News Shocks and Terms of Trade: A Quantitative Investigation*

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May 9, 2012

Abstract

In this paper we investigate the effects of “news shocks” to technology on the terms of trade. To do so, we augment a standard, frictionless model of the international business cycle with news shocks and check the changes in the model’s prediction with regard to persistence and volatility of model-generated data. Our results show that news can increase the persistence of the terms of trade, but decrease its variability, albeit slightly. We provide intuitive explanations for the above based on two theoretical assertions. First, news-shocks generate wealth effects; hence, movements in relative prices reflect changes in relative demands for the home and foreign goods. Second, the desire for consumption-smoothing urges agents to smooth-out this wealth effect. Coupled with complete markets, the processes of consumption and investment are smooth and persistent.

Keywords: Terms of Trade, News-shocks, International Business Cycles.

*I thank Patrick Fève, Martial Dupaigne, Christian Hellwig, Franck Portier, Evi Pappa, seminar participants in Toulouse and at the Universitat Autonoma Barcelona for useful comments and discussions. All remaining errors and omissions are mine.

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JEL Classification: E, F.
1 Introduction

“A central puzzle in international real business cycle literature is that fluctuations in real exchange rates are volatile and persistent” (Chari, Kehoe and McGrattan 2002). In general, both New Keynesian (see e.g. Chari, Kehoe and McGrattan 2002) as well as Neoclassical (see e.g Backus, Kehoe and Kydland 1994) type of models have difficulty matching these features of relative prices. Recent work has shed more light in what can be an important source for the aforementioned “irregularities” like non-tradeable services in the production of tradeables (Corsetti et al 2007), pricing-to-market (Betts and Deveroux 2000), habits and learning (Johri and Lahiri 2008), agent heterogeneity and private information (Kocherlakota and Pistaferi 2007), different productivity processes (Heathcote and Perri 2002, Rabanal et al 2008) and investment-specific shocks (Raffo 2010, Mandelman et al 2011). The common workhorse of these works is a two country, open-economy DSGE model augmented by an exogenous, stochastic process for (mainly) technology driven by unexpected innovations. However, Beaudry and Portier (2006) have shown that technology improvements are to a large extent foreseeable and diffuse only slowly over time; implying a change in agents expectations before the technology index actually improves. The authors demonstrate that this very change in expectations can be an important source of fluctuations, possibly more than the actual change itself. Following the pioneering work of Beaudry and Portier (2006) the effects of these so called “news shocks” have been investigated quite extensively both in closed economy (Jamonvich and Rebello 2006, Blanchard, L’Huillier, and Lorenzoni 2009) and open-economy set-ups (Beaudry, Dupaigne and Portier 2009, Jamonvich and Rebello 2008, Cova et al 2008). The emphasis of these papers is on macroeconomic aggregates, mainly cyclical co-movements in these aggregates, at the national and the international level. In this paper, we take a different approach. We investigate the extent at which changes in expectations, as captured by “news shocks”, can help us better understand movements in relative prices; and in particular the behaviour of the terms of trade. News shocks are a pure wealth effect, as agents discover about higher future wealth due to
the forthcoming improvement in productivity and thereby their wage income. The latter, together with the forward-looking nature of prices in a world where agents are fully-rational and take into account all available information in their consumption and investment decisions; makes the terms of trade responsive to changes in expectations even if fundamentals have not changed. The terms of trade, the relative price of imports in terms of exports, reflect the relative use of home and foreign goods for investment and consumption purposes. Consumption-smoothing implies an immediate adjustment of agents’ consumption plans faced with new information about higher wealth (Beaudry and Portier 2006), and this adjustment is reflected both in prices and quantities. In this paper we try to understand the direction of the effect in the terms of trade, as well as its implication on the series’ empirical regularities.

More precisely, we investigate the quantitative and qualitative changes of a standard, frictionless model of the international business cycle in relation to the terms of trade persistence and volatility when changes in technology are forecastable. As our workhorse, we use the model of Backus, Kehoe and Kydland (1994), henceforth BKK. This is a well understood, flexible-price complete-market model whose successes and failures are well known; thus making comparison easy. In our analysis for persistence we document a robust theoretical result: news-shocks can increase the persistence of the terms of trade under all our measures of persistence, that is the autocorrelation function, half-lives of import responses, largest roots of lag polynomials and the sum of autoregressive coefficients. Nevertheless, this relation is not monotonic in so far that longer foresight does not imply more persistence. Fève et al (2009) and Leeper et al (2011) have shown that news shocks add moving-average components in the specification of economic aggregates, which explains from a statistical viewpoint that news can indeed increase persistence of time-series. Our work is related to theirs for we also provide intuition as to why this might be the case for the terms of trade in the context of a micro-founded theoretical model. Once compared to the data, we observe that all models generate too much persistence in the relative price of exports against imports if we consider only the post Bretton Woods period.

