The Balassa-Samuelson and the Penn effect: are they really the same ?*

Job Market Paper

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Abstract

According to the Balassa-Samuelson effect, productivity gains in the domestic tradable sector raise the relative price of domestic non-tradables causing deviations from the purchasing power parity. In the literature, the Balassa-Samuelson effect is typically invoked to explain the Penn effect, according to which the price level is higher in richer countries, so that their real income is overstated if converted at market exchange rates. In this paper, using a two-country, two-sector international real business cycle model, which closely follows Stockman and Tesar (1995) and Benigno and Thoenissen (2008), we show that the Balassa-Samuelson effect only explains the Penn effect either for a sufficiently high trade elasticity or for a low degree of home bias; if asset markets are incomplete, furthermore, it does so also in the presence of high complementarity between tradables and non-tradables or for a low share of tradables in consumption. These results are coherent with the empirical evidence, which generally supports the prediction of the Balassa-Samuelson model about relative price of non-tradables but is more controversial about real exchange rate appreciation in response to productivity gains in tradables.

Keywords: Balassa-Samuelson effect, Penn effect, real exchange rate.
JEL Codes: F3, F4.

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1 Introduction

The real exchange rate (RER), defined as the relative price of a common basket of goods denominated in the same currency across countries, is one of the most important and debated prices in international economics. Comprehending its dynamics is extremely relevant to understand the performance of the main macroeconomic variables in an open economy framework. The economic literature on this topic is extensive but it has not yet reached a general consensus. The interpretation of the RER behavior generally rests on the purchasing power parity (PPP) theory which was introduced by Cassel in 1916 and, in its absolute version, states that the RER must be constant and equal to 1 over time. Therefore RER variations represent deviations from the PPP equilibrium.

The Penn studies of Gilbert and Kravis (1954) and of Heston, Kravis and Summers (1978, 1983) prove that the PPP in its absolute version does not hold. They show that comparing GDP per capita converted at market exchange rates across countries provide biased results. The incomes per capita of rich countries are overestimated while those of low income countries are underestimated. Market exchange rates give a misleading picture because they are largely affected by capital movements and are computed taking into account only tradable goods, whose prices tend to converge across countries because of international trade. They do not consider the prices of non-tradable goods which are higher in richer countries and vary with the level of incomes. The deviations between GDP per capita converted at market rates and at PPP rates shrink as we move from low to high income countries. These findings were firstly defined by Samuelson as the Penn effect.

The Penn effect and the misalignments of the RER from its PPP equilibrium are often explained in terms of the Balassa-Samuelson (B-S) theorem which was introduced by Balassa and Samuelson in two seminal papers in 1964. The B-S hypothesis in its original form rests on some stringent premises. It assumes a perfectly competitive economy that produces a tradable and a non-tradable good, where the variations in relative prices are independent of changes in agents' demand and preferences. Agents have the same preferences across countries. Capital is perfectly mobile. Labor is internationally immobile but it can perfectly migrate among the two sectors within the same economy. The PPP always holds for tradable goods. The economy is constantly at its full-employment level. The B-S model provides two main predictions. A faster growth of productivity in the tradable sector than in the non-tradable sector causes an increase in the relative price of non-tradable goods, i.e. movements in the relative price of non-tradables are explained by productivity differentials across sectors. This mechanism is known as the internal transmission channel of the B-S effect. However the B-S model also encompasses an external transmission mechanism: a more rapid growth of the relative prices of the non-tradable goods in the domestic country with respect to the foreign country, implied by a raise in the relative productivity differential across countries, leads to an appreciation of the RER, i.e. RER dynamics are explained by deviations in the relative price of non-tradables across countries.

In this paper, we use a baseline 2-country, 2-sector, international real business cycle model, which closely follows Stockman and Tesar (1995) and Benigno and Thoenissen (2008), to test both the predictions of the B-S theorem. We analyze the response of the relative price of non-tradable goods, the terms of trade, the RER and the relative consumption across countries to a 1% productivity shock in the domestic tradable sector, both in a complete and in an incomplete asset market framework with only one non contingent bond traded across countries. This choice is due to our aspire to study the link between productivity gains in the domestic tradable sector and both the relative price of non-tradable goods and the RER. Our aim is to understand under what conditions the predictions of the B-S model hold and in particular when an increase in the relative price of non-tradables led by a productivity shock to the tradable sector causes a RER appreciation, i.e. when the B-S effect is able to explain the Penn effect. The terms of trade are included among the relevant variables because, in presence of home bias, they also contribute to the dynamics of the RER. Furthermore the relative consumption across countries is a significant variable because in this type of models it is structurally linked to the RER by the international risk sharing condition.

We first conduct our investigation under a standard parameterization which allows a careful interpretation of the basic mechanisms of the model and then we carry out a large sensitivity analysis. Our results show that a productivity innovation to the tradable sector always leads to an increase in the relative price of non-tradable goods while the effect on the RER largely depends on the model parameterization. In particular, we find that, if asset markets are complete, the RER appreciates either for a sufficiently high intratemporal elasticity of substitution between domestic and foreign goods or for a low degree of home bias. If markets are incomplete, instead, the RER appreciates not only under these two calibrations but also either for a low intratemporal elasticity of substitution between tradables and non-tradables or for a low share of tradables in consumption basket. Hence, we argue that the use of the B-S effect and the Penn effect as synonymous, as often occurs in the literature, it is not correct. Indeed, with realistic home bias in spending, the RER dynamics depend on the contrasting effects of both the relative price of non-tradables and the terms of trade. Thus whether a rise in the relative price of non-tradable goods implies a RER appreciation depends on the size and the sign of the terms of trade movements. With high trade elasticity, international relative prices are less sensitive to a change in the relative supply of tradable goods while quantities are more responsive. This implies that the response of the terms of trade is flatter and thus the RER dynamics are dominated by the increase in the relative price of non-tradables. With low home bias, the terms of trade variations affect the RER to a limited extent. Thus, after a productivity gain in the domestic tradable sector, the RER appreciates because of the raise in the relative price of non-tradables. A higher complementarity between tradable and non-tradable goods implies a stronger response of the relative price of non-tradables to a productivity innovation in the tradable sector which consequently dominates the terms of trade effect and causes a RER appreciation. Finally, with a high share of non-tradable goods in the consumption basket the role of the terms of trade in affecting the RER weakens in favor of the relative price of non-tradables and thus the RER appreciates.

The theoretical results of this model are coherent with the empirical literature on the topic as it is illustrated in the next section. The empirical evidence generally supports the validity of the internal transmission mechanism while the support in favor of the external transmission channel is much weaker and controversial.

The remainder of the paper is structured as follows: section 2 provides a brief overview of the recent developments in the empirical and theoretical literature on the B-S effect. Section 3 describes the 2-country, 2-sector international real business cycle model. Section 4 illustrates the calibration. Section 5 presents the impulse response analysis. Section 6 shows a mapping of the results. Section 7 offers some concluding remarks.

2 Related literature

With regard to the theoretical literature[1] on the B-S effect, Rogoff (1992) is the first work to encompass the B-S theorem in a dynamic general equilibrium framework. He shows that in a small open economy with perfect competition, perfect capital market, perfect mobility of production factors within a country and with the LOOP that holds for tradable goods, relative prices depend only on technology and factor intensities since demand side factors have no effect and the terms of trade are constant.

De Gregorio, Giovannini and Wolf (1994) building up on Rogoff (1992)'s model but relaxing his stringent assumptions, show that the supply curve is not flat and thus shifts in government expenditures and preferences affect relative prices. Moreover they provide a proof of the role played by the terms of trade in determining the variability of the RER.

Asea and Mendoza (1994), using a 2-country neoclassic dynamic general equilibrium model, obtain closed form solutions for the RER and the relative price of non-tradable goods and generate the main B-S propositions as long run implications. Their model shows that in the long run deviations from the PPP are driven by the relative price of non-tradable goods which is a function of the ratio of marginal productivity of labor in the tradable and non-tradable sector. However in the short run the relative productivity of the tradable sector determines only the supply of non-tradable goods relative to tradable goods. Demand depends on the marginal rate of substitution between tradable and non-tradable goods.

Ghironi and Melitz (2004) develop a 2-country dynamic stochastic general equilibrium model which is able to explain both international trade and macroeconomic dynamics. This model, which features imperfect market competition, heterogeneous firms, endogenous entry and exit in the do-

[1] For a large review of the theoretical and empirical literature on the B-S theorem see Bahmani-Oskooe and Nasir (2005) and Tica and Druzic (2006).

mestic and in the export markets, generates persistent deviations of the RER from the PPP equilibrium and provides an endogenous micro founded explanation of the B-S effect.

Bergin, Glick and Taylor (2006) observe that in a large sample of countries over the period 1950-1995 the B-S effect on relative prices strengthened only in recent years while it was almost insignificant 50 years ago. Then they build up a model with a continuum of good differentiated by productivity, heterogeneous trade costs and endogenous tradability of goods which reproduces the evolution of the B-S effect over time.

The empirical work that studies the validity of the B-S theorem is very extensive. Many different econometric techniques have been adopted: cross section, time series, panel data and more recently cointegration. Most of the studies refer to the advanced countries but there are also some contributions that focus on the emerging markets. In the 90s, there have been numerous papers on the role of the B-S effect in central-eastern European countries in transition.

