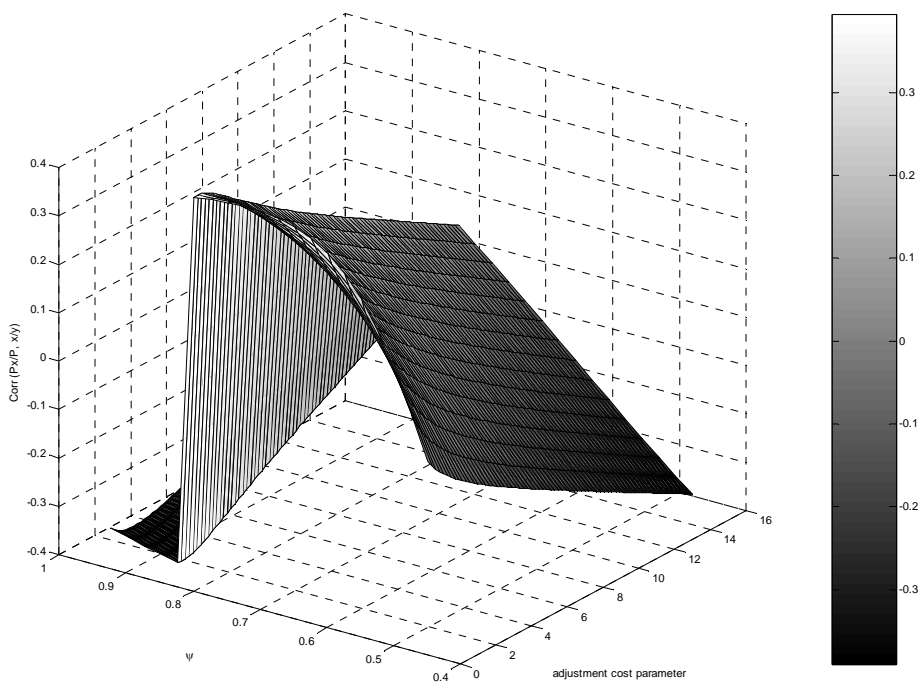


Figure 7 Quadratic capital adjustment costs, a la Hayashi (1982). Average correlation: -0.05

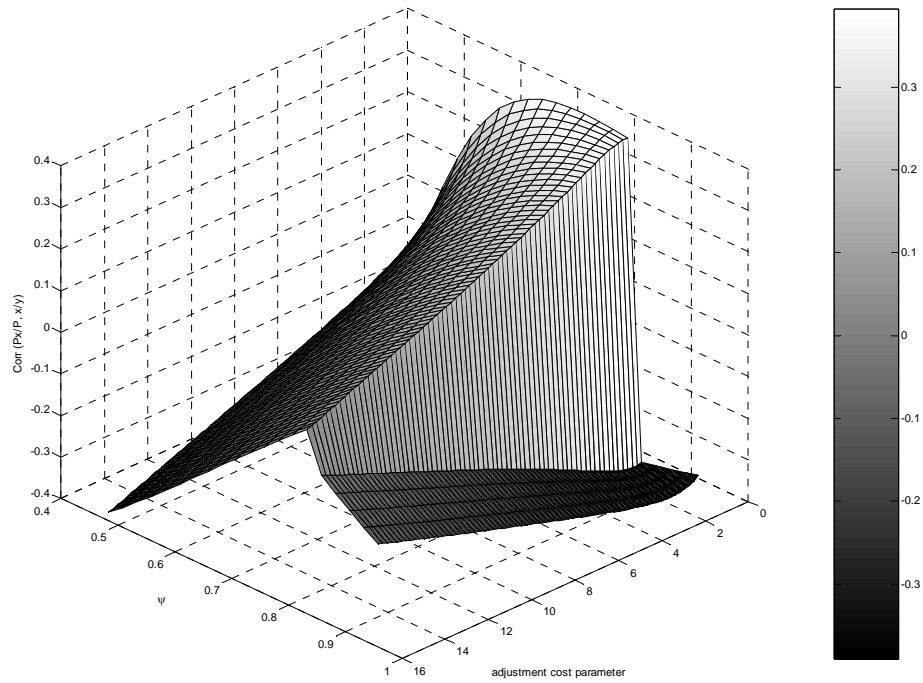


Figure 8 Quadratic adjustment costs, reverse angle.