As far as volatility of the terms of trade is concerned, the benchmark model gen-
erates substantially less than what is observed in the data. We show that augmenting the model with news does not help much on that front, in so far that the variability of relative price hardly changes with news, and if anything is decreased.

The key intuition to the above findings is the consumption-investment behaviour of forward looking agents. In a news-driven environment, movements in relative prices reflect changes in relative demands of the intermediate goods for consumption and investment purposes. Agents smooth-out the wealth effect generated by good news about the future, resulting in a process for (relative) consumption that is smoother and more persistent. Consequently, the process of the terms of trade is also more persistent since under complete markets relative prices follow very closely the process of relative consumption. In this context, investment plays a particularly important role (similarly to Raffo 2010) for the implications of our model to the variance of the terms of trade. As agents discover about the increase in the future marginal productivity of capital, they postpone investment and increase consumption. The fact that the two move in opposite directions implies lower demand-side effects than otherwise, hence decreasing the need for an adjustment in relative price. Moreover, investment is more responsive to actual changes in technology than to expected ones, which explains a lower volatility in prices in news-drive environments.

The following section describes briefly our benchmark, the BKK model, section 3 presents and discusses the results. The final section provides some final remarks and the way forward coming out of this exercise.

2 The BKK model

2.1 Description

In this section we briefly describe the BKK model. There are two countries in the world, named one and two, inhabited by a large number of identical agents. Their preferences are symmetric and characterised by utility functions of the form:
\[ E_0 \sum_{t=0}^{\infty} \beta^t \frac{(C_{it}^\tau (1 - N_{it})^{1-\tau})^\gamma}{\gamma} \quad i = 1, 2 \]  
(1)

where \( C_{it} \) and \( N_{it} \) are consumption and hours worked in each country \( i \).

There is full-specialisation of production and each country produces an intermediate good, namely country one produces intermediate good \( a \) and country two the intermediate good \( b \). Neither capital nor labour are mobile across countries but intermediate goods can be freely and costlessly exchanged around the world. Output, \( Y_{it} \) is produced using a standard Cobb-Douglas production function \( Y_{it} = Z_{it}^\alpha K_{it}^{1-\alpha} \), \( i = 1, 2 \) where \( K_{it} \) and \( Z_{it} \) denote capital and technology in each country. The latter give rise to the following world’s resource constraints:

\[ Y_{1t} = a_{1t} + a_{2t} \]
\[ Y_{2t} = b_{1t} + b_{2t} \]  
(2)

where \( a_{it} \) and \( b_{it} \) denote the use of good \( a \) and \( b \) in each country \( i \). Therefore, \( Y_{it} \) is measured in units of the local intermediate good.

Intermediate goods are thereafter used in each country to produce final goods using a CES aggregator of the form \( G_{1t} = \left\{ \omega a_{1t}^{\theta-1} + (1 - \omega)b_{1t}^{\theta-1} \right\}^{\frac{\theta}{\theta-1}} \) for country 1 and \( G_{2t} = \left\{ (1 - \omega)a_{2t}^{\theta-1} + \omega b_{2t}^{\theta-1} \right\}^{\frac{\theta}{\theta-1}} \) for country two. We introduce home-bias in each country by letting \( \omega > 0.5 \), and \( \theta > 0 \) is the elasticity of substitution between the two goods. For values of \( \theta \) close to zero intermediate goods are compliments, \( \theta = 1 \) corresponds to the Cobb-Douglas case and for \( \theta \to \infty \) goods are perfect substitutes. Final goods are used only locally for consumption and investment purposes:

\[ C_{it} + I_{it} = G_{it} \]  
(3)

Capital stocks evolve according to\(^1\)

\(^1\)Note that we abstract from the time-to-build structure that the original paper proposes.
Finally, we close the model by specifying the technology process which constitutes
the exogenous variable to our system and the sole driving force of fluctuations:

\[
\begin{pmatrix}
Z_{1t} \\
Z_{2t}
\end{pmatrix} = \begin{pmatrix}
0.906 & 0.088 \\
0.088 & 0.906
\end{pmatrix} \begin{pmatrix}
Z_{1t-1} \\
Z_{2t-1}
\end{pmatrix} + \begin{pmatrix}
\epsilon_{1t-q} \\
\epsilon_{2t-q}
\end{pmatrix}, \quad q \geq 0
\] (5)

For \(q = 0\) the model matches exactly the one in the original BKK paper. Allowing
for the innovations to the technology process to be forecastable, that is \(q > 0\),
constitutes the main contribution of this paper. Here we emphasise that this is the
sole modification to the original model. Neither the endogenous, nor the exogenous
structure of the model change since we retain the same values of persistence and
spillovers - i.e. the matrix of \(AR(1)\) coefficients - as well as correlation of shocks (see
below). Any changes to the model’s predictions in terms of persistence and volatility
in the terms of trade come from the mere fact that technological improvements are
now known in advance. Thereby, our work is a controlled experiment on the effects
of news-shocks on the persistence and volatility of relative prices, where the BKK
model is used as a measuring device.