Among the cross-sectional studies, Officer (1976), using a sample of 15 industrial countries over the period 1950-1973 independently of the benchmark country and of the productivity measure, does not find supporting evidence for the B-S theorem. His results show that there is no significant relationship between the RER and the relative productivity differential. On the contrary Kravis and Lipsey (1982), utilizing a sample of 16 countries for 1970 and of 34 countries for 1975, find a significant relationship between the RER and the relative productivity differential. They also provide evidence of the role played by some structural factors, such as the degree of openness of the economy and the share of non-tradable goods in output, in driving the RER dynamics.

Hsieh (1982) claims that cross-sectional studies are not able to find support for the B-S findings because ignore country-specific factors. He considers Germany and Japan against their respective trading partner over the period 1954-1976. Exploiting time series methodologies, he finds that deviations of the RER from the PPP are significantly explained by cross-country relative productivity differentials. Whether time series studies do not take into account the possible non-stationarity of the data they are likely affected by spurious regression problems. To cope with this concern, cointegration techniques have been adopted. Rogoff (1992) using quarterly data for the real yen-dollar exchange rate for the period 1975-1991 and Engel and Granger cointegration analysis, finds that RER variations can not be forecasted by traded goods productivity. Instead Strauss (1996) using the Johansen cointegration procedure for seven OECD economies between 1960 and 1990 shows that productivity differentials significantly affect permanent movements in RER and in relative prices. Corsetti, Dedola and Leduc (2006) study the international transmission of a productivity innovation to the tradable sector across 5 industrial countries, Germany, Italy, Japan, the UK and the US carrying out a structural VAR where the shock is identified using long run restrictions. They find that the relative price of non-tradable goods always increases after a tradable productivity gain but the response of the RER and the terms of trade are heterogeneous across countries. Their results are remarkable under two main aspects: the B-S effect is not a reliable explanation of the Penn effect for the UK and Italy and terms of trade movements can also raise the consumption risk linked to asymmetric productivity shocks as in the case of the USA and Japan.

With regard to panel data studies, Asea and Mendoza (1994) in a sample of 14 OECD countries over the period 1970-1985 , show that in the long run there is a significant positive relationship between productivity differentials and relative prices but the relationship between relative prices of non-tradables and the RER is not significant. A similar conclusion is reached by De Gregorio, Giovannini and Wolf (1994). They also find a role for demand shifts in driving relative price movements. These conclusions may not be robust because of the low power of the test with short samples, thus many studies exploit panel cointegration techniques to overcome this concern. Canzoneri, Cumbi and Diba (1999) in a sample of 13 OECD countries over the period 1960-1993 test both the validity of the PPP for tradable goods and the relationship between relative prices and relative productivity using Pedroni cointegration test. Their results bring empirical support only to the latter mechanism predicted by the B-S theorem. Finally, Ricci, Milesi-Ferretti and Lee (2008) estimate a cointegrating relationship between the RER and a large set of macroeconomic fundamentals for a panel of 48 countries that represent more than 90% of the world trade between 1980 and 2004. They find a significant relationship between relative productivity differentials and the RER but the estimated coefficient is small.

Overall the empirical literature supports the validity of the internal transmission channel of the B-S effect. Instead, the evidence in favor of the external transmission channel is much weaker and controversial mainly when countries with a flexible exchange rate are considered. Under a floating exchange rate the high variability of the nominal exchange rate drives the international relative price of tradable goods away from the PPP therefore the most important assumption on which the B-S theorem is based does not hold. The assumptions on which the B-S theorem rests are very stringent (LOOP, full employment, perfect mobility of labor, equal tastes across countries) and many reasons may cause the lack of empirical consensus towards the validity of the external channel of the B-S theorem. For instance, it is a common result in the literature that the LOOP holds only for a limited number of commodities (e.g. gold) which are highly traded internationally. For all the other goods the deviations from the LOOP are large, persistent, volatile and highly correlated to the volatility of the nominal exchange rate. Transaction costs and among these mainly transportation costs are surely the main cause because the LOOP is not verified in the data. The failure of the LOOP invalidates the possibility that relative productivity differentials affect the RER. Furthermore, as proposed by Tica and Druzic (2006), the choice of the numeraire country affects the significance of the results. It appears that the validity of the external B-S channel for OECD countries is more often verified when as numeraire is chosen Germany instead than the USA. This, as Obstfeld (2009) suggests, may depend on the degree of trade integration between the OECD countries and the numeraire. Moreover, the assumption of a higher growth of productivity in the tradable sector was generally confirmed in the past (e.g. Baumol and Bowen (1966)) but nowadays the introduction of new information technology tools and the liberalization of service markets pushed the productivity growth of the non-tradable service as well. Mac Donald and Ricci (2005, 2007) show that an increase in productivity in the non-tradable sector contributes to the appreciation of the RER. They justify this result noticing that tradable are produced and distributed using non-tradables. Furthermore Lee and Tang (2007) find that using as measure of the productivity the labor productivity or the total factor productivity (TFP) is not indifferent. Whether in the former case the results obtained are in line with the predictions of the B-S model, i.e. a rise of the relative productivity differential of the tradable sector leads to an appreciation of the RER, in the latter this does not happen, at the best this relationship results to be not significant. Finally, Samuelson himself claims that the Penn effect can be difficultly enlightened by only one phenomenon.

In the literature there are other theories that explain the deviations of the RER from the PPP long run equilibrium. Bergstrand (1992) proposes a demand-oriented explanation. Agents have non-homothetic preferences, i.e. the elasticity of demand for non-tradable goods with respect to a variation of income per capita is higher than 1 whereas the same elasticity for tradable goods is lower than 1. Hence in equilibrium the demand for non-tradable goods is stronger in countries with higher income per capita and thus their relative price is higher inducing an appreciated RER with respect to to developing countries. Price levels are higher in the advance countries because non-traded goods are luxury goods whereas traded goods are needed goods. As we highlighted above, De Gregorio, Giovannini and Wolf (1994) also suggest that in the short run demand factors such as an increase in government spending and income per capita drive the relative price of non-tradables. Bhagwati (1984) offers a further justification. Non-tradable goods are labor intensive while tradable goods are capital intensive. Advanced countries are capital abundant whereas developing countries are labor abundant, thus the former will have a comparative advantage in producing tradables and therefore their relative price of non-tradable goods will be higher leading to a more appreciated RER.

3 The model

The model, which follows closely Stockman and Tesar (1995) and Benigno Thoenissen (2008), is a two-country, two-sector international real business cycle model. The 2 countries are perfectly symmetric[2]. Each country is completely specialized in the production of a tradable intemediate input. Moreover it also produces a non-tradable intermediate input. We consider 2 alternative asset market structures: a complete and an incomplete market framework.

[2] Foreign variables and parameters are denoted by a star ($*$).

3.1 Preferences

The two countries have equal size and are inhabited by a large equivalent number of identical, infinitely lived households. They are referred as the Home (H) and the Foreign (F) country. The preferences of the Home representative agent are defined by the following expected lifetime utility function:

$$U_t = E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left(U \left(C_t, (1 - N_t) \right) \right) \right\} \tag{1}$$

The representative agent derives utility from consumption (C_t) and from leisure $(1 - N_t)$[3] at time t . E_0 denotes the expectation conditional on the information set at time 0 and $0 < \beta < 1$ is the subjective discount factor.

The aggregate consumption index is defined by the following constant elasticity of substitution (CES) aggregator of consumption of both tradable (c_{Tt}) and non-tradable goods (c_{NTt}):

$$C_t = \left[\omega^{\frac{1}{\mu}} c_{Tt}^{\frac{\mu-1}{\mu}} + (1 - \omega)^{\frac{1}{\mu}} c_{NTt}^{\frac{\mu-1}{\mu}} \right]^{\frac{\mu}{\mu-1}} \tag{2}$$

where ω defines the wheight of the tradable good in final consumption and μ is the intratemporal elasticity of substitution between tradable and non-tradable goods. The aggregate consumption of tradable goods is given by the combination of domestic tradable good (c_{Ht}) and foreign tradable good (c_{Ft}) via a similar CES aggregator:

$$c_{Tt} = \left[\theta^{\frac{1}{\varepsilon}} c_{Ht}^{\frac{\varepsilon-1}{\varepsilon}} + (1 - \theta)^{\frac{1}{\varepsilon}} c_{Ft}^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{3}$$

where θ defines the degree of home bias in tradables and ε is the international intratemporal elasticity of substitution between domestic tradable and foreign tradable goods.

