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Product Quality and International Price Dynamics

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Abstract: Two puzzling facts of international real business cycles are 1) weak or negative correlations between the terms of trade and output, and 2) a rise in relative consumption for countries where national goods become relatively more expensive. We show these puzzles either vanish or become much weaker in recent data. We propose a new mechanism that generates endogenous international price movements that are consistent with both the "old" and the "new" facts. In this mechanism, firms operating in a monopolistically competitive environment adjust price and quality of their products in response to technological shocks. This model is consistent with the old facts if price levels are not adjusted for quality. Instead, if quality adjustments to price level are introduced, the model's properties are in line with the new facts.

JEL Codes: E31, F44.

Keywords: Quality, International Real Business Cycle, Ba kus- Smith puzzle, Hedoni Prices.

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1 Introduction

Two common observations of the international real business cycle literature with regard to international price dynamics are 1) a negative correlation between the terms of trade[1] and output (Backus et al., 1994) and 2) a rise in relative consumption in a country where goods become relatively more expensive (Backus and Smith, 1993). Columns 2 and 3 of Table 3 in the Appendix report these correlations for the twelve largest economies in the Organisation for Economic Co-operation and Development (OECD) between 1971 and 1998.[2] Standard models of international RBCs predict the exact opposite of these observations. In particular, the failure to replicate the correlation between relative consumption and the real exchange rate is typically referred to as the Backus-Smith puzzle. The first goal of this paper is to provide an explanation for the failure of standard models to account for these facts.

Interestingly, a closer look at more recent data would suggest that a fundamental change has occurred to the dynamics of international prices. Columns 4-7 of Table 3 show the same correlations for the period 1999-2009 and their change. Surprisingly, the correlation between output and the terms of trade is now strongly positive for most countries. The Backus-Smith puzzle

[1] We adhere to standards of the international RBC literature and define terms of trade as the price of imports divided by the price of exports.

[2] Terms of trade are computed as the ratio of the price deflator for imports and the price deflator for exports, while price deflators are calculated as the ratio of imports (exports) in current prices and their corresponding value in real terms. See the appendix for details on the data.

is weaker for all but one of the twelve OECD economies in our sample. This poses a great challenge for any theory of international price dynamics. Not only should this theory explain the old puzzles, but it should also be able to provide a rationale for the dramatic change of these correlations in recent years. The second objective of this paper is to provide a possible explanation for the reversal or weakening of the aforementioned puzzles.

We present a simple yet powerful mechanism capable of generating international price correlations that are consistent with these facts. Our mechanism consists of giving firms a second dimension of production, namely quality. In standard models, price-taking firms choose to expand production in response to lower production costs as a result of a positive technology shock (firms like to "make hay when the sun shines"). This is the only possible response for firms, so naturally an increase in the domestic supply of goods puts downward pressure on prices. In the model proposed, producers have the option to spend their productivity gains differently by improving the quality of their products. This affects goods prices through two channels: 1) a demand-side channel, whereby higher-quality goods are more valued by consumers, and 2) a supply-side channel, since producing higher quality goods is generally costlier. Both effects push prices of domestic goods up instead of down.

Quantity and quality changes push prices in opposite directions whereas, when firms could only reduce prices after technology improvements, we only had downward pressure on prices. It then remains a quantitative question whether the effect of quality improvements is strong enough to offset or even dominate the response in quantities. To test this, we calibrate the model to match a number of features of the US economy over the 1971-1998 period. We argue that the signs and magnitudes of international price correlations generated by this model crucially depend on how price levels are measured. We find that international price fluctuations are much closer to the ones we observe in the data for 1971-1998 if we assume that statistical agencies ignore changes in quality in their price level calculations. On the other hand, adjusting price levels for shifts in good quality affects the time series properties of the model in a way that is consistent with more recent data.

This change in the way price levels are determined by statistical agencies is in line with their methodological history. Quality adjustments to price indices in the US and elsewhere have improved over the years. One big push in this direction came partly in response to the 1996 Boskin commission report[3]. This report lead to an expanded use of hedonic methods and more frequent updating of the goods in the consumer's basket used to calculate the CPI (Johnson et al., 2006). Quality adjustments have also been increasingly important in price adjustments performed by the U.S. Bureau of Economic Analysis (BEA) in the national accounts (Wasshausen and Moulton, 2006). They are quite significant in categories of goods that are of great importance to trade, such as vehicles, consumer electronics, or apparel.[4] The findings in

[3] http://www.ssa.gov/history/reports/boskinrpt.html#list

[4] For a short and comprehensive introduction with examples to hedonic price construction and its relevancy in CPI, search for "Hedonic Quality Adjustment in the CPI" in

Table 3 suggest the possibility that recently introduced quality adjustments to price indices have reduced the discrepancies between theory and data. We interpret this as evidence of the importance of the mechanism presented in this paper.[5]

Following the seminal works of Backus, Kehoe, and Kydland (1992, 1994), many studies have tried to explain the puzzle of strongly pro-cyclical terms of trade as well as the Backus-Smith puzzle, though so far the results seem unconvincing. As we mentioned before, the correlation reversal observed in the data is a fact that has not yet been addressed by the literature: none of the papers we refer to in the following paragraphs seeks to explain this issue.

The solutions proposed generally fall within one of the following two lines of research: First, a number of papers address the issue by introducing new shocks that mitigate or even reverse the effects of productivity shocks on the terms of trade. This avenue was pioneered by Stockman and Tesar (1995), who add exogenous taste shocks to a standard model with non-traded goods. This innovation solves many of the problems of the theory, but at the expense of a deterioration in the correlation between the trade balance and output and the introduction of hardly identifiable structural disturbances. The effects of quality changes are similar to the effects of taste shocks. The advantage

Bureau of Labor Statistics (BLS) web-page.