Finally, in equilibrium we have that:

\[
C_{1t} + I_{1t} = q_{a1t}^1 a_{1t} + q_{b1t}^1 b_{1t}
\]

\[
Q_t(C_{2t} + I_{2t}) = q_{a2t}^2 a_{2t} + q_{b2t}^2 b_{2t}
\] (6)

where \(q_{a1t}^1\) and \(q_{b1t}^1\) are the prices of the two goods in each country, expressed in
units of the country-one final good and \(Q_t\) is the relative price of the country-two
final good with respect to the country-one final good (the numeraire), i.e. the real
exchange rate. Obviously, with free-movement of intermediate goods the law of one
price holds: \(q_{a1t}^1 = q_{a2t}^2\) and \(q_{b1t}^1 = q_{b2t}^2\) \(\forall t\). We thus define the terms of trade as the
marginal rate of transformation between the two intermediate goods in country 1.
evaluated at equilibrium quantities; which (in equilibrium) equals their relative price\(^2\):

\[
p_t = \frac{q_{bt}}{q_{at}} = \frac{\frac{dG_{1t}}{db_{1t}}}{\frac{dG_{1t}}{da_{1t}}} \tag{7}
\]

The real exchange rate is defined as the ratio of marginal utilities of consumption in each country, evaluated at equilibrium final-goods consumption\(^3\):

\[
RER_t = \frac{MU_{C2}}{MU_{C1}} \tag{8}
\]

where \(MU_{Ci}\) stands for marginal utility of consumption in country \(i = 1, 2\).

### 2.2 Solution, steady state and calibration

As in the original paper, we take country one to be US and country two to be “the rest of the world”. In terms of calibration, we choose the exact same parameters as in BKK, thus we refer to the original paper for justification of these choices. The table below gives a list of benchmark values, some of which we alter at a later section for tests of robustness. As a solution method, given the values of the model’s parameters we solve the social planner’s problem that weights equally the utility of consumers in the two countries. We define the steady-state as the situation where all variables grow at constant, zero rates and where \(\epsilon_{it} = 0 \forall i, t\). Thereafter, we approximate the model by taking a first-order log-linear approximation around the steady-state and we solve it numerically in Dynare.

This finalises the exposition to the benchmark model which is to be used as a workhorse for the quantitative exercise, the results of which we present in the following section.

\(^2\)Notice that this is not the standard definition of terms of trade, as it constitutes the relative price of imports (the foreign good) in terms of exports (the local good). However, this is consistent to the standard way the real exchange rate is defined in macroeconomic models.

\(^3\)In solving the model, imposing this condition is redundant.
<table>
<thead>
<tr>
<th>Preferences</th>
<th>Technology</th>
<th>Shocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \beta = 0.99 )</td>
<td>( \alpha = 0.36 )</td>
<td>( \text{var}(\epsilon_{1t}) = \text{var}(\epsilon_{2t}) = 0.00852^2 )</td>
</tr>
<tr>
<td>( \tau = 0.34 )</td>
<td>( \delta = 0.025 )</td>
<td>( \text{corr}(\epsilon_{1t}, \epsilon_{2t}) = 0.258 )</td>
</tr>
<tr>
<td>( \gamma = -1 )</td>
<td>( \theta = 1.5 )</td>
<td></td>
</tr>
<tr>
<td>Risk Aversion</td>
<td>Capital share</td>
<td>Elastocity of substitution</td>
</tr>
<tr>
<td>Discount factor</td>
<td>Depreciation rate</td>
<td></td>
</tr>
</tbody>
</table>

Calibration to approximate US steady-state values.

3 Results

3.1 Impulse-Response Functions and Intuition

Below we present the response of the terms of trade to one-standard deviation innovation in the technology index of country one (\( Z_{1t} \)) for different values of \( q \). Following Beaudry, Dupaigne and Portier (2009) we name the period between the announcement and actual change as the “interim period”. First, we observe that the terms of trade responds to news on impact as expected to be the case by the forward-looking nature of prices. Rational agents adjust their behaviour in light of new information, thus prices move to clear the market (see more detail below). Second, we observe that the highest impact-response occurs when the impulse comes as a surprise, i.e. an actual change in technology occurs, rather than when an announcement is made. Third, the impact response falls with \( q \), that is the further in the future the actual change in technology will occur, the lower the response on impact. Fourth, the responses follow a hump-shaped behaviour which implies endogenous propagation mechanisms, since the technology index - the sole exogenous driving force of the system - decays as an \( AR(1) \) process. Finally, we observe that following the peak, each response decays at a different speed. We turn to each of these topics below.
An actual, unexpected, temporary change in the technology index causes a general expansion: consumption increases because people are wealthier, employment and investment increase because of the temporarily higher marginal product of labour and capital. Thus, output necessarily increases. The terms of trade depreciate to reflect the scarcity of the foreign good, which is now the least efficient to produce. Nevertheless, the terms of trade increase on impact even when an actual change in technology has not occurred as forward-looking agents adjust their behaviour to new information. To make things more transparent we show below the equation of the (log-linearised) terms of trade $\hat{p}_t$, derived by log-linearising equation (7):

$$\hat{p}_t \simeq \frac{1}{\theta}(\hat{a}_{1t} - \hat{b}_{1t})$$

(9)