Individual demands for the non-tradable good, the domestic and the foreign tradable goods are given by:

$$c_{NTt} = (1 - \omega) \left(\frac{P_{NTt}}{P_t} \right)^{-\mu} C_t \tag{4}$$

$$c_{Ht} = \omega\theta \left(\frac{P_{Ht}}{P_{Tt}} \right)^{-\varepsilon} \left(\frac{P_{Tt}}{P_t} \right)^{-\mu} C_t \tag{5}$$

$$c_{Ft} = \omega (1 - \theta) \left(\frac{P_{Ft}}{P_{Tt}} \right)^{-\varepsilon} \left(\frac{P_{Tt}}{P_t} \right)^{-\mu} C_t \tag{6}$$

The general consumption price index is defined as:

[3] $N_t = N_t^T + N_t^{NT}$; N_t is the total labor supply, N_t^T is the labor supply allocated to the tradable sector and N_t^{NT} is the labor supply allocated to the non-tradable sector.

$$P_t = \left[\omega P_{Tt}^{1-\mu} + (1-\omega)\, P_{NTt}^{1-\mu}\right]^{\frac{1}{1-\mu}} \tag{7}$$

P_{Tt}, P_{NTt} are respectively the prices of tradable and non-tradable goods. The price index for the composite tradable good is defined as:

$$P_{Tt} = \left[\theta P_{Ht}^{1-\varepsilon} + (1-\theta)\, P_{Ft}^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} \tag{8}$$

P_{Ht}, P_{Ft} are respectively the prices of the Home and Foreign intermediate inputs.

3.2 The firms'problem

Households supply labor and rent capital to perfectly competitive intermediate-goods producing firms. Intermediate firms in the Home country produce a tradable and a non-tradable intermediate input. These input goods are produced employing capital (K_{Tt}, K_{NTt}) and labor (N_{Tt}, N_{NTt}) according to a Cobb-Douglas production function:

$$Y_{Tt} = A_{Tt} K_{Tt}^{\alpha_T} N_{Tt}^{(1-\alpha_T)} \tag{9}$$

$$Y_{NTt} = A_{NTt} K_{NTt}^{\alpha_{NT}} N_{NTt}^{(1-\alpha_{NT})} \tag{10}$$

Neither capital nor labor is internationally mobile. A_{Tt} and A_{NTt} are exogenous technology shocks and α_T and α_{NT} are the capital shares in output. Domestic and foreign tradable and non-tradable technologies, $\mathbf{A}_t = [A_{Tt};\ A_{NTt}; A_{Tt}^*;\ A_{NTt}^*]$, follow an autoregressive process:

$$\mathbf{A}_{t+1} = \mathbf{\Gamma} \mathbf{A}_t + \boldsymbol{\xi}_t \tag{11}$$

and $\mathbf{\Gamma}$ is a 4x4 matrix which characterize the autoregressive component of the process and $\boldsymbol{\xi}_t$ is a 4x1 vector of independently distributed random variables with variance covariance matrix $\mathbf{\Sigma}$. The problem of the intermediate goods producing fims is given by:

$$P_{Ht} Y_{Tt} - W_{Tt} N_{Tt} - R_{Tt} K_{Tt} \tag{12}$$

$$P_{NTt} Y_{NTt} - W_{NTt} N_{NTt} - R_{NTt} K_{NTt} \tag{13}$$

(W_{Tt}, W_{NTt}) and (R_{Tt}, R_{NTt}) denote the wage rate and the rental rate of capital. Intermediate firms choose labor and capital to maximize profits. The following first order conditions derive from the firms'maximization problem:

$$W_{Tt} = P_{Ht}\left(1-\alpha_T\right) A_{Tt} K_{Tt}^{\alpha_T} N_{Tt}^{(-\alpha_T)} \tag{14}$$

$$R_{Tt} = P_{Ht}\alpha_T A_{Tt} K_{Tt}^{(\alpha_T-1)} N_{Tt}^{(1-\alpha_T)} \tag{15}$$

$$W_{NTt} = P_{NTt}\left(1-\alpha_{NT}\right) A_{NTt} K_{NTt}^{\alpha_{NT}} N_{NTt}^{(-\alpha_{NT})} \tag{16}$$

$$R_{NTt} = P_{NTt}\alpha_{NT} A_{NTt} K_{NTt}^{(\alpha_{NT}-1)} N_{NTt}^{(1-\alpha_{NT})} \tag{17}$$

3.3 The households'problem under alternative asset market frameworks

Complete markets: households face a complete set of state-contingent securities denominated in units of domestic currency. They maximize their utility subject to the following budget constraint:

$$\begin{gathered} P\left(s^t\right) C\left(s^t\right) + P_H\left(s^t\right) I_T\left(s^t\right) + P_{NT}\left(s^t\right) I_{NT}\left(s^t\right) + \textstyle\sum_{s_{t+1}} Q\left(s^t, s_{t+1}\right) B\left(s^t, s_{t+1}\right) = \\ = B\left(s^{t-1}, s_t\right) + W_T\left(s^t\right) N_T\left(s^t\right) + W_{NT}\left(s^t\right) N_{NT}\left(s^t\right) + R_T\left(s^t\right) K_T\left(s^t\right) + R_{NT}\left(s^t\right) K_{NT}\left(s^t\right) \end{gathered} \tag{18}$$

$I_T\left(s^t\right)$ and $I_{NT}\left(s^t\right)$ are the investment respectively carried out in the tradable and in the non-tradable sector. $B\left(s^t, s_{t+1}\right)$ is the amount of bonds purchased by the domestic households after history s^t that pays one unit of domestic currency if and only if state s_{t+1} occurs. $Q\left(s^t, s_{t+1}\right)$ is the price of the bond denominated in units of the Home currency. Households'incomes stem from providing labor and renting capital to intermediate firms. Moreover they receive interest payments from bonds. Households allocate their resources to final consumption and investment. Under the complete market assumption the equilibrium is always stationary.

Incomplete markets: a single nominal risk-free non-contingent bond is traded internationally. Households maximize their utility subject to the following budget constraint:

$$P_t C_t + P_{Ht} I_{Tt} + P_{NTt} I_{NTt} + Q_t B_t = B_{t-1} + W_{Tt} N_{Tt} + W_{NTt} N_{NTt} + R_{Tt} K_{Tt} + R_{NTt} K_{NTt} \tag{19}$$

Q_t is the price of the bond purchased at time t. B_t is the nominal bond denominated in Home currency purchased at time t which pays one unit of domestic currency at time $t+1$ independently of the state that occurs. In this framework, one country's debt corresponds to the other country's credit ($B_t < 0$ is a debt). The international trade of the bond is subject to a quadratic bond holding cost that, as shown by Schmitt-Grohé and Uribe (2001), ensures the stationarity of the solution.

As we highlighted above, investments are carried out both in the tradable and in the non-tradable sector. Thus aggregate investment is a composite good comprising both tradable and non-tradable goods:

$$I_t = \left[\omega^{\frac{1}{\mu}} I_{Tt}^{\frac{\mu-1}{\mu}} + (1-\omega)^{\frac{1}{\mu}} I_{NTt}^{\frac{\mu-1}{\mu}}\right]^{\frac{\mu}{\mu-1}} \tag{20}$$

Investment can be allocated freely to both sectors:

$$K_t = K_{Tt} + K_{NTt} \tag{21}$$

and they have the same price deflators of consumption. Capital in both sectors is subject to a standard law of motion:

$$K_{Tt+1} = (1-\delta) K_{Tt} + I_{Tt} \tag{22}$$

$$K_{NTt+1} = (1-\delta) K_{NTt} + I_{NTt} \tag{23}$$

where δ is the depreciation rate which is assumed to be equal across sectors. Combining the first order conditions with respect to K_{Tt+1}, K_{NTt+1}, N_{Tt}, N_{NTt} and B_{t+1} with the first order condition with respect to C_t, we obtain:

$$U_C(C_t, (1-N_t)) \frac{P_{Ht}}{P_t} = \beta E_t \left\{ \frac{U_C(C_{t+1}, (1-N_{t+1}))}{P_{t+1}} \left[(1-\delta) P_{Ht+1} + R_{t+1}^T\right] \right\} \tag{24}$$

$$U_C(C_t, (1-N_t)) \frac{P_{NTt}}{P_t} = \beta E_t \left\{ \frac{U_C(C_{t+1}, (1-N_{t+1}))}{P_{t+1}} \left[(1-\delta) P_{NTt+1} + R_{t+1}^{NT}\right] \right\} \tag{25}$$

$$\frac{U_{N^T}(C_t, (1-N_t))}{U_C(C_t, (1-N_t))} = \frac{W_t^T}{P_t} \tag{26}$$

$$\frac{U_{N^{NT}}(C_t, (1-N_t))}{U_C(C_t, (1-N_t))} = \frac{W_t^{NT}}{P_t} \tag{27}$$

$$Q_t = \beta E_t \left\{ \frac{U_C(C_{t+1}, (1-N_{t+1}))}{U_C(C_t, (1-N_t))} \frac{P_t}{P_{t+1}} \right\} \tag{28}$$

3.4 Market clearing conditions

The market clearing for intermediate tradable input goods requires that:

$$Y_{Tt} = c_{Ht} + c_{Ht}^* + I_{Tt} \tag{29}$$

$$Y_{Tt}^* = c_{Ft} + c_{Ft}^* + I_{Tt}^* \tag{30}$$

The market clearing for intermediate non-tradable input goods requires that:

$$Y_{NTt} = c_{NTt} + I_{NTt} \tag{31}$$

$$Y^*_{NTt} = c^*_{NTt} + I^*_{NTt} \tag{32}$$

Since we assume that the endowment of time in each country is equal to 1, we obtain the following labor constraints[4]:

$$1 = N_{Tt} + N_{NTt} + L_t \tag{33}$$

$$1 = N^*_{Tt} + N^*_{NTt} + L^*_t \tag{34}$$

The market clearing for bonds depends on the asset market framework assumed. If markets are complete we have:

$$B\left(s^t, s_{t+1}\right) + B^*\left(s^t, s_{t+1}\right) = 0 \tag{35}$$

If there is a single noncontingent bond we have:

$$B_t = B^*_t \tag{36}$$

3.5 Equilibrium

An equilibrium is a a set of prices P_{Ht}, P_{NTt}, P_{Ft}, W_{Tt}, W_{NTt}, R_{Tt}, R_{NTt}, P^*_{Ht}, P^*_{NTt}, P^*_{Ft}, W^*_{Tt}, W^*_{NTt}, R^*_{Tt}, R^*_{NTt}, Q_{t+1} and allocations c_{Ht}, c_{NTt}, c_{Ft}, I_{Tt}, I_{NTt}, L_t, B_{t+1}, K_{Tt}, K_{NTt}, N_{Tt}, N_{NTt}, c^*_{Ht}, c^*_{NTt}, c^*_{Ft}, I^*_{Tt}, I^*_{NTt}, L^*_t, B^*_{t+1}, K^*_{Tt}, K^*_{NTt}, N^*_{Tt}, N^*_{NTt} such that for all $t > 0$ equations (2) to (10) and (12) to (36) are satisfied given (11) and the initial conditions B_0, K_0 and K^*_0.