[5]BLS kindly answered to our questions that they have not computed hedonic prices in retrospect to homogenize the series. It would be, indeed, extremely difficult to go back to every period and compute the progression of quality, feature by feature of every good in the basket of consumption. Moreover, at the time, this basket was not updated as often as it has been recommended after Boskin commission report.

of the mechanism we propose is that it retains most of the parsimony of the original model because it refrains from introducing new exogenous disturbances into the standard theory, as quality is determined endogenously. Backus and Crucini (2000) extend the basic international RBC model to include oil as a production input and, a third oil producing country with exogenous shocks to its supply of oil. Their baseline model has problems in matching the volatility of trade and terms of trade yet it does a reasonably good job at matching the direction (but not the magnitude) of the correlations between output, the trade ratio, and the terms of trade. They also explore a variation of their model with no technological shocks, which does a better job at matching moments of international trade variables, but encounters difficulties in other regards. Raffo (2010) introduces investment-specific technological (IST) shocks and variable capacity utilization to a standard model with Greenwood-Hercowitz-Huffman (GHH) preferences.[6] He shows that generating large shifts in domestic absorption relative to output is crucial to understand the dynamics of international quantities and prices. He suggests that IST shocks provide a plausible source of variation to this effect. IST shocks resemble taste shocks in that they do not change aggregate production possibilities, but with the advantage that there are plausible ways

[6]IST shocks affect the level of investment that effectively goes into capital accumulation. GHH preferences, introduced by Greenwood et al. (1988), have the property that the marginal rate of substitution between consumption and leisure is independent of the consumption level within the period. In Raffo (2008), GHH preferences address the excessive smoothness of consumption that is common in international RBC models. See the appendix (Section4) for details.

of identifying these shocks in the data. This model has many good properties and does a good job of capturing the observed moments of international trade variables. However, Mandelman et al. (2011) raise some serious concerns about the robustness of these results.

A second group of studies explores the effects of restricting the flow of capital to countries that receive a positive shock. The idea is that this would mitigate the expansion of production and the drop in domestic prices. Baxter and Crucini (1995) replace the complete markets structure of the standard model by a bond economy. They find that the incomplete markets model is not too different from the complete markets version unless there is high persistence of shocks and very little spillovers. In light of this and for simplicity, the model presented in this paper features a single asset that can be traded internationally. Heathcote and Perri (2002) take this idea further and compare both the complete markets model and the incomplete markets model to an economy in which countries are financially autarkic. They find that the model with financial autarky behaves very differently and does a better job at replicating the volatility of the terms of trade as well as cross country correlations. However, counter to the data, the financial autarky model predicts pro-cyclical net exports. Corsetti et al. (2008) take the model with non-traded goods of Stockman and Tesar (1995) and add an incomplete financial market structure and distribution costs. They find that when the trade elasticity is low, incomplete markets reconcile theory and data to a large degree and the Backus-Smith puzzle largely goes away, but the strong, positive correlation between output and the terms of trade remains.

Finally, one study that does not fall in either group was carried out by Ghironi and Melitz (2005), who endogenize the 'non-tradedness' of goods by introducing Melitz' heterogeneous firms structure to the production of intermediate goods. Their model provides an endogenous, micro-founded explanation for a Harrod-Balassa-Samuelson effect: More productive economies exhibit higher average prices relative to their trading partners. Terms of trade in this setting can be uncorrelated or even negatively correlated with output, but the Backus-Smith puzzle remains. The structure of production introduced in section 2 is closest to this work: there is monopolistic competition in the market for intermediate goods and firm technology is linear in labor. However, intermediate good firms in our model are homogeneous and they have to make two decisions each period, one for price and one for quality. The following section outlines these differences in detail.

The rest of the paper is organized as follows: Section 2 presents the basic model of a dynamic, general equilibrium economy with quality selection in production. Section 3 explains how statistical agencies in our model measure business cycle statistics with and without quality adjustments, and then evaluates the quantitative predictions of the model. Section 4 concludes.

2 An Economy with Quality Production

The economy consists of two countries, Home and Foreign, receiving different streams of technological shocks. Whenever necessary, we use an asterisk to differentiate Foreign country variables from Home country variables. Population is normalized to a mass one of households that live and work in their own country.We assume the price of the final good to be the numeraire.

2.1 Households

Preferences of the representative agent in each country are characterized by a utility function of the form $U(c, 1-n)$, where c and n are consumption and the share of hours worked over the endowment of time, respectively. The function is concave in both arguments. Individuals can save in form of capital k, or bonds b; capital is immobile across countries, while bonds allow international borrowing and lending so that trade need not be balanced every period. Let x denote irreversible investment in capital goods. Let w_t, R_t, and r_t respectively denote wages, the rental price of capital at time t, and the price of bonds at time t that pay one unit of the final good the next period. Following Heathcote and Perri (2002), we assume there is a small quadratic cost to holding bonds to make the model stationary. Households solve

$$\max E_0 \sum_{t=0}^{\infty} \beta^t U(c_t, 1-n_t) \tag{2.1}$$

subject, every period, to

$$c_t + x_t + r_t b_t + \frac{\phi_b}{2} b_{t-1}^2 \leq w_t n_t + R_t k_{t-1} + b_{t-1}$$
$$k_t = (1-\delta)k_{t-1} + \psi(x_t/k_{t\text{-}1})k_{t-1}.$$

Following Backus and Crucini (2000), physical capital formation is subject to adjustment costs captured by ψ, a function such that $\psi > 0$, $\psi' > 0$, and $\psi'' < 0$. In particular, we use $\psi(x/k) = (x/k)^{\eta}$, where $\eta \in (0,1)$.