The terms of trade move to clear the market of intermediate goods, as they are used in the production process of final goods in both countries. Where faced with actual, unexpected technology improvements the terms of trade depreciate to reflect
the scarcity of the foreign good; they depreciate in response to positive news about the future to reflect the fall in the relative demand of the home good. News generate a pure wealth effect and act as a world demand shock (Beaudry, Dupaigne and Portier 2009). As people learn about higher productivity in the future, which implies higher wealth, the desire for consumption smoothing induces an immediate increase in consumption. Agents also consume more leisure, thus employment falls. Investment is also lower as agents allocate capital to the future when its marginal productivity is going to be higher. Thereby, output necessarily falls and, as it is known (Beaudry, Dupaigne Portier 2009, Jaimonvich and Rebello 2008), abstracting from the increase in consumption good news about the future create a general recession (see figure 2 above). The fall in investment in country one is so big that in equilibrium the overall demand for final goods in that country is now lower than before the announcement. As Raffo (2010) explains, domestic absorption, defined as $G_{it} = C_{it} + I_{it}$, $i = 1, 2$,
Figure 3: IRFs of Investment and Domestic Absorption in country one at different lengths of the interim period. Percentage deviations from steady state. Solid-lines: two quarters. Dashed-lines: four quarters

falls on aggregate (see figure 3). Due to the home bias in the production of the final goods the intermediate good $a$ is now less valuable than good $b$. In Figure 2 we also plot the responses of country two. Note that output and investment fall in country two as well, thus lowering somehow the demand of good $b$, however the drop in these aggregates is lower than in country one since the wealth effect in the country that is going to benefit the least from the technological change is much lower. Residents of country 2 benefit from a temporary increase in country’s one technology only via spillovers. Overall, the relative world demand for country one intermediate good falls by more as shown by the response of domestic absorption in each country during the interim period. Market clearing requires the terms of trade to depreciate in view of the fact that good $a$ is now less valuable for world residents.

A similar argument explains why the impact-response of $p_t$ is lower for a higher lag between the announcement and the actual technology improvement. First, the wealth effect at present is less strong the more into the future income is to increase because of discounting; the present value of income is lower for higher values of $q$. Most importantly, investment is also less responsive with higher values of $q$, as shown in figure 3. The longer the interim period, the lower the fall (in absolute value) of domestic absorption, thereby the lower the fall in relative demand of the country one intermediate good and the lower the decrease in its relative price. Nevertheless, relative demand for the home intermediate good still falls causing a depreciation in
the terms of trade. Further, since the required adjustment of prices is now necessarily lower; the variability in the terms of trade can be expected to fall with the length of the interim period. Finally, slower decay of the response for higher levels of $q$ can a priori translate into higher persistence. We discuss issues of persistence and variability in later sections of the paper. First, we test the intuition outlined so far by performing an extreme experiment: we allow for a long interim period.

### 3.1.1 Long interim periods

We allow that agents learn about the forthcoming one-standard-deviation technology improvement twenty periods in advance, such that $q = 20$. The response of the terms of trade is shown in figure 4 whereas other variables of interest in figures 11 to 13 in the Appendix. We observe that the responses of the main variables of interest are not vastly different from above (figure 11). That is, all variables respond on impact to the news, consumption in both countries increases as agents smooth future gains of productivity, whereas hours and investment fall for the reasons explained above. Nevertheless, we do observe some differences in magnitudes that confirm our intuition. As agents value less heavily future than present periods, the wealth effects stemming from the news-shock are pretty low. Indeed, in figure 12 we see that the response of consumption, investment and other variables is lower (in absolute value) than those shown before; that is responses do fall with the length of the interim period.

How do the terms of trade behave along the path? In figure 4 we see that the terms of trade respond positively on impact, the response is lower than all the other values of $q$ studied above and following the actual increase in the technology index the response of the terms of trade is hump-shaped. This behaviour confirms the basics of the intuition already outlined in the previous section. A lower impact-response reflects the fact that the wealth effect is less strong and the fall in relative demands is not as pronounced. This is evident from the lower response of domestic absorption and investment as depicted in figure 12 in the appendix. The desire to smooth the benefits from future income increase over the interim period is also evident in the consumption path; which is very stable throughout this period. With a lower income
effect, a smooth consumption path and a lower response of investment; domestic absorption falls by less, the difference in relative demands is less pronounced and eventually the necessary movement in relative prices to clear the world market for intermediate goods is lower. Once again, the fall in relative demand causes the terms of trade to depreciate on impact, albeit slightly, and remain below its steady-state value throughout the interim period.