3.6 Additional variables of interest

The RER, i.e. the relative price of a common basket of goods denominated in the same currency across countries, is defined as:

$$RER_t = \frac{\nu_t P^*_t}{P_t} \tag{37}$$

where ν_t is the nominal exchange rate and P^*_t is the general price index in the foreign country. An increase (decrease) of RER_t corresponds to a RER depreciation (appreciation).

The terms of trade, i.e. the relative price of domestic imports in terms of Home exports, are defined as follows:

$$TOT_t = \frac{P_{Ft}}{\nu_t P^*_{Ht}} \tag{38}$$

An increase (decrease) of TOT_t corresponds to a terms of trade worsening (improvement).

Whether the absolute PPP holds, the RER is equal to 1, i.e. the price of a same basket of goods denominated in the same currency is equal across countries. Thus RER variations represent

[4] L_t and L^*_t define the time allocated to leisure respectively in the Home and in the Foreign country.

misalignments from the PPP equilibrium. In this model, notwithstanding the LOOP for tradable goods always holds ($P_{Ht} = \nu_t P^*_{Ht}$ and $P_{Ft} = \nu_t P^*_{Ft}$), the PPP fails because of the home bias in spending of tradable goods and the presence of non-tradable goods in the consumption basket. To understand the RER dynamics and the role of the B-S effect in driving its deviations from the PPP equilibrium, we express the RER as the product of two different components[5]:

$$RER_t = \left(\frac{\nu_t P^*_{Tt}}{P_{Tt}}\right)\left(\frac{P_{Tt}}{P_t}\frac{P^*_t}{P^*_{Tt}}\right) \tag{39}$$

which can be approximated following Corsetti, Dedola, Leduc (2008) as:

$$R\hat{E}R_t = \left[(2\theta - 1)\, T\hat{O}T_t\right] + \left[\Omega\left(\hat{q}^*_t - \hat{q}_t\right)\right] \tag{40}$$

where q_t is the relative price of non-tradable goods $\left(\frac{P_{NTt}}{P_{Ht}}\right)$ and Ω is a constant[6]. The first parenthesis contains the terms of trade component: movements in the terms of trade are a source of failure of the PPP in presence of home bias in spending of tradable goods. Variations in the terms of trade are not included in the standard B-S model presented by Obstfeld and Rogoff (1996). The second parenthesis contains the B-S channel: changes in the relative prices of non-tradable goods across countries cause RER deviations from the PPP equilibrium. Therefore under certain conditions the dynamics of the RER are driven both by changes in the terms of trade and in the relative price of non-tradable goods. In presence of home bias, a shift of the terms of trade has, ceteris paribus, a positive effect on the RER, i.e. a depreciation (an appreciation) of the terms of trade implies a depreciation (an appreciation) of the RER. The larger is the degree of home bias the greater is the effect of a variation of the terms of trade on the RER. Whether $\theta = 0.5$ a change in the terms of trade has no effect on the RER. On the other side, an increase in the relative price of non-tradables leads, ceteris paribus, to an appreciation of the RER. The effect on the RER of a change in the relative price of non-tradables is stronger, the larger is the share of non-tradable goods in the consumption basket, i.e. the smaller is ω. Overall wether productivity gains in the domestic tradable sector cause a RER appreciation depends on the trade-off between the contrasting effects on the RER of the terms of trade and of the relative price of non-tradables.

[5] Whether the LOOP does not hold, the RER, as Thoenissen (2006) shows, can be decomposed as follows: $RER_t = \left(\frac{\nu_t P^*_{Ht}}{P_{Ht}}\right)\left(\frac{P_{Ht}}{P_{Tt}}\frac{P^*_{Tt}}{P^*_{Ht}}\right)\left(\frac{P_{Tt}}{P_t}\frac{P^*_t}{P^*_{Tt}}\right)$. The failure of the LOOP is an additional source of RER misalignment from the PPP equilibrium. It could be of interest for further research to study the functioning of the B-S theorem in a framework of this type.

[6] Ω is equal to $\left[(1-\omega)\,\bar{q}^{1+\varepsilon}\right] / \left[\omega + (1-\omega)\,\bar{q}^{1+\varepsilon}\right]$. $\bar{q}$ is the value of the relative price of non-tradables in steady state. Ω is a negative function of ω. $R\hat{E}R_t$, $T\hat{O}T_t$ and $\hat{q}_t$ define respectively the RER, the terms of trade and the relative price of non-tradables as deviations from their steady state levels.

4 Calibration

The primary aim of the paper is to study the essential mechanism of the B-S theorem to comprehend under what conditions a productivity shock to the tradable sector implies an increase in the relative price of non-tradables and an appreciation of the RER. Therefore we set a basic calibration to facilitate the impulse response function analysis. The parameters adopted are standard in the international business cycle literature. However, to check the robustness of the results obtained under the benchmark calibration, we carry out a large sensitivity analysis.

For purposes of calibration, we assume that one period of time corresponds to one quarter and that the 2 countries are perfectly symmetric and have equal size[7]. We assume that the utility function is separable in consumption and leisure:

$$U\left(C_t, (1-N_t)\right) = \left[\frac{1}{1-\sigma}C_t^{1-\sigma} + \frac{(1-N_t)^{1-a}}{1-a}\right] \tag{41}$$

The elasticity of intertemporal substitution in consumption $\left(\frac{1}{\sigma}\right)$ is set equal to 0.5. The elasticity of intertemporal substitution in leisure $\left(\frac{1}{a}\right)$ is set equal to 0.1348 such that in steady state the time allocated to leisure is equal to the 80% of the total time endowment. All the households have a discount factor (β) equal to 0.99 such that the annual interest rate is equal to 4%. The weight of tradable goods in the consumption basket ω is 0.55 as in Benigno and Thoenissen (2008) and Corsetti, Dedola, Leduc (2008). The intratemporal elasticity of substitution between tradable and non-tradable goods (μ) is equal to 0.44 as in Stockman and Tesar (1995). The weight of Home intermediate tradable good in the tradable consumption basket θ is 0.72 as in Benigno and Thoenissen (2008) and Corsetti, Dedola, Leduc (2008). The intratemporal elasticity of substitution between foreign and domestic goods (ε) is equal to 0.9 as in Heathcote and Perri (2002). The quarterly rate of depreciation of the capital stock (δ) is 2.5%. The capital share of output in the tradable sector (α_T) is 39% while in the non-tradable sector (α_{NT}) is 44%. The parameter ψ that defines the amount of the bond holding cost which ensures the stability of the solution in the incomplete market case is set equal to 0.001.

In line with our objective of maintaining the interpretation of the model mechanisms simple, we assume that all off-diagonal elements of the autocorrelation matrix are equal to 0 and the autoregressive parameters, that define the persistence of the shock, are equal to 0.9 both across sectors and countries. The variance-covariance matrix of the productivity shock is set equal to an identity matrix. These assumptions imply that we ignore spillover effects and that shocks to the tradable and non-tradable sector both in the Home and in the Foreign country have the same size and the same persistence.

[7]We report the values of the parameters of the baseline calibration in table 1 and 2 in the appendix.

5 Impulse response function analysis: the internal and the external transmission channels of the B-S theorem

In the following impulse response analysis, we focus on the responses of the relative price of non-tradable goods, the terms of trade, the RER and the relative consumption across countries[8], to a 1% shock to productivity in the tradable sector in the Home country both in a complete and in an incomplete market framework under the benchmark calibration. Our choice is coherent with the primary target of the paper which is to study the performance of the B-S theorem in a baseline model and to figure out when its predictions hold. In particular, we analyze the link between the relative productivity of the tradable sector and the relative price of non-tradable goods (B-S internal transmission channel) and the relationship between the relative productivity differential of the tradable sector across countries and the RER (B-S external transmission channel). The terms of trade are included among the relevant variables because, as we highlighted above, in presence of home bias in spending of tradables, contribute to drive the dynamics of the RER along with the relative price of non-tradables. Furthermore the relative consumption across countries is a significant variable because in this type of models is linked by a structural relation with the RER.