2.2 Final good firm

The final goods sector is competitive. Final goods technology uses both domestic and imported inputs, both of which are available in a large number of varieties. Final output depends on the quantity as well as the quality of each of the intermediate goods used in production and it is sold domestically. The final good firm takes prices and qualities of intermediates as given and chooses the amount of each input that it needs for production. Therefore, the production function is

$$Y_t = \left(\alpha \sum_{i=1}^{I_t} (q_{i,t} d_{i,t})^{\nu} + (1-\alpha) \sum_{i=1}^{I_t^*} (q_{i^*,t} m_{i,t})^{\nu} \right)^{\frac{1}{\nu}}$$

where I_t stands for the number of domestic and I_t^* for the number of foreign firms/varieties, $d_{i,t}$ is the total quantity produced domestically and consumed domestically, $m_{i^*,t}$ is the total quantity produced abroad and consumed domestically, while q_i and q_{i^*} capture quality at home and abroad, respectively. More broadly, q may be interpreted as a characteristic of the good that makes it more or less desirable. Producers can invest in increasing "desirability" of their goods by raising the quality of their products as well as by spending on advertising that affects how consumers perceive the benefits they derive from consumption of this good. $\nu \in (0,1)$ determines the elasticity of substitution between varieties, and $\alpha \in (0.5,1)$ captures home bias in consumption. The problem of the final good firm is:

$$\max_{x_{i,t},m_{i,t}} \left\{ Y_t - \left(\sum_{i=1}^{I_t} p_{i,t} d_{i,t} + \sum_{i=1}^{I_t^*} \tilde{p}_{i^*,t} m_{i,t} \right) \right\},$$

where $\tilde{p}_{i^*,t}$ are foreign export prices. This determines the demand for each variety as

$$d_{i,t} = Y_t \left(\alpha \frac{q_{i,t}^{\nu}}{p_{i,t}} \right)^{\frac{1}{1-\nu}}, \tag{2.2}$$

$$m_{i,t} = Y_t \left((1-\alpha) \frac{q_{i^*,t}^{\nu}}{\tilde{p}_{i^*,t}} \right)^{\frac{1}{1-\nu}}. \tag{2.3}$$

The demand of each production input increases with domestic absorption, Y_t, decreases with the price and increases with the quality of the input. In a model without quality if a final good producer takes aggregate final good production as given, the demand of intermediates depends exclusively on prices: if prices go up, demand must automatically go down. In this model however, the demand of a good also depends on its quality. If quality goes up enough, demand for an intermediate good may increase even after an increase in its price.

2.3 Intermediate good firms

Intermediate good firms operate in a monopolistically competitive environment, so in terms of market structure this model is closest to Ghironi and Melitz (2005) with three important differences: First, to keep things simple, firms in this setting are homogeneous (they all have the same level of productivity and receive the same productivity shock). Second, firms choose not only a price for their products but also an associated quality. More broadly, q may be interpreted as a characteristic of the good other than price that makes it more or less desirable. Hence, producers may invest in increasing "desirability" of their goods by raising the perceived quality of their products or, for instance, by improving the quality of the materials. So that, producers can actually decide the level of quality every period, climbing up and down the quality ladder.[7] And third, we explicitly introduce capital by requiring that firms rent F units of capital every period to operate.

The only (variable) input of production in this sector is labor. Workers

[7] Have in mind, for example, Skoda, which offered a basic model of their Fabia without air-conditioning or electric windows during the last crisis, although they have the technology to introduce these extras. Introducing them would not require R+D but it would raise the cost of production.

in each firm can be assigned to either production tasks or quality generating tasks. Demand for labor devoted to manufacturing of good i is labeled $l_{i,y}$, while demand for labor devoted to generating a certain level of good quality is labeled $l_{i,q}$. Quality is purely determined by the amount of labor put into quality augmenting activities, $q_i = l_{i,q}$. The production technology is given by

$$y_{it} = \frac{z_t\, l_{i,yt}}{q_{it}^{\rho}} = z_t\, l_{i,yt}\, l_{i,qt}^{-\rho}, \quad \rho \in (0,1),$$

where z_t is a productivity draw common to every firm at time t. The constant ρ captures how q affects production costs: holding z constant, if $\rho > 0$ then higher quality goods require more production workers per unit of output. Taking factor prices as given, intermediate firms maximize profits every period t:

$$max \pi_{i,t} = \max_{l_{i,yt}, l_{i,qt}, p_{it}, \tilde{p}_{it}} \left\{ d_{it} p_{it} + m_{it}^{*} \tilde{p}_{it} - l_{i,yt} w_t - l_{i,q} w_t - F\, R_t \right\},$$

subject to the optimal demand equations (2.2), (2.3), and the condition that production must be able to meet demand

$$d_{it} + m_{it}^{*} \leq z_t\, l_{i,yt} l_{i,qt}^{-\rho}.$$

One can easily show that for a maximum it is sufficient to have $\nu < 1/(2 - \rho)$. There are no barriers of entry for new firms in this sector so that the equilibrium number of firms is given by the zero profit condition. From the maximization problem, optimal quality and prices are given by

$$\bar{q}_t = \left[(1-\rho)\, z_t^{\frac{\nu}{1-\nu}} W_t \left(\frac{\nu}{w_t} \right)^{\frac{1}{1-\nu}} \right]^{\frac{1-\nu}{1-(2-\rho)\nu}}, \tag{2.4}$$

$$\bar{p}_t = \bar{\tilde{p}}_t = \frac{1}{\nu} \frac{\bar{q}_t^{\rho}}{z_t} w_t, \tag{2.5}$$

where

$$W_t = \left(\alpha^{\frac{1}{1-\nu}} Y_t + (1-\alpha^*)^{\frac{1}{1-\nu}} Y_t^* \right).$$

Note that prices are dependent on quality. There is a fixed mark-up over the unit cost of $1/\nu$. Note also that the condition $\nu < 1/(2-\rho)$ ensures that the outer exponential in the expression for quality is positive. So that, we can expect to observe that quality increases with positive technology shocks. Finally, the solution to this problem implies a constant relationship between l_y and l_q. This is very convenient in calibrating the model:

$$l_q = (1-\rho) l_y. \tag{2.6}$$

2.4 Equilibrium

Let $s_t = (z_t, z_t^*)$ denote the state of the economy at time t. This economy is said to be in equilibrium if every period, given a state of the economy, there is a sequence of international interest rates r_t and, for each country, sequences of: wages w_t, rental prices R_t, number of firms I_t, capital stocks k_t, household decisions $\{c_t, n_t, x_{t,} b_t\}$, final good firm decisions $\{d_t, m_t\}$, intermediate good firm decisions $\{p_t, \tilde{p}_t, q_t, l_{y,t}, l_{q,t}\}$ such that: given wages, prices, the interest rate, the number of firms, the current stock of capital and savings, and a transition rule $s_{t+1} = g(s_t)$, the household's decision variables solve the household's problem 2.1; given qualities, intermediate good prices, and the number of intermediate good firms, the final firm's decisions are 2.2 and 2.3 that solve intermediate good firms problem; given the state of the economy and wages, qualities and prices are given by 2.4, 2.5; good markets clear, i.e. $c_t + x_t = Y_t$ and $d_t + m_t^* = (z_{y,t}/q_t^{\rho})l_{y,t}$; labor markets clear, i.e. $n_t = I_t(l_{y,t} + l_{q,t})$; capital markets clear, i.e. $k_{t-1} = I_t F$; financial markets clear, i.e. $b_t = -b_t^*$; firms make zero profits, i.e. $\Pi_t = \pi_{i,t} = 0 \quad \forall i$; and no-Ponzi-scheme conditions hold.