A longer interim period can give us some signals about the potential implication of expected shocks on the persistence and variability of the terms of trade. Other than the fact that the impact response is smaller for higher lags, we also see that most of the necessary price adjustment occurs on impact; as the variation in the terms of trade is very small during the interim period. This small and smooth change is consistent with lower variability in the terms of trade, as we shall see in the relevant section below. However, we cannot say with certainty that the overall persistence of the terms of trade increases with news. This might be the case for short interim periods, where the effect of the response during news accounts for less relative to the overall response, but whether this remains to be the case at higher lags is not clear.
A high value of $q$ allows also to grasp more intuition on economic behaviour about the transition path the economy undergoes before it reverts back to the initial steady-state. First, once news are revealed, consumption increases instantly whereas capital decreases. For a period, the economy is on an explosive path and consumers eat their capital since by assumption (final) consumption and capital goods are homogeneous. Note that this explains the lower response of investment when $q$ is high as well. As agents find it optimal to eat their capital during the interim period, and as they like consumption smoothing, they want to eat approximately equal levels of capital all along. For this consumption plan to be feasible, investment cannot decrease by much as the economy needs more capital stock for consumption purposes than it does when the technology improvement is more imminent. Heuristically, it takes more capital to feed the agents for twenty periods than for two.

In figure 12 we observe that throughout the interim period consumption decreases, albeit slightly, until it eventually jumps once the technology improvement is realised. The preference for consumption in earlier periods than in later ones explains this declining trend; whereas the dislike for big variations in consumption explains its smoothness. Note also that investment drops at a higher pace and magnitude than consumption does (figure 12) therefore, during the interim period the economy is on a path where both consumption and capital are falling. When the shock actually materialises though, consumption and capital jump to new higher values and the economy finds itself on a transition path where both variables increase. This is not the final path as both variables cannot continue increasing forever. With a transitory shock, as assumed in this case, they have to eventually decrease so that the economy goes back to the initial steady-state. Indeed, following a long expansionary period, the economy enters a path where both consumption and capital fall (see figure 13, variables start falling after a bit less than 100 periods following the news-shock) until the economy is stabilised to the same steady-state it was before the shock. Note that the latter path is one of the initial stable paths of the saddle-path-stable system.

Overall, this section confirms the basics of our intuition above: what guides the response of variables and the response of the terms of trade is the fact that a lower in-
come effect, coupled with the desire to smooth consumption and investment, decrease the response of domestic absorption as the length of the interim period increases. The differences in world relative demands for the intermediate goods are smaller and their relative price needs to move less to clear the world markets of intermediate goods. A longer interim period also reveals more clearly the transition paths of consumption and capital.

3.2 Persistence

We now move on to the main part of our paper, the analysis of persistence and volatility in relative prices in news-driven cycles. We choose to focus on terms of trade, rather than the real exchange rate, because it is easier to define. Specifically, we can measure terms of trade in the data as we do in the model. See the Appendix for the exact definition of the terms of trade in the data. We compare model-generated data under different lengths for the interim-period, against actual data. Our sample spans over 1950:1-2010:4 and is depicted in figure 11. Close inspection of the figure reveals the possible existence of a structural break, something that as we shall see can generate unit-root issues in our sample. For this reason, we also compare our results to a limited period - which we refer to as “Limited Sample” below - that spans over 1975:1-2010:4 (figure 12). We followed Steinson (2009) in choosing the beginning of our limited sample, that also allows us to focus on the post Bretton-Woods period.

A problem in exercises of this type is that there is not a universally accepted measure of persistence. The most widely used measure are the coefficients of autocorrelation; especially of order one. We spend most on our analysis on persistence on the latter, but emphasise also the role of autocorrelation at higher order as well as the sum of autocorrelation coefficients. Thereafter, we analyse two other measures less widely used: half-lives of impulse-responses and the largest roots of lag polynomials.