We first consider the responses of these 4 variables in a complete market framework[9].

A positive productivity shock to the tradable sector in the Home country raises the marginal productivity of labor, and therefore the demand for labor in this sector, bidding up domestic wages. With competitive labor markets, the relative price of tradable in terms of domestic non-tradables must fall: while productivity has only improved in the former sector; the increase in wage is common to both. The terms of trade depreciate to clear the market for tradable goods. Aggregate consumption goes up both at Home and abroad since country specific risks are perfectly insured. However domestic consumption rises more than foreign consumption and therefore the RER depreciates. This results stem from the risk sharing condition that in a complete market framework links the behavior of the RER to the dynamics of relative consumption across countries:

$$R\hat{E}R_t = \left(\hat{U}^*_{C^*_t} - \hat{U}_{C_t}\right) \tag{42}$$

where $\hat{U}^*_{C^*_t}$ and $\hat{U}_{C_t}$ are respectively the foreign and the domestic marginal utility of consumption expressed as deviations from their steady state values. This condition implies a positive proportional relationship between the RER and the relative consumption. An appreciation (depreciation) of the RER implies a reduction (increase) of domestic consumption relative to foreign consumption. This positive link between these two variables is in conflict with the data which generally provide evidence of a negative correlation between the RER and relative consumption. This peculiar result is the

[8] Relative consumption is given by the difference between the deviations of Home and Foreign consumption from their steady state levels.

[9] Look at figure 1, figure 2 and figure 3.

origin of the Backus-Smith puzzle.

We now take into account the responses of the same 4 variables to 1% shock to productivity in the tradable sector in the incomplete market framework[10].

In the bond economy there is not a market providing an insurance against country specific risk but, under the benchmark parameterization, the response of the model to a productivity shock in the domestic tradable sector is similar to its reaction under complete markets since a fraction of the wealth effect generated by the productivity gain is transmitted to the Foreign country through a depreciation of the terms of trade. The output of the Home produced tradable good and consumption increase and the terms of trade depreciate to clear the market. The relative price of non-tradable goods rises, the RER depreciates and the relative consumption raises as under complete market. However, it is worth to stress that the international risk sharing condition which holds in an incomplete market framework is different:

$$E_t(R\hat{E}R_{t+1} - R\hat{E}R_t) \approx E_t\left[\left(\hat{U}^*_{C^*,t+1} - \hat{U}^*_{C^*,t}\right) - \left(\hat{U}_{C,t+1} - \hat{U}_{C,t}\right)\right] \tag{43}$$

In the bond economy the condition that relates the RER with the relative consumption across countries is weaker that in complete markets. This condition implies that, in expectations, real depreciation is associated with higher growth of domestic consumption with respect to the growth of foreign consumption. The relationship between the RER and relative consumption across countries holds only in expected first differences. Thus in a stochastic environment with incomplete financial markets the tight link between these variables is broken. The non-contingent bond does not provide an ex-ante insurance against country specific risks but it only allows to smooth consumption and to partially reallocate wealth over time. In this framework a large unexpected wealth effect can even produce negative relationship between the two variables on impact.

Overall both in a complete and in an incomplete market framework, under the benchmark parameterization, the internal transmission mechanism of the B-S theorem holds but the B-S effect is not able to explain the Penn effect. A productivity shock to the tradable sector implies an increase in the relative prices of non-tradables but the RER depreciates since, under this calibration, the effect of the terms of trade, which worsens, on the RER dominates the rise in the relative price of non-tradables.

6 Mapping of the results

In the following section, we first study how the performance of the model in response to a productivity gain in the tradable sector changes when the benchmark parametrization is modified. In particular, we analyze the sensitivity of the model predictions about the internal and the external

[10] Look at figure 1, figure 2 and figure 3.

transmission channels of the B-S effect to a variation of the intratemporal elasticity of substitution between domestic and foreign goods (ε), the degree of openness (θ), the intratemporal elasticity of substitution between tradable and non-tradable goods (μ) and the weight of tradable goods in the consumption basket (ω). Figure 4, figure 5, figure 6 and figure 7 show the impulse response functions of the relative price of non-tradable goods, the terms of trade, the RER and the relative consumption across countries to a 1% productivity shock in the tradable sector in the Home country as functions of the respective parameters both under complete and incomplete markets. Then we carry out the same exercise assuming a utility function with non-separable preferences.

6.1 Intratemporal elasticity of substitution between domestic and foreign goods

In the international business cycle literature there is a large range of estimates for the trade elasticity of substitution. For instance, Taylor [1993] estimates the value for the U.S. to be 0.39, while Whalley [1985], in the study used by Backus et al. [1995], reports a value of 1.5. For European countries most empirical studies suggest a value below 1. For instance, Anderton et al. [2004] report values between 0.5 and 0.81 for the Euro area. Recently, models with low trade elasticities as Corsetti, Dedola and Leduc (2008) received considerable attention because they seem able to replicate better international business cycles statistics. Obstfeld and Rogoff (2000) present a survey regarding the empirical estimates of trade elasticity and suggest high values for this elasticity. Also trade studies generally use high values for trade elasticity, between 5 and 6 (Trefler and Lai (1999)). Therefore in this sensitivity analysis, for the trade elasticity we consider values between 0.5 and 5.

With complete markets[11], after a 1% productivity shock to the tradable sector, the relative price of non-tradable goods increases for all values of the intratemporal elasticity of substitution between domestic and foreign tradables (ε) in the considered range. But, as ε rises, the price of Home produced tradables is less responsive to the shock and consequently decreases less. Hence the raise in the relative price of non-tradables becomes weaker. As under the benchmark parameterization, the terms of trade worsens for $\varepsilon < 4.08$, whereas it improves for higher values of trade elasticity. The response of the terms of trade largely depends on the calibration of the intratemporal elasticity of substitution between domestic and foreign tradable goods. As ε rises, quantities become more sensitive to a productivity innovation than prices and the response of the terms of trade becomes flatter. For high trade elasticity, the response of the terms of trade becomes negative. On impact domestic demand, reflecting mainly the increase in investment led by expectations of persisting productivity gains, expands more than domestic supply. Thus, because of home bias in consumption of tradables, the terms of trade appreciates for the market to clear. Since the peak in investment is short lived, after a few quarters the terms of trade turns positive. The RER depreciates for $\varepsilon < 1.69$, while it appreciates for higher values. This occurs because of the performance of the

[11] Look at figure 4.

terms of trade that, along with the relative price of non-tradables, drive the RER dynamics. The relative consumption across countries is positive for $\varepsilon < 1.69$. For higher values of trade elasticity foreign consumption rises slightly more than domestic consumption thus the relative consumption across countries turns to be negative. Obviously, the model exhibits a positive correlation between the relative consumption and the RER. Overall the model shows that with complete markets the B-S effect leads to an increase in the relative price of non-tradable goods for all values of trade elasticity but it causes an appreciation of the RER and therefore it is able to explain the Penn effect only for relatively high values of ε. Observe that, as shown above, for these high values of the elasticity, consumption rises by less in the country benefitting from a positive productivity shock, than abroad, on impact.

With incomplete markets[12], once again, the relative price of non-tradable goods raises for all values of ε in the considered range but, as the trade elasticity rises, a stronger raise in aggregate consumption causes an increase in the size of the response of the relative price of non-tradables. The terms of trade is driven by a similar mechanism than in complete markets. It depreciates for $\varepsilon < 1.93$ while it appreciates for higher values. The RER depreciates for $\varepsilon < 0.95$. For higher values of ε it appreciates because of the strengthening of the response of the relative price of non-tradable goods and the weakening of the response of the terms of trade. Relative consumption decreases for low values of ε because the rise of foreign consumption is larger than that of domestic consumption. Otherwise it increases. Therefore for $\varepsilon \in [0.5, 0.71]$ and for $\varepsilon \in [0.95, 5]$ there is a negative correlation between relative consumption across countries and the RER after a positive productivity shock to the tradable sector. In these two ranges of values of trade elasticity the model with incomplete markets is able to address the Backus-Smith puzzle. Overall the model shows that in incomplete markets the B-S effect leads to a raise in the relative price of non-tradables for all values of ε but it implies a RER appreciation and explains the Penn effect for values of $\varepsilon > 0.95$.

6.2 Degree of home bias

In the open economy literature, the value of the parameter θ that defines the degree of home bias is generally derived from the data to match the share of domestic produced tradable goods in the tradable consumption basket. Hereafter, we consider values of θ included in the range between 0.5 and 0.99.

Figure 5 shows the main impulse responses of the model on impact to a 1% productivity shock in the tradable sector in the complete market framework as functions of different parametrizations of θ. The response of the relative price of non-tradable goods is positive for all values of θ in the considered range. Relative consumption across countries falls for $\theta < 0.58$ whereas, as θ rises, its response turns positive and becomes stronger. Consequently the RER appreciates for $\theta < 0.58$,

[12] Look at figure 4.

while it depreciates for higher values. Therefore to be consistent with the reaction of these variables and with equations (40) and (42), the terms of trade depreciation must necessarily increase as θ rises. With complete markets the B-S effect causes an increase in the relative price of non-tradables for all values of θ but it explains the Penn effect only for relatively low values of θ.