3 Numerical Analysis

3.1 Measurement and adjustment for quality

Before proceeding to calibrate the model to the data, think about the variables in the model and their observability to agencies that compute the statistics we use in the calibration. Assume that statistical agencies do not adjust for quality so that steady-state prices are taken to be the base year prices.[8]

[8]This implies that a product is defined at the beginning of the series, with its initial price as a reference, and it is considered to be exactly the same product over the whole period.

In this scenario, real Gross Domestic Product (GDP) is measured as

$$GDP_t = I_t \, p_{ss} \, (d_t + m_t^*),$$

while observed domestic absorption (i.e., the total demand of all final goods and services used in the country, originated either from domestic production (GDP) or imported from abroad) is given by

$$\hat{Y}_t = GDP_t - (I_t \, p_{ss} m_t^* - I_t^* \, p_{ss}^* m_t).$$

Y_t is allocated to consumption and investment. We assume the share of $\hat{Y}_t$ that is consumed is exactly the same as the share of Y_t that is consumed, hence observed consumption is:

$$\hat{c}_t \equiv \frac{c_t}{c_t + x_t} \hat{Y}_t = \frac{\hat{Y}_t}{Y_t} c_t.$$

Similarly, observed investment is $\hat{x}_t \equiv \frac{\hat{Y}_t}{Y_t} x_t$. Terms of trade are defined as the ratio of import price deflators to export price deflators. Since in equilibrium all goods from the same country have the same price, the terms of trade can be defined simply as

$$tot_t \equiv \frac{I_t^* p_t^* m_t / I_t^* p_{ss}^* m_t}{I_t \, p_t m_t^* / I_t \, p_{ss} m_t^*} = \frac{p_t^*}{p_t} \frac{p_{ss}}{p_{ss}^*}.$$

Calculating the consumption real exchange rate requires the construction of a consumption price index for each country. Let M_t be the period t share of imported goods in consumption. Then,

$$P_t \equiv (1 - M_t)\,\frac{p_t}{p_{ss}} + M_t\,\frac{p_t^*}{p_{ss}^*}.$$

Finally, we define the real exchange rate as the ratio of these price indexes:

$$rer_t \equiv \frac{P_t^*}{P_t}.$$

Now suppose that the statistical agency observes quality and it can adjust prices to reflect changes in this dimension of each good. We assume that the statistical agency makes the following correction:

$$\check{p}_t = \left(\frac{q_t}{q_{ss}}\right)^{\rho} p_{ss}. \tag{3.1}$$

This is the ideal correction given the expression for optimal prices ((2.5)). It guarantees that in the steady state both adjusted and non-adjusted variables are the same. The agency then replaces p_{ss} by $\check{p}_t$ in all the expressions above.

3.2 Calibration

We use the standard utility function $U(c, 1-n) = [c^{\mu}(1-n)^{1-\mu}]^{\theta}/\theta$. Our economy is calibrated to match features of the US economy over the 1971-

1998 period as follows: we set the value of the discount factor β to 0.99 to match an annualized interest rate of about 4%, the capital depreciation rate δ is set to 0.025 to match an annualized depreciation rate of 10%. Following the literature the coefficient of risk aversion θ is set to -1. Following Mandelman et al. (2011) we assume a cost of holding bonds (ϕ_b) equal to one basis point. We set α to obtain an import share of 15% and μ to obtain a share of hours worked equal to 0.34. The capital adjustment cost parameter η is set so that the standard deviation of investment is about three times that of output. The value of the trade elasticity ν is set to 0.67, so that investment is close to 23% of GDP. The reason why this parameter strongly affects the level of investment is that under monopolistic competition with free entry, a low degree of substitutability between intermediate goods implies a high mark-up over marginal costs, which creates incentives for many firms to enter the market. Since capital is a fixed cost that is independent of the firm, the level of investment will crucially depend on the number of firms that enter the market each period. The value used is in line with the one in Ghironi and Melitz (2005), who justify their choice based on firm level evidence documented by Bernard et al. (2003). The parameter F is set so that the correlation between output and investment is close to 0.94.

The parameters calibrated so far are pretty common to most of the papers in the literature, and their values do not significantly differ from those in other studies either. This is not the case of ρ, which captures how changes in quality affect the costs of production. Equation (2.6) shows that this parameter determines the fixed relationship between the number of workers in production tasks and the number of workers in quality tasks. To calibrate this parameter we first determine a plausible range. BLS data for 2009 reveals that between 2.3 and 6.5% of the workforce in US may be classified as quality tasks employees, depending on the conservativeness of the measure.[9] These results suggest a ρ between 0.93 and 0.98 for 2009. We take $\rho = 0.96$ as the baseline value and perform a sensitivity analysis for other values in the identified range. The main implications of the model are not affected by moving ρ within these limits: lower values of ρ imply that quality enhancements are cheaper, therefore the firm responds by making quality even more strongly pro-cyclical. If, on the other hand, one takes ρ arbitrarily close to its maximum possible value of 1, this is still not enough to affect the sign of the correlations of interest.