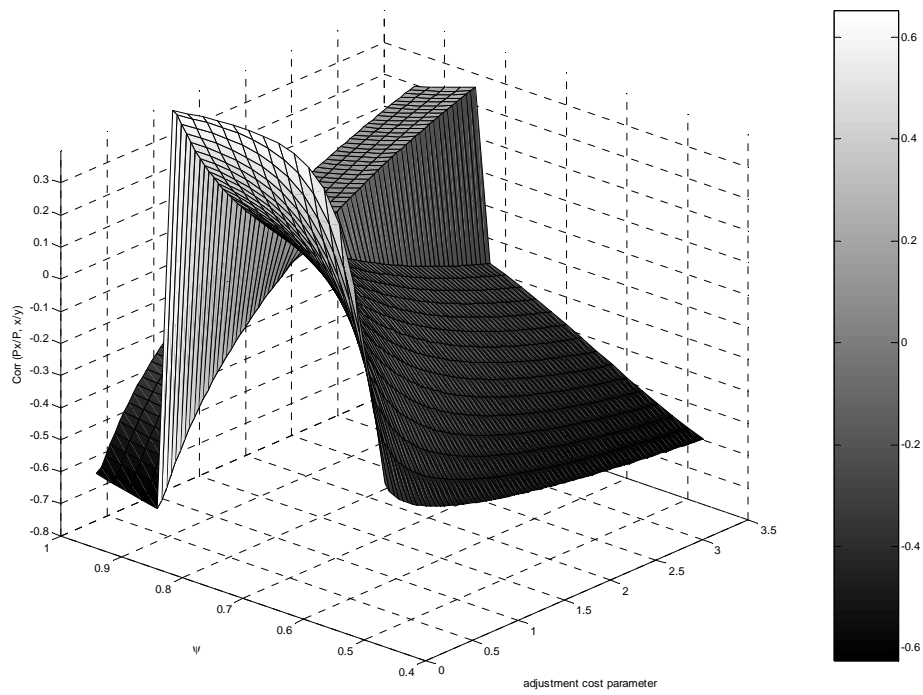


Figure 9 No consumption habits. Average correlation: -0.15

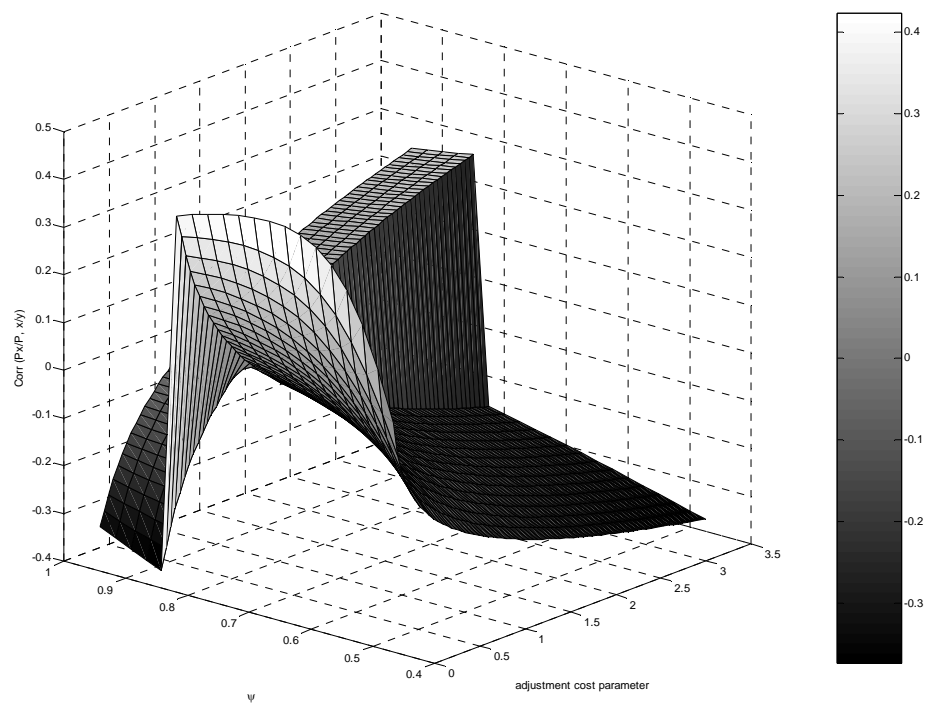


Figure 10 Investment adjustment costs, $\eta = \rho$. Average correlation: -0.1

ABOUT THE CDMA

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Johannes Geissler
Castlecliffe, School of Economics and Finance
University of St Andrews
Fife, UK, KY16 9AL

Email: jg374@at-andrews.ac.uk; Phone: +44 (0)1334 462445; Fax: +44 (0)1334 462444.