Figure 5 shows the main responses of the model on impact to a 1% productivity shock in the tradable sector in the incomplete market framework as functions of different parametrizations of θ. The relative price of non-tradable goods raises for all values of θ in the considered range. The size of this response is not considerably affected by changes in θ. The response of the terms of trade is positive for all values of θ in the range, but as θ rises, the terms of trade worsens less, since a smaller depreciation is necessary to clear the market. For low values of θ[13], the movements of the RER are dominated by the dynamics of the relative price of non-tradable goods thus the RER appreciates. Otherwise for $\theta > 0.59$ it depreciates. Relative consumption increases for $\theta > 0.58$. Overall the model shows that in incomplete markets the B-S effect leads to a raise of the relative price of non-tradables for all values of θ but it implies a RER appreciation and explains the Penn effect only for low values of θ.

6.3 Intratemporal elasticity of substitution between tradable and non-tradable goods

In open economy models, the intratemporal elasticity of substitution between tradable and non-tradable goods (μ) is often assumed to be equal either to 0.44 which is the value estimated by Stockmann and Tesar (1995) for a sample of both developed and developing countries or to 0.74 the estimate of Mendoza (1991) for a sample of only industrialized countries. However the range of values of μ adopted in the literature is wider. For instance, Rabanal and Tuesta (2009), using data for the US and the Euro area, obtain an estimate of μ equal to 0.13. Obstfeld and Rogoff (2000) as a benchmark calibration use a unitary intratemporal elasticity of substitution between tradable and non-tradable goods but then Obstfeld and Rogoff (2005) allow for a value of μ equal to 2. In this sensitivity analysis, we consider values of the intratemporal elasticity of substitution between tradables and non-tradables included in the range between 0.1 and 2.5.

With complete markets[14], after a 1% productivity shock in the tradable sector, the relative price of non-tradable goods rises for all the values of μ in the considered range. However, as the intratemporal elasticity of substitution between tradable and non-tradable goods rises, the relative price of non-tradable goods becomes less sensitive to a change in the relative supply of non-tradable goods, thus its response to a productivity innovation in the tradable sector becomes flatter. Both, the terms of trade and the RER depreciate for all values of μ in the range. A change in the value

[13] As highlighted in section 3.6 when θ is equal to 0.5, the terms of trade does not play any role in determining the pattern of the RER.

[14] Look at figure 6.

of μ does not significantly affect the magnitude of the response of these two variables. The relative consumption, consistently with the dynamics of the RER, is always positive. Hence, in complete markets, the internal transmission channel of the B-S effect holds for all values of μ but the B-S effect can not be an explanation of the Penn effect.

With incomplete markets[15], after a 1% productivity shock in the tradable sector, the performance of the relative price of non-tradables does not significantly differ by its performance in complete markets. The terms of trade always worsen, but it features a higher variability. It has a less positive reaction for low values of μ while it depreciates more for high values. As tradable and non-tradable goods become more substitutes, a larger portion of demand falls on tradables. Since the supply of foreign tradables does not adjust proportionally, the terms of trade worsens more for high values of μ. The RER behaves consequently. It appreciates for $\mu < 0.28$ while it depreciates for higher values. The relative consumption is always positive. Thus for low values of μ there is a negative relationship between relative consumption and the RER and the model is able to address the Backus-Smith puzzle. In incomplete markets, the internal transmission channel of the B-S effect holds for all values of μ but the B-S effect can explain the Penn effect only for low values of the intratemporal elasticity of substitution between tradable and non-tradable goods.

6.4 Share of tradable goods in consumption

The parameter ω, which is generally calibrated to match the data, defines the share of tradable goods in consumption. We consider values of ω included in the range between 0.3 and 0.99.

With complete markets[16], after a 1% shock to productivity in the tradable sector, the relative price of non-tradable goods increases for all values of ω. Changes in ω do not really affect the response of this variable. However, as the share of tradable goods in consumption becomes larger, the prices of tradable goods are less responsive to the shock and consequently the terms of trade depreciate slightly less. The RER depreciates for all values of ω in the considered range but it depreciates more for higher values of ω. As ω increases, the role of the relative price of non-tradable goods in driving the RER decreases. Thus the RER dynamics follow closer the behavior of the terms of trade. Obviously, in complete markets, there is always a positive relationship between the RER and relative consumption across countries. Overall the model shows that with complete markets the B-S effect leads to an increase in the relative price of non-tradable goods for all values of the share of tradable goods in consumption but it never causes an appreciation of the RER and therefore it is never able to explain the Penn effect.

With incomplete markets[17], the variables of interest follow a similar pattern than in complete markets. However, it is worth to notice, that the terms of trade worsens slightly less. This implies

[15] Look at figure 6.
[16] Look at figure 7.
[17] Look at figure 7.

that the RER appreciates for $\omega < 0.45$. Relative consumption always rises also under incomplete markets. Thus for $\omega < 0.45$ there is a negative relationship with the RER and the model is able to address the Backus-Smith puzzle. Overall the model shows that in incomplete markets the B-S effect leads to a raise in the relative price of non-tradables for all values of ω but it implies a RER appreciation and explains the Penn effect only for values of $\omega < 0.45$.

6.5 Non-separable preferences

Hereafter, we assume that the utility function is non-separable in consumption and leisure:

$$U\left(C_t, (1 - N_t)\right) = E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \frac{1}{1-\sigma} C_t^{1-\sigma} L_t^a \right\} \tag{44}$$

The behavior of the model with non-separable preferences after a 1% productivity shock in the tradable sector both under complete and incomplete markets does not significantly differ from the performance of the model with separable preferences. The only major variation regards the dynamics of relative consumption across countries. With non-separable preferences the positive relationship between relative consumption and the RER is weaker because of the interaction between leisure and consumption.

7 Conclusions

Balassa and Samuelson, in two seminal papers in 1964, independently argued that a faster growth of productivity in the tradable sector than in the non-tradable sector leads to higher prices of non-tradables. Moreover, they claimed that a faster growth of relative productivity in the domestic country than in the foreign country causes an appreciation of the RER. This insight has been called in the literature B-S model and it has been often used to explain the RER misalignments from the PPP and the Penn effect, i.e. the economic finding that real income ratios between industrial and developing countries are always overstated if converted at market exchange rates because the price level is higher in richer countries. In this paper, exploiting a two-country, two-sector international real business cycle model, which closely follows Stockman and Tesar (1995) and Benigno and Thoenissen (2008), taking into account both a complete and an incomplete asset market framework, we show that using the B-S effect and the Penn effect as synonymous, as often occurs in the literature, it is not correct. Indeed, this model proves that a productivity innovation to the domestic tradable sector always leads to an increase in the relative price of non-tradable goods but the effect on the RER largely depends on the model parameterization. RER dynamics are driven not only by the response to the shock of the relative price of non-tradables but also by the reaction of the terms of trade. Hence, wether productivity gains in the domestic tradable sector cause a RER appreciation depends on the trade-off between the conflicting effects on the RER of the movements of the relative price of non-tradables and the terms of trade. These results are consinstent with the empirical evidence which supports the tradable productivity effect on the relative price of non-tradables but it is more controversial about the effect on the RER. Finally, Samuelson himself claimed that the Penn effect can be difficultly enlightened by only one phenomenon.

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APPENDIX

Table 1: Benchmark parameters value.

Subjective discount factor	β	0.99
Intertemporal elasticity of substitution in consumption	$1/\sigma$	0.5
Intertemporal elasticity of substitution in leisure	$1/a$	0.1348
Weight of tradable goods in the consumption basket	ω	0.55
Elasticity of substitution between tradable and nontradable goods	μ	0.44
Weight of Home tradables in the tradable consumption basket	θ	0.72
Elasticity of substitution between domestic and foreign goods	ε	0.9
Capital share of output in the tradable sector	α_T	0.39
Capital share of output in the nontradable sector	α_{NT}	0.44
Depreciation rate	δ	0.025
Bond holding cost	ψ	0.001

Table 2: Productivity process.