Productivity process

The shock process has the usual form,

$$s_t = As_{t-1} + \epsilon_t,$$

where ϵ_t is a vector of normally distributed shocks, independent from past values. The cross-country correlation of shocks is set to match the cross-

[9] Our model considers two types of workers: those devoted to quality and those devoted to production tasks. Therefore, to obtain ρ from the data, we also consider two general groups: quality workers and the rest. See the Appendix for details.

country correlation of outputs, while the variance of shocks is set so that the standard deviation of output is 0.017. Finally, the values in the transition matrix of technology shocks (A) are set to coincide with empirical estimations available in the literature. The cross-country spillovers are set to 0.088, as in Backus et al. (1994). The persistence of the shock is 0.85. Pancrazi and Vukotic (2013) provide evidence that shows how total factor productivity shocks have increased their persistence over the last decades, from around 0.6 to 0.85.[10]

Compared to the values estimated in the literature (see, for instance Heathcote and Perri (2002)), the model requires a productivity process that has about 50% higher variance, and a cross-country correlation that is also about 50% above their value. It should be noted, however, that if instead of the calibrated process one uses the specifications from this literature, the main results from the paper are not affected. The complete parameterization of the model is given in Table 1.

3.3 Simulation

Simulation results are presented in Table 2. These are averages over 50 simulations of 200 periods after discarding the first 100 periods. Let us first evaluate the fit of the model with no adjustments for quality to the data for

[10]They use a set of statistical tools: computing split sample statistics, rolling window estimates, recursive estimates, and fitting a time-varying parameters stochastic volatility model. Their most recent sub-sample, 1983-2010, covers the greater part of our sample. This is the reason we choose 0.85 instead of a value closer to 0.60.

Table 1: Benchmark parameter values.

Household parameters	*Value*	*Target description*	*Target*
θ	-1	From the literature	-
β	0.99	r_{ss}	1% (4% ann.)
μ	0.37	n_{ss}	0.34
δ	0.025	x_{ss}/k_{ss}	2.5%
η	0.96	$sd(\hat{x})/sd(GDP)$	2.9
ϕ_b	0.01	Bond holding costs	1%
Firm parameters			
ν	0.67	$\hat{x}_{ss}/GDP_{ss}$	23%
α	0.64	$\hat{m}_{ss}/GDP_{ss}$	15%
ρ	0.96	l_q/l_y	4%
F	0.2	$corr(GDP, \hat{x})$	0.94
Shock process			
V_ϵ	$10^{-5}\begin{bmatrix} 17 & 29 \\ 29 & 17 \end{bmatrix}$	$sd(GDP)$ $corr(GDP, GDP^*)$	0.017 0.58
A	$\begin{bmatrix} 0.85 & 0.088 \\ 0.088 & 0.85 \end{bmatrix}$	From the literature From the literature	- -

Calibrated to 1971-1998 US data.

the 1971-1998 period. The model suffers from a common ailment of international RBC models: consumption and net exports are excessively smooth. Terms of trade in our model also suffer from excessive smoothness, partly as a result of excessive risk sharing, which may be a cause of concern. Raffo (2008) suggests that excessive smoothness can be alleviated by introducing GreenwoodHercowitzHuffman (GHH) preferences, a possibility that we explore in the appendix. The model matches domestic correlations remarkably well: output, consumption, and investment are strongly positively correlated with each other, while net exports are counter-cyclical. The cross-country correlation of investment is too strong in the model compared to the data. The model is capable of generating counter-cyclical terms of trade that are very similar in magnitude to what we observe in the data. The Backus-Smith puzzle vanishes: both the sign and magnitude of the correlation between relative consumption and the real exchange rate are in line with the data, although the magnitude is a bit too large. Therefore, the model does appear to successfully address both of the "old" puzzles.

The column labeled *adjusted* contains the results from an adjustment to price level calculations for changes in quality in the way described in equation (3.1). What changes predicted by the model will result from this shift in the way we measure prices? Consider first the two correlations that are the main objective of this paper. The correlation between the terms of trade and GDP increases from -0.27 to $+0.42$. This is a remarkable change, almost as remarkable as the $+0.89$ increase observed in the data. The correlation between relative consumption and the real exchange rate increases by even more, from -0.89 to $+0.97$. The direction of the change is in line with the data, but the magnitude of the change is much too strong. We believe that the discrepancies in the magnitudes of these changes might be explained by a composition effect. Adjustments for quality are not performed for all categories of goods in the actual Consumer Price Index (CPI). Some of the categories of goods that are affected by these adjustments are vehicles, computers, other consumer electronics, apparel, and appliances. These categories of goods represent a large fraction of international trade, but are not as important to the consumption basket of the average consumer. Therefore quality adjustments to these categories will affect import and export deflators much more than they affect the CPI. As a consequence, we should expect to see a stronger effect to the terms of trade than to the real exchange rate. However, the model does not take into account this composition effect.

There are discrepancies in some other aspects of the changes in the data and in the model. The model suggests we should observe an increase in the volatility of macroeconomic aggregates, a reversal in the correlation between net exports and output, and an international de-coupling in the form of weaker cross-country correlations. In fact, the opposite has been observed. We understand these phenomena may easily be caused by factors that are external to our model. If this is the case, we can exogenously introduce a "Great Moderation" in the form of lower volatility of the exogenous shocks

Table 2: Simulation results.

	Data[b]		*Model*	
Standard deviations[a]	71-98	99-09	Non-adjusted	Adjusted
Output	1.00	0.94	1.00	1.41
Hours	1.22	1.30	0.42	0.43
Consumption	0.84	0.67	0.54	0.86
Investment	2.81	2.72	3.11	3.51
Net exports	0.34	0.39	0.04	0.08
Terms of trade	1.78	1.17	0.19	0.33
Corr. with domestic output				
Hours	0.86	0.93	0.95	0.99
Consumption	0.93	0.96	0.93	0.99
Investment	0.94	0.95	0.97	0.98
Net exports	−0.41	−0.68	−0.30	0.35
Terms of trade	−0.26	0.54	−0.39	0.49
Cross-country correlations				
Output	0.58	0.85	0.56	0.48
Hours	0.42	0.45	0.31	0.32
Consumption	0.36	0.87	0.16	0.26
Investment	0.30	0.78	0.77	0.76
Rel. consumption-RER	−0.71	−0.06	−0.88	0.97