The coefficients of autocorrelation are given in Tables 2 (full sample) and 3 (limited sample) and figures 5 (full-sample) and 6 (limited sample). First, we observe one

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When we refer to limited sample model-generated data we mean data that have been generated after simulating the model for the number of periods equal to the “limited sample” case.
Table 2: Persistence of Terms of Trade - Coefficients of Autocorrelation - Full Sample

<table>
<thead>
<tr>
<th>Data</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>TT - Full Sample</td>
<td>0.9900</td>
<td>0.9767</td>
<td>0.9626</td>
<td>0.9484</td>
<td>0.9363</td>
<td>4.814</td>
</tr>
<tr>
<td>TT - Limited Sample</td>
<td>0.9297</td>
<td>0.8327</td>
<td>0.7246</td>
<td>0.6155</td>
<td>0.5254</td>
<td>3.628</td>
</tr>
<tr>
<td>Models</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>q=0</td>
<td>0.9728</td>
<td>0.9344</td>
<td>0.8885</td>
<td>0.8381</td>
<td>0.7853</td>
<td>4.119</td>
</tr>
<tr>
<td>q=1</td>
<td>0.9823</td>
<td>0.9508</td>
<td>0.9096</td>
<td>0.8622</td>
<td>0.8109</td>
<td>4.516</td>
</tr>
<tr>
<td>q=2</td>
<td>0.9828</td>
<td>0.9599</td>
<td>0.9250</td>
<td>0.8817</td>
<td>0.8330</td>
<td>4.582</td>
</tr>
<tr>
<td>q=3</td>
<td>0.9831</td>
<td>0.9600</td>
<td>0.9329</td>
<td>0.8951</td>
<td>0.8502</td>
<td>4.621</td>
</tr>
<tr>
<td>q=4</td>
<td>0.9834</td>
<td>0.9599</td>
<td>0.9318</td>
<td>0.9012</td>
<td>0.8615</td>
<td>4.638</td>
</tr>
</tbody>
</table>

Model-generated data were derived from 100 simulations of 244 periods each, the size of the “Full Sample”.

Table 3: Persistence of Terms of Trade - Coefficients of Autocorrelation - Limited Sample

<table>
<thead>
<tr>
<th>Data</th>
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<td>0.9484</td>
<td>0.9363</td>
<td>4.8140</td>
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<tr>
<td>TT - Limited Sample</td>
<td>0.9297</td>
<td>0.8327</td>
<td>0.7246</td>
<td>0.6155</td>
<td>0.5254</td>
<td>3.6279</td>
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<tr>
<td>Models</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>q=0</td>
<td>0.9636</td>
<td>0.9139</td>
<td>0.8559</td>
<td>0.7927</td>
<td>0.7279</td>
<td>4.2539</td>
</tr>
<tr>
<td>q=1</td>
<td>0.9743</td>
<td>0.9319</td>
<td>0.8784</td>
<td>0.8178</td>
<td>0.7535</td>
<td>4.3559</td>
</tr>
<tr>
<td>q=2</td>
<td>0.9743</td>
<td>0.9417</td>
<td>0.8949</td>
<td>0.8382</td>
<td>0.7761</td>
<td>4.4252</td>
</tr>
<tr>
<td>q=3</td>
<td>0.9741</td>
<td>0.9407</td>
<td>0.9027</td>
<td>0.8522</td>
<td>0.7939</td>
<td>4.4635</td>
</tr>
<tr>
<td>q=4</td>
<td>0.9741</td>
<td>0.9395</td>
<td>0.8999</td>
<td>0.8577</td>
<td>0.8052</td>
<td>4.4764</td>
</tr>
</tbody>
</table>

Model-generated data were derived from 100 simulations of 144 periods each, the size of the “Limited Sample”.

17
theoretical result: persistence in the terms of trade - as measured by autocorrelation coefficients of one but as we as higher order - increases monotonically with the interim period. The model that produces the least persistence in the terms of trade is the one where shocks come as pure surprises, and that is when comparing the coefficient of autocorrelation at any order. The autocorrelation function (ACF) increases monotonically as we allow shocks to be forecastable further in advance, something that is especially evident in figure 7, where we plot autocorrelation coefficients up to the 12th order. Moreover, we reach the same conclusion if we assume as a measure of aggregate persistence the sum of all five autocorrelation coefficients (Table 2, last column). Which model performs better when compared to actual data depends on the sample period we focus on, and obviously on the specificities of the latter. If we focus on the full-sample, the series of the actual US terms of trade appears to be very persistent - almost a unit root process. In that case, the autocorrelation function generated by any variant of our benchmark model fails to generate enough persistence. Naturally, based on the theoretical outcome above the longer the interim-period the closer to the actual autocorrelation function we get. In this sense, news help the model to better much the observed persistence in the terms of trade. However, our results are totally reversed once we look at the empirical autocorrelation function generated for the post Bretton-Woods period. In that case the persistence of the process is much lower and the models generate too much persistence. Thus, again consistent with our previous finding, the model with shocks as pure surprises matches the data the best; but even in that case it generates too much persistence. High persistence in the model without news is an outcome of persistent Solow residuals (see our calibration exercise above).