Autocorrelation matrix	$\Gamma = \begin{bmatrix} 0.90 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.90 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.90 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.90 \end{bmatrix}$
Variance-covariance matrix	$\Sigma = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

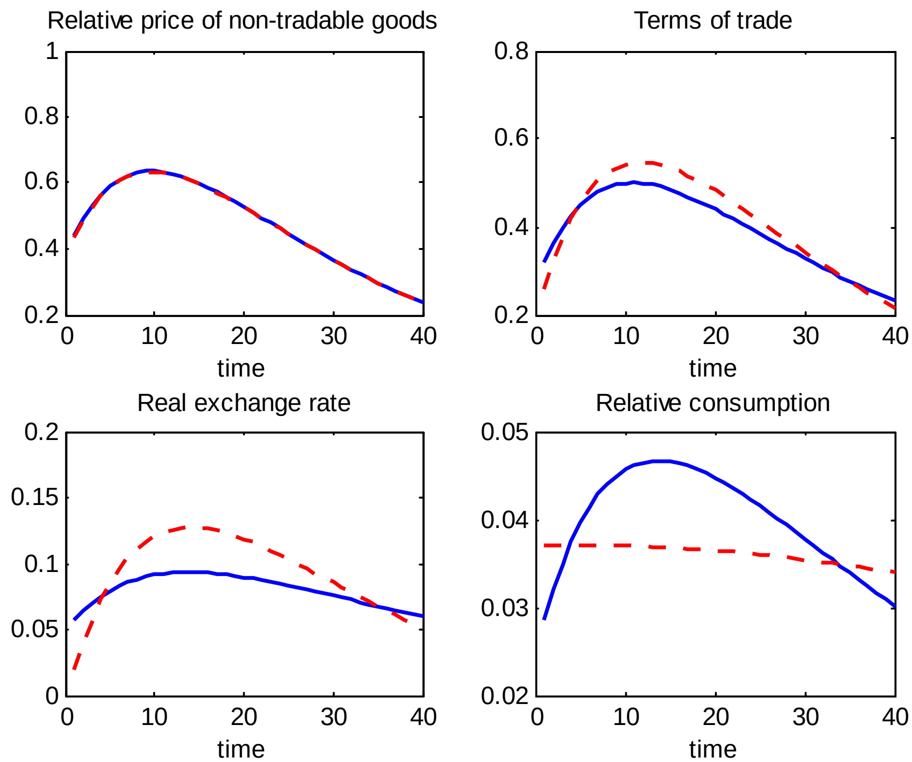

Figure 1: Productivity shock to the tradable sector under the benchmark parametrization. The solid blue lines denote the variable responses in complete markets. The dashed red lines denote the variable responses in incomplete markets.

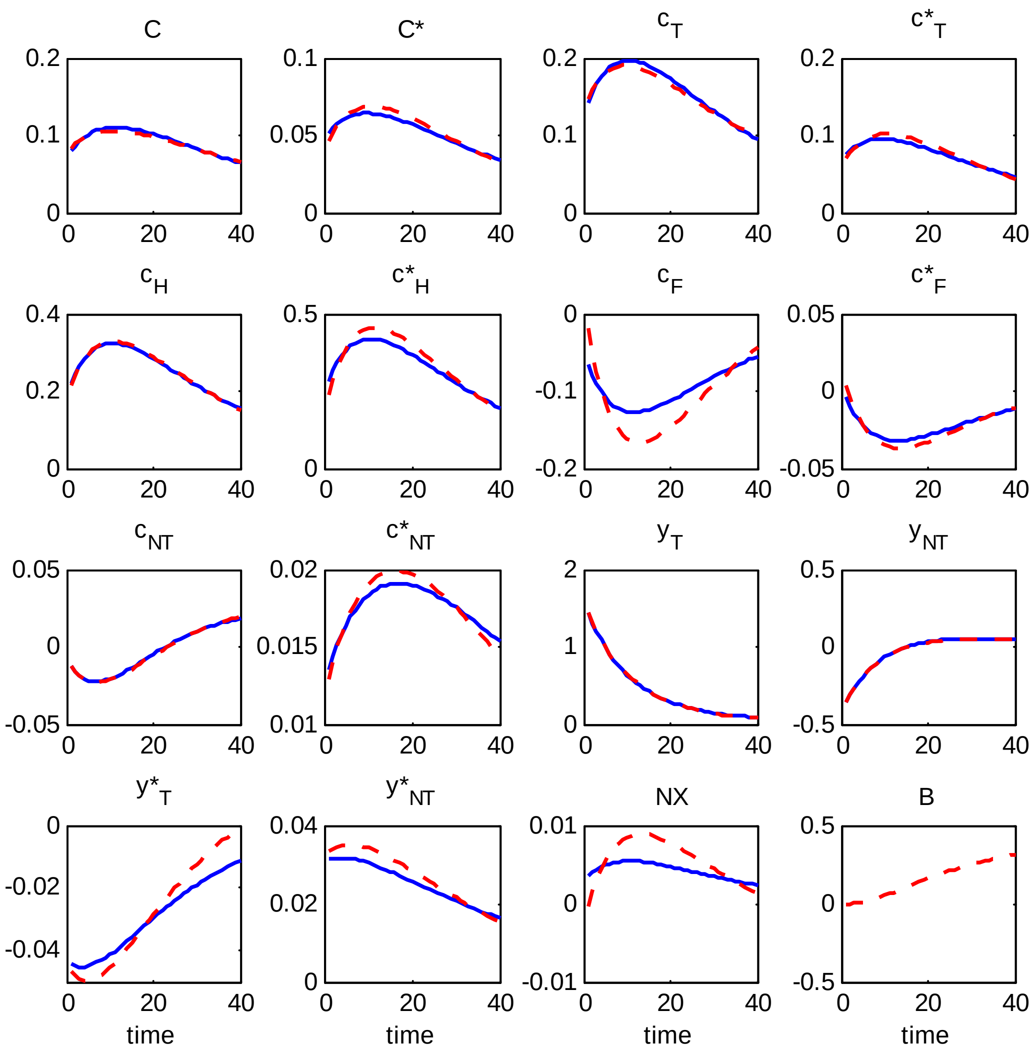

Figure 2: Productivity shock to the tradable sector under the benchmark parametrization. The solid blue lines denote the variable responses in complete markets. The dashed red lines denote the variable responses in incomplete markets.

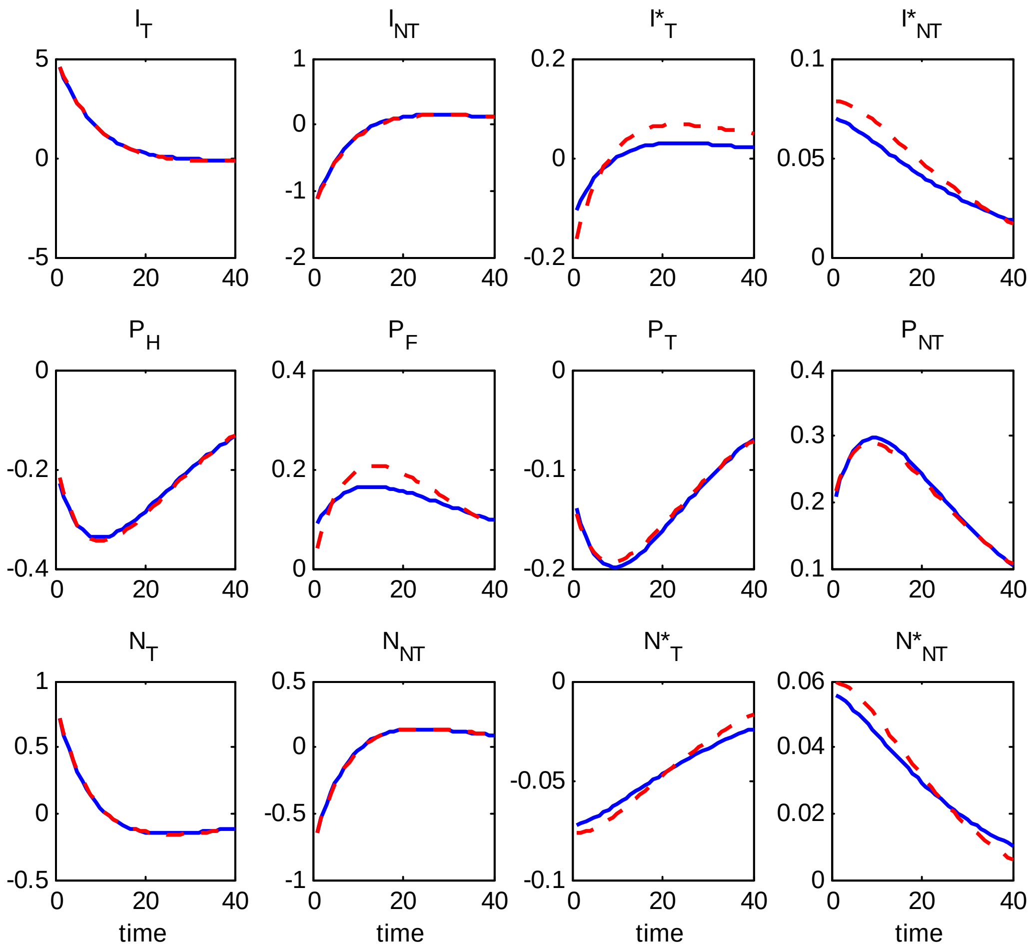

Figure 3: Productivity shock to the tradable sector under the benchmark parametrization. The solid blue lines denote the variable responses in complete markets. The dashed red lines denote the variable responses in incomplete markets.