[a] Relative to the standard deviation of output for the period 1971-1998.
[b] Source: OECD and FRED.

and, an increase in globalization in the form of higher interdependence of exogenous shocks, as well as, a reduction of the home bias parameter, when we compare the model with recent data. If, by doing so, we calibrate to match the volatility and cross-country correlation of output and the share of imports in GDP for the 1999-2009 period, the sign turns in the correlations of interest are robust to the changes observed in the data, and their magnitudes are not greatly affected. However, we prefer to show the results from a homogeneous calibration for both adjusted and non-adjusted versions of the model to identify what and how much of the changes may be explained by quality adjustments considerations.[11]

To appreciate the mechanism driving our results, we plot impulse response functions in Figures 3.1 and 3.2. As the country receives a positive technology shock, quality goes up. This leads to an increase in the price of goods and a decline of quality-adjusted prices. Hence, terms of trade (in the right panel) move in opposite directions depending on whether we apply quality adjustments or not. Output (in the left panel) increases in both cases, though its response is stronger when prices are adjusted for quality. Taken together, this illustrates the negative correlation between output and net exports that

[11] Since some production has shifted toward cheaper places such as China, we were concerned about capturing the changes in world production allocation through the variations in GDP-TOT correlations. If this would have been the case, we would expect a relative increase in import prices and a relative decline in export prices due to changes in composition. To disregard this explanation, we checked the correlation between real GNP and TOT for the two periods and the results are consistent with those of GDP correlations. For US we find -0.22 for 1971-1998 and $+0.64$ for 1999-2009. The correlation between GNP and TOT changes in the same direction and almost the same magnitude of that of GDP-TOT.

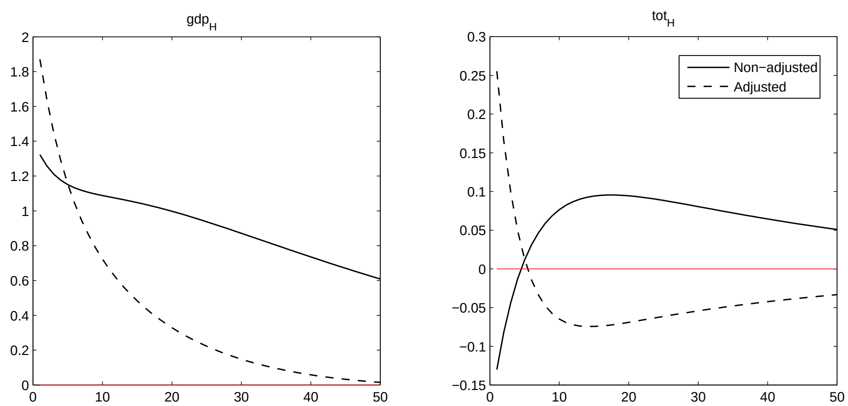

Figure 3.1: Impulse responses of output and terms of trade.

is observed in the data before the 1990s, and the reversal of this correlation once quality adjustments are introduced to price level calculations.

The top left panel in figure 3.2 shows the effects of the shock on the aggregate price level. Since domestic good prices increase relative to foreign good prices and consumers are biased towards domestic goods, the price level increases as well. Of course, the opposite happens when prices are adjusted for changes in quality. Therefore, the real exchange rate (bottom-left panel) declines in the first case, but it increases in the second. Consumption (top-right panel) increases in both cases, though the response is slightly larger when quality adjustments take place. Similarly, relative consumption (bottom-right panel) increases in both cases. Taken together, this illustrates the negative correlation between relative consumption and the real exchange rate that is observed in the data before the 1990s, and the reversal of this

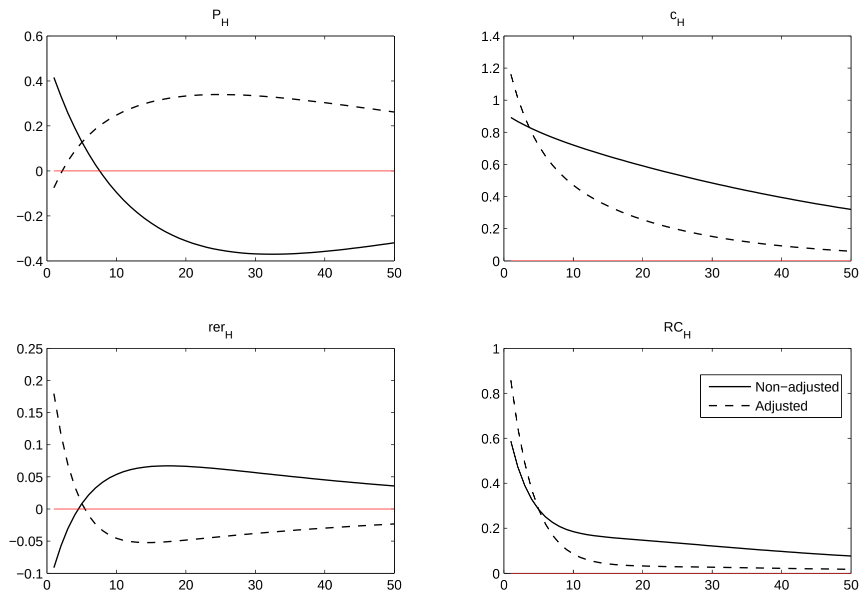

Figure 3.2: Impulse responses of relative consumption and the real exchange rate.

correlation after the introduction of quality adjustments.

4 Conclusions

Over the course of a few years, many of the goods we consume have experienced dramatic changes in quality. Most of these have been innovations that occurred slowly but steadily. To the best of our knowledge, this is a fact that has been largely ignored by the international real business cycle literature. From our point of view, it is an important reason for the discrepancies that exist between theoretical model predictions and actual data estimates. Interestingly, these discrepancies have dwindled in recent years.