The above results are not surprising. As Leeper et al (2011) have shown, perfect-foresight adds a moving-average (MA) component in the process of economic variables, with recent news being more heavily discounted than past ones since they provide information about changes that lie in the more distant future. More foresight implies more MA components, thus somehow mechanically the persistence of the process increases. For example, Fève et al (2009) show that a purely forward-looking
variable:

\[ y_t = \alpha y_{t+1} + \epsilon_{t-q}, \quad \alpha < 1, \ q \geq 0 \]

admits a solution of the form:

\[ y_t = \sum_{i=0}^{q} \alpha^{q-i} \epsilon_{t-i} \]

Obviously, a higher value of \( q \), equivalently more foresight, means more persistence. Since \( \alpha < 1 \), recent news receive less weight (Fève et al 2009, Leeper et al 2011). Statistically, where economic aggregates behave as AR(p) processes with unexpected shocks, they behave as ARMA(p,s) with news. The complexity of this model does not allow to solve the expression for the terms of trade analytically to demon-
strate these issues, but we can use the coefficients of the model’s policy function to get something similar.

For example, consider an economy where shocks are pure surprises (equation 10) and when $q = 2$ (equation 11).

$$\Phi(L)p_t = \hat{u}_{1t} - \hat{u}_{2t}$$

$$-0.542 (\hat{u}_{1t-1} - \hat{u}_{2t-1}) - \alpha_0 (\hat{u}_{1t-2} - \hat{u}_{2t-2})$$

(10)

$$\Phi(L)p_t = \hat{u}_{1t} - \hat{u}_{2t} - 0.783 (\hat{u}_{1t-1} - \hat{u}_{2t-1})$$

$$+0.551 (\hat{u}_{1t-2} - \hat{u}_{2t-2}) + \alpha_1 (\hat{u}_{1t-3} - \hat{u}_{2t-3})$$

$$+\alpha_2 (\hat{u}_{1t-4} - \hat{u}_{2t-4})$$

(11)

with $\hat{u}_{it}$ being the model’s structural innovations and $\alpha_0$, $\alpha_1$ and $\alpha_2$ are very low, almost zero numbers. Note that the second equation involves more moving average components, at lags three and four even though their significance is minor. Even though it is not evident at a first sight, the persistence of the process implied by the second equation is higher, as shown by their implied ACF (figure 8).
Figure 8: The autocorrelation function of the terms of trade, implied by the ARMA representation of the terms of trade under $q = 0$ and $q = 2$.

The main outcome of this section is that news-driven economies generate higher persistence in the terms of trade. The intuition is as follows: News shocks generate wealth effects, which cause an immediate response of consumption and investment. However, because rational agents smooth consumption the potential increase in wealth is spread throughout the interim period. The longer the interim-period, the further into the future this wealth increase is to be realised and the more people smooth consumption during that period; i.e. they change consumption “little by little” thereby increasing its persistence (see figure 9). The terms of trade, on the other hand, mirror the relative use of the two intermediate goods in the production of final consumption and investment goods. Therefore, the process for the relative use of the intermediate goods follows closely that of consumption, meaning that news-shocks can increase the persistence of the terms of trade as well.

3.3 Other measures of persistence

The coefficients of autocorrelation are the most common measure of persistence. In this section, we use other measures less widely used in the literature, in particular half-lives of impulse responses and the largest root of the lag polynomial for the terms of trade. As we shall see these statistics add more substance to our previous results.

Half-life is the largest time $T$ “such that $IR(T - 1) \geq 0.5 \times impulse$ and $IR(T) <$
Figure 9: The autocorrelation function of relative consumption- Full Sample.

0.5 × impulse” (Steinsson 2008, p. 520), where IR(T) denotes the impulse response of the terms of trade at time T. Thus, half-life measures the time needed for a response to fall below half the size of the impulse.

Figures 15 and 16 plots the reduced-form impulse responses of terms of trade data, constructed as explained in the Appendix. The number of lags we set according to the Akaike Criterion, which instructs five lags in the full sample and eight lags in the limited sample case. First, we observe that the IRF of the terms of trade follows a hump-shape behaviour, which implies some propagation mechanisms in the true data generating process. Remember that this is not a response from an identified VAR, thus the shock represents a mixture of all shocks in the economy. Steinsson (2008) uses this empirical regularity to motivate that “real shocks” are the primal source of real exchange rate movements, because contrary to monetary shocks, they imply hump-shape responses. Interestingly, data generated from our model with only temporary technology shocks in the two countries exhibit a hump-shape response to one-unit reduced-form shock (see figure 16).