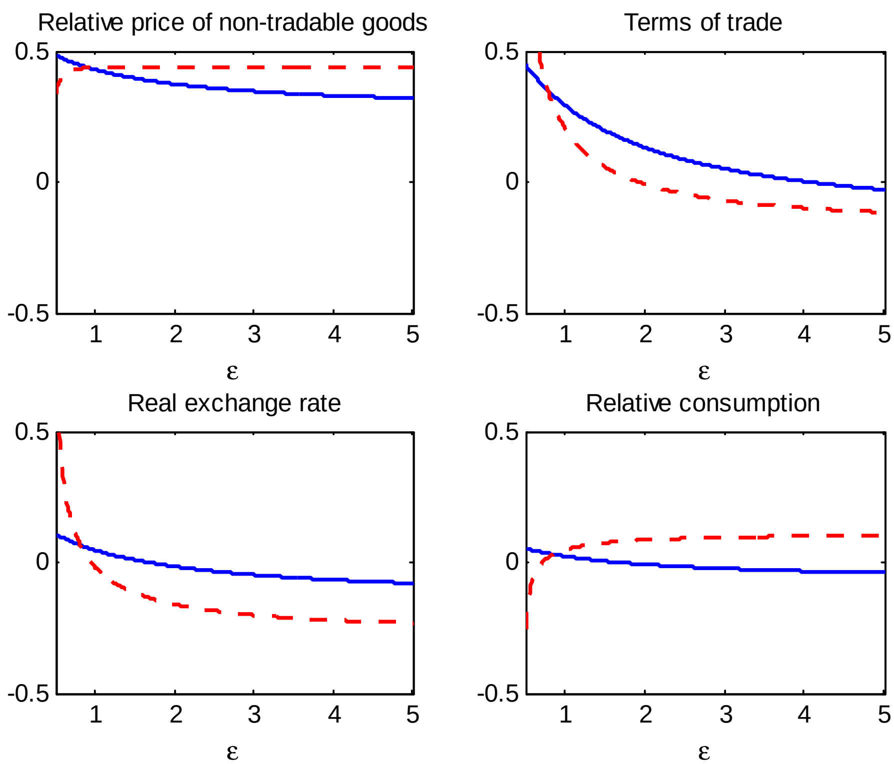

Figure 4: Productivity shock to the tradable sector. The solid blue lines denote the variable responses on impact in complete markets as fuctions of the trade elasticity (ε). The dashed red lines denote the variable responses on impact in incomplete markets as fuctions of the trade elasticity (ε).

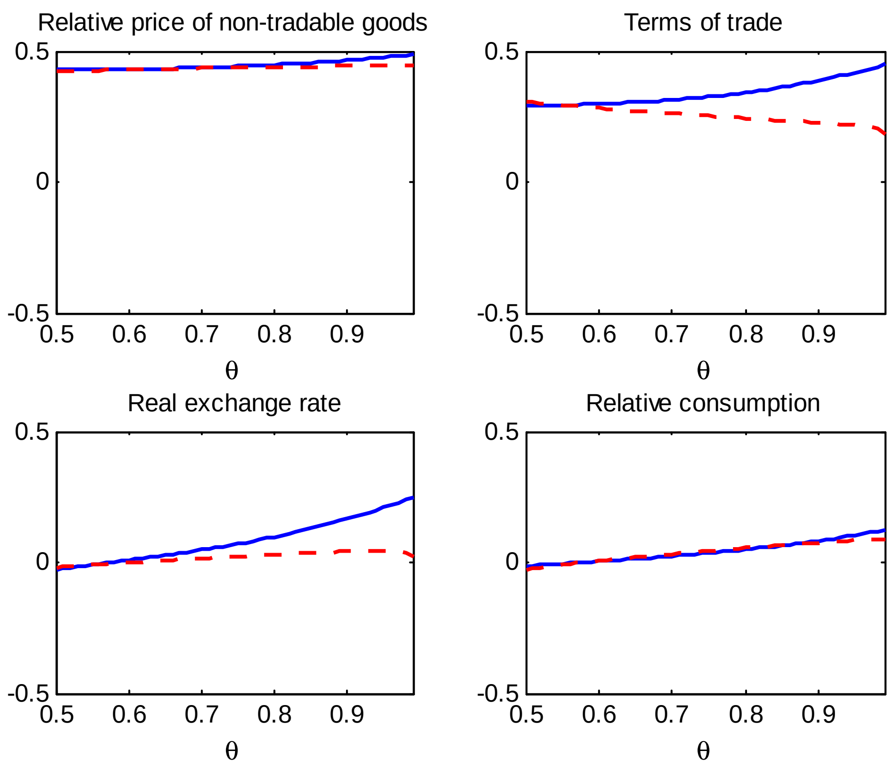

Figure 5: Productivity shock to the tradable sector. The solid blue lines denote the variable responses on impact in complete markets as fuctions of the degree of home bias (θ). The dashed red lines denote the variable responses on impact in incomplete markets as fuctions of the degree of home bias (θ).

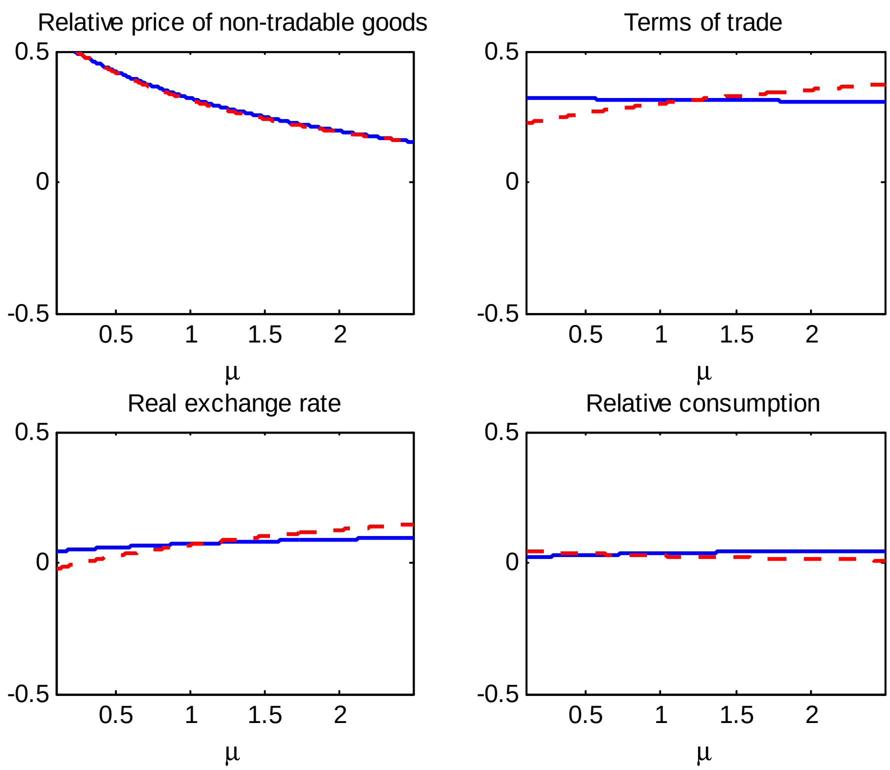

Figure 6: Productivity shock to the tradable sector. The solid blue lines denote the variable responses on impact in complete markets as fuctions of the elasticity between tradable and non-tradable goods (μ). The dashed red lines denote the variable responses on impact in incomplete markets as fuctions of the elasticity between tradable and non-tradable goods (μ).

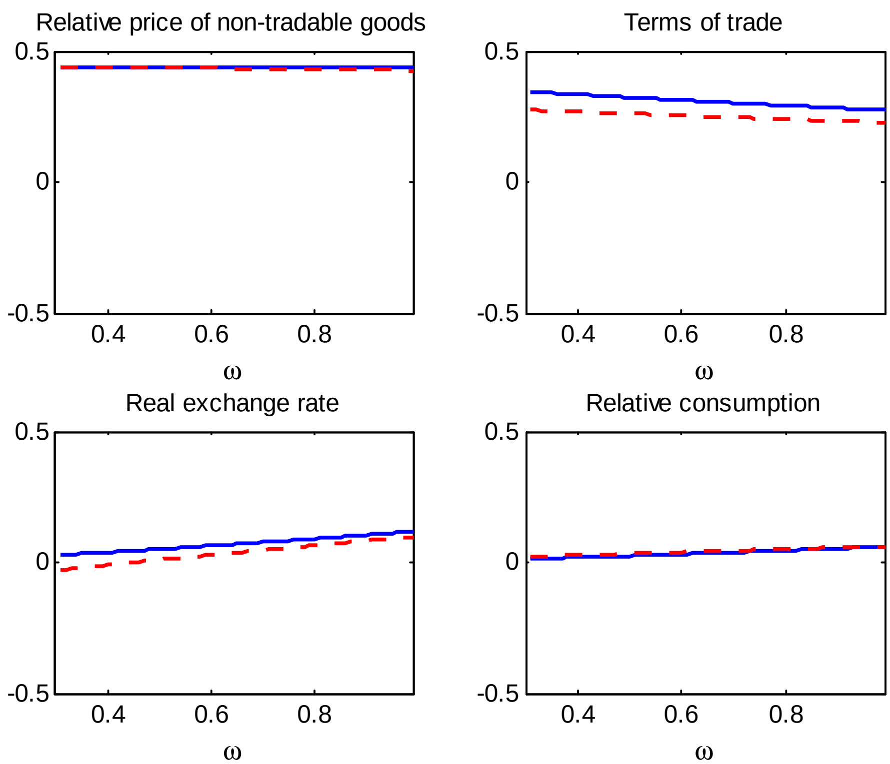

Figure 7: Productivity shock to the tradable sector. The solid blue lines denote the variable responses on impact in complete markets as fuctions of the share of tradables in consumption (ω). The dashed red lines denote the variable responses on impact in incomplete markets as fuctions of the share of tradables in consumption (ω).