How can we arrive at a theory that explains both the reasons for these puzzles as well as their gradual banishment? We have argued that, in order to achieve both of these objectives, one needs two elements: First, a modification of the standard model of international RBCs that takes changes in good quality into account; and Second, a change in price measurement techniques that reflects improvements in quality adjustment practices of statistical agencies. The results presented in this study show that taking changes in quality into account has the potential to explain some of the puzzles related to the co-movement of international prices and quantities. The model introduces a mechanism capable of endogenously arriving at this result, without the need of introducing new shocks, thus preserving most of the simplicity of the original model and avoiding many of the pitfalls typically brought about by the introduction of exogenous disturbances. Furthermore, it shows that taking into account recent changes in the methodology of price level calculations has the potential to explain the diminishing importance of the puzzles.

It could be argued that prices in previous models could simply be understood as being “quality adjusted,” and therefore price drops following productivity gains already reflected changes in good quality. The advantage of the framework in this paper is that by explicitly modeling both pricing and quality decisions it is possible to answer the question of whether quality improvements are quantitatively important enough to explain the aforementioned puzzles. Furthermore, our framework acknowledges that price drops and quality enhancements are not necessarily two sides of the same coin. In many cases, the decision to improve quality comes at the expense of higher production costs, such as hiring better engineers or using better materials. Profit maximizing firms often face this trade-off, and a purely symmetrical model in which price drops and quality improvements are interchangeable completely ignores it.

While the idea that investments in quality are important to business cycle properties is highly intuitive, it would be desirable to find additional support in the data for this mechanism. Paradoxically, it is precisely the lack of good data on quality that creates the biases in price indices that give relevance to this idea in the first place. This difficulty is probably easier to overcome in certain industries than in others. Finding industry-level data to test the cyclical properties of quality suggested in this paper would be an important complement to the model and an avenue for research to be pursued in the future.

This model also has interesting implications for the estimation of shocks. Given that changes in quality resemble demand shocks, an econometrician could potentially mistake changes in quality driven by technological shocks with demand shocks that are independent of technology shocks. A closer evaluation of this possibility is another interesting potential extension of this model.

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Appendix

About the Data

Data in Tables 2 and 3 are taken from the OECD's Quarterly National Accounts database. We obtain series for the countries listed in Table 3 in current prices (CPCARSA) as well as volume estimates (VPVOBARSA) in US dollars at PPP adjusted prices, and use the OECD's reference year. The series are total private consumption, investment in gross fixed capital formation, exports of goods and services, and imports of goods and services. We define GDP to match the definition of the model, that is the sum of consumption, investment, and the trade balance. Net exports are defined as exports minus imports as a share of GDP. Price deflators are calculated as the ratio of imports (exports) in current prices and their corresponding value in real terms. Terms of trade are defined as the ratio of the price deflator for imports and the price deflator for exports. To construct the real exchange rate we obtain nominal exchange rates and consumer price indices from the Federal Reserve Bank of St. Louis (Federal Reserve Economic Data (FRED)).

Table 3: International correlations

	1971-1998		1999-2009			
Country	(GDP, tot)	$(c_{US}/c, RER)$	(GDP, tot)		$(c_{US}/c, RER)$	
United States	−0.24	N/A	0.54	[+0.78]	N/A	N/A
Japan	−0.11	0.26	0.77	[+0.88]	0.33	[+0.07]
Germany	−0.07	−0.15	0.66	[+0.73]	0.09	[+0.24]
France	−0.06	−0.94	0.54	[+0.60]	−0.45	[+0.49]
United Kingdom	0.06	−0.46	0.08	[+0.02]	−0.32	[+0.14]
Italy	0.22	−0.10	0.77	[+0.55]	0.05	[+0.15]
Canada	−0.00	−0.09	−0.37	[−0.37]	0.24	[+0.33]
Spain	−0.05	−0.63	0.63	[+0.68]	0.27	[+0.90]
Australia	0.07	−0.22	0.30	[+0.23]	−0.41	[−0.19]
Mexico	−0.38	−0.61	−0.40	[−0.02]	−0.61	[+0.00]
South Korea	−0.36	−0.64	0.19	[+0.55]	−0.60	[+0.04]
Netherlands	−0.05	−0.14	0.23	[+0.28]	0.10	[+0.24]

Source: OECD, FRED.
In brackets: Change with respect to 1971-1998 period.

Hours worked series are constructed from the OECD-MEI civilian employment index. "Rest of the world" aggregates are constructed using data from all countries in Table 3 other than the US. Real exchange rates between the US and this fictional country are computed using trade-weighted averages, and hours worked are population-weighted averages. Weights correspond to 1995-2005 averages. Finally, to compute standard deviations and correlations we take logarithms of each of the series (except for net exports, which can be negative) and apply a Hodrick-Prescott filter to detrend them.

Columns 2 and 3 of Table 3 report the correlations between the terms of trade and output and between relative consumption and real exchange rate for the twelve largest economies in the OECD between 1971 and 1998. In most cases the correlation between output and the terms of trade is negative or close to zero, while US consumption relative to other countries typically rises following a drop in the real exchange rate. Columns 4-7 of Table 3 show the same correlations for the period 1999-2009 and the changes experienced. The correlation between output and the terms of trade is now strongly positive for most countries, except for Canada and Mexico. The Backus-Smith puzzle is weaker for all but one of the twelve OECD economies in our sample (Australia).

Determine a suitable ρ

The Standard Occupational Classification 2000 (SOC 2000) of the Bureau of Labor Statistics, provides with a detailed classification of employees based on their working tasks (See http://www.bls.gov/oes/2009/may/oes_nat.htm#11-0000). It considers 821 detailed occupations and lists the tasks for every category. Data is collected annually, but the classification changes over time. SOC 2000 finishes in 2009. However, the changes from the immediately previous year, 1999, are not dramatic and we can homogenize them to compare 2009 and 1999 (we cannot claim the same for 1998 data).

After revising the definitions for every occupation, we construct two measures of quality tasks employees. We select occupations that imply the design, creation, invention, customization for specific clients or group of clients, research (and similar tasks) on/of products and services, as well as the direct control of quality and its improvement. We also include those occupations involved in the enhancement of the interest of the public on goods and services (i.e., marketing activities). The first measure, called *broad measure*, includes 53 categories. These categories are: Advertising and Promotions Managers, Marketing Managers, Sales Managers, Public Relations Managers, Engineering Managers, Computer and Information Scientists (Research), Computer Programmers, Computer Software Engineers (Applications), Computer Software Engineers (Systems Software), Architects, Landscape Architects, Aerospace Engineers, Agricultural Engineers, Biomedical Engineers, Chemical Engineers, Civil Engineers, Computer Hardware Engineers, Electrical Engineers, Electronics Engineers (Except Computer), Environmental Engineers, Health and Safety Engineers (Except Mining Safety Engineers and Inspectors), Industrial Engineers, Marine Engineers and Naval Architects, Materials Engineers, Mechanical Engineers, Petroleum Engineers, Engineers (All Other: Mining, Geological and Nuclear are not included), Food Scientists and Technologists, Chemists, Materials Scientists, Market Research Analysts, Agricultural and Food Science Technicians, Commercial and Industrial Designers, Fashion Designers, Floral Designers, Graphic Designers, Interior Designers, Merchandise Displayers and Window Trimmers, Set and Exhibit Designers, Designers (All Other), Sound Engineering Technicians, Chefs and Head Cooks, First-Line Supervisors/Managers of Retail Sales Workers, First-Line Supervisors/Managers of Non-Retail Sales Workers, Advertising Sales Agents, Sales Representatives (Services, All Other), Sales Representatives (Wholesale and Manufacturing, Technical and Scientific Products), Sales Representatives (Wholesale and Manufacturing, Except Technical and Scientific Products), Demonstrators and Product Promoters, Sales Engineers, Agricultural Inspectors, First-Line Supervisors/Managers of Construction Trades and Extraction Workers, and First-Line Supervisors/Managers of Mechanics (Installers, and Repairers). All of them together represent a 6.57% of total employment in 2009 and a 5.74% in 1999.

The *conservative measure* is more restrictive. It includes 25 categories and it requires the appearance of the words creation, design, conversion, product safety, conservation, new uses, discovery, quality, marketing or advertising in the definition. Moreover we are cautious with a broad category labeled *Industrial Engineers*, which specifies that they: *"Design, develop, test, and evaluate integrated systems for managing industrial production processes including human work factors, quality control, inventory control, logistics and material flow, cost analysis, and production coordination.*" Therefore, they are actually involved in the enhancement and control of quality and in some design. However, the latter are not the only tasks they perform. We decided to include only 1/4 of industrial engineers in our conservative measure. The other 24 categories are: Advertising and Promotions Managers, Marketing Managers, Computer and Information Scientists (Research), Computer Programmers, Computer Software Engineers (Applications), Computer Software Engineers (Systems Software), Aerospace Engineers, Agricultural Engineers, Biomedical Engineers, Chemical Engineers, Civil Engineers, Computer Hardware Engineers, Electrical Engineers, Electronics Engineers (Except Computer), Health and Safety Engineers (Except Mining Safety Engineers and Inspectors), Materials Engineers, Food Scientists and Technologists, Materials Scientists, Commercial and Industrial Designers, Fashion Designers, Graphic Designers, Set and Exhibit Designers, Advertising Sales Agents and Demonstrators and Product Promoters. This measure implies a 2.33% and a 2.12% of the work force devoted to quality tasks in 2009 and 1999 respectively.

From equation 2.6 we derive $\rho = 1 - \frac{l_q}{l_y}$. In the model, we only consider two types of labor and so we must do in the data. Therefore, due to labor market clearing,

$$\rho = 1 - \frac{l_q I}{n - l_q I}.$$

The ratio divides total work force in quality tasks by total employment minus total work force in quality tasks. This implies a ρ of 0.93 and 0.94 for 2009 and 1999 respectively, by using the broad measure; and a $\rho = 0.98$ for both years by using the conservative measure.

GHH preferences

Raffo (2008, 2010) shows that many of the inconsistencies between the theory and the data stem from the low volatility of consumption implied by the standard model. He argues that the introduction of an alternative specification of household preferences increases consumption volatility, eliminating some of the model's inconsistencies with the data. We briefly explore this possibility. GHH preferences, introduced by Greenwood et al. (1988), have the property that the marginal rate of substitution between consumption and leisure is independent of the consumption level within the period. This implies that there is no income effect on labor supply and therefore hours worked respond more strongly to productivity changes, which in turn generates volatility of consumption more in line with the data. GHH preferences are characterized by the following utility function:

$$U(c, 1-n) = \frac{[c_t - \lambda {n_t}^{\mu}]^{\theta}}{\theta}.$$

For this exercise we set $\mu = 3.3$ to match a Frisch elasticity of 0.43, consistent with estimates (see McClelland and Mok (2012) and Reichling and Whalen (2012) for a discussion), and $\lambda = 8$ to match a share of hours worked of a third. We leave all other parameters unchanged with respect to the benchmark model. In contrast to Raffo's results, GHH preferences in our model do not generate consumption volatility that is closer to what is observed in the data. This is also the case for net exports and terms of trade (see Table 4).

Table 4: GHH simulation results.

	Data[b]		*Model*	
Standard deviations[a]	71-98	99-09	Non-adjusted	Adjusted
Output	1.00	0.94	1.00	1.41
Hours	1.22	1.30	0.42	0.41
Consumption	0.84	0.67	0.54	0.94
Investment	2.81	2.72	3.11	3.28
Net exports	0.34	0.39	0.04	1.80
Terms of trade	1.78	1.17	0.19	0.27
Corr. with domestic output				
Hours	0.86	0.93	0.95	0.99
Consumption	0.93	0.96	0.93	0.99
Investment	0.94	0.95	0.97	0.99
Net exports	−0.41	−0.68	−0.30	0.15
Terms of trade	−0.26	0.54	−0.39	0.43
Cross-country correlations				
Output	0.58	0.85	0.56	0.60
Hours	0.42	0.45	0.32	0.73
Consumption	0.36	0.87	0.16	0.46
Investment	0.30	0.78	0.78	0.77
Rel. consumption-RER	−0.71	−0.82	−0.88	0.96

[a] Relative to the standard deviation of output for the period 1971-1998.
[b] Source: OECD and FRED.