We observe that the implied IRFs in the data to one-unit reduced form innovation,
Table 4: Persistence of Terms of Trade - Half-lives

<table>
<thead>
<tr>
<th>Data</th>
<th>Full Sample</th>
<th></th>
<th>Limited Sample</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$AR(5)$</td>
<td>$AR(2)$</td>
<td>$AR(8)$</td>
<td>$AR(3)$</td>
</tr>
<tr>
<td>Raw</td>
<td>172</td>
<td>105</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>HP-filtered</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Models</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$q=0$</td>
<td>25</td>
<td>31</td>
<td>25</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>[12, 50]</td>
<td>[13, 68]</td>
<td>[11, 50]</td>
<td>[11, 54]</td>
</tr>
<tr>
<td>$q=1$</td>
<td>31</td>
<td>39</td>
<td>32</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>[16, 59]</td>
<td>[17, 80]</td>
<td>[14, 76]</td>
<td>[13, 69]</td>
</tr>
<tr>
<td>$q=2$</td>
<td>30</td>
<td>57</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>[18, 60]</td>
<td>[21, 130]</td>
<td>[14, 92]</td>
<td>[15, 78]</td>
</tr>
<tr>
<td>$q=3$</td>
<td>32</td>
<td>57</td>
<td>32</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>[19, 62]</td>
<td>[21, 141]</td>
<td>[15, 83]</td>
<td>[16, 155]</td>
</tr>
<tr>
<td>$q=4$</td>
<td>33</td>
<td>59</td>
<td>28</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>[19, 70]</td>
<td>[25, 136]</td>
<td>[15, 51]</td>
<td>[16, 113]</td>
</tr>
</tbody>
</table>

as well as the corresponding half-life, depend heavily on the filtering procedure, as well as the relevant sample. The reason behind this is the same and it stems from the potential structural break existing in the process of the terms of trade in the beginning of the 1980s. Figure 15 in the Appendix plots the series together with two alternative filtering methods. We observe that an HP-filter with the conventional filtering parameter $\lambda = 1600$ takes away a lot of its persistence, as it can be “visually” measured by the impulse responses. The response dies out much faster than the one in the raw data, as well as the response of the data for which we simply removed a linear trend. This is evident in the implied half-lives: where the half-life in the raw-data minus a linear trend is as high as 33 periods, it is only four(!) once we apply the filter. Issues and flaws of the HP-filter are discussed in King and Rebello (1993).

Turning to the theoretical models, we observe that news shocks do add persistence to the terms of trade, as measured by the half-life of impulse responses. Impulse responses were estimated on both samples and we have chosen the number of lags

\[ ^5\text{However, we do not achieve stationarity in the log-terms of trade by simply removing a linear trend (ADF tests).} \]
according to the Akaike and the Baysian Information Criteria\(^6\). Table 4 gives the results. The half-life of the impulse in the model with technology shocks coming as pure surprises ranges from 25-31 periods depending on the number of lags and the simulation exercise, with all other models having longer half-lives. Nevertheless, this relation is not necessarily monotonic but part of the reason is the uncertainty surrounding the estimation of half-lives (Cheung and Lei 2000). What is important though is that in all cases, models with expected shocks imply higher persistence than models without, as measured by half-lives.

As to which model is closer to the half-life in the data depends on which measure of the data is the right one to look at. Consistently with above, if it is indeed more sensible to look at the limited-sample process of the US terms of trade, then all models - including the one with traditional shocks - generate too much persistence. The reverse is true if we look at the full-sample but once again the possibility of a unit-root jeopardises the relevance of the latter.

As the two final measures of persistence, we document the largest roots of lag polynomials and the sum of autoregressive coefficients, using different versions of the benchmark model as our data generating processes. Results are presented in tables 5 and 6. Outcomes are largely in accordance with those of half-lives just analysed in so far that all models generate more persistent processes for the terms of trade when compared to the benchmark one; with the relation between persistence and length of the interim period not being necessarily monotonic. An exception to this rule concerns the largest root of model-generated data under \(q = 0\) and \(q = 1\), where economies without news appear to be more persistent in three out of four experiments.

Overall, this section provides the analyst with a robust conclusion: expected shocks can indeed increase the persistence of the terms of trade in the context of a fully flexible, complete markets model. This is a sound theoretical outcome and is consistent with all different measures of persistence employed in this quantitative exercise. Nevertheless, the empirical relevance of the latter is jeopardised once these

\(^6\)Those were five and two in the full-sample, according to the Akaike and the Baysian criterion respectively, and eight and three in the limited-sample case.
Table 5: Persistence of Terms of Trade - Largest Root

<table>
<thead>
<tr>
<th></th>
<th>Full Sample</th>
<th></th>
<th>Limited Sample</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$AR(5)$</td>
<td>$AR(2)$</td>
<td>$AR(8)$</td>
<td>$AR(3)$</td>
</tr>
<tr>
<td>Data Raw</td>
<td>0.9942</td>
<td>0.9885</td>
<td>0.8389</td>
<td>0.8713</td>
</tr>
<tr>
<td></td>
<td>0.8029</td>
<td>0.6652</td>
<td>0.8659</td>
<td>0.6690</td>
</tr>
<tr>
<td>Models q=0</td>
<td>0.9170</td>
<td>0.9581</td>
<td>0.9204</td>
<td>0.9216</td>
</tr>
<tr>
<td>q=1</td>
<td>0.9141</td>
<td>0.9460</td>
<td>0.9265</td>
<td>0.9061</td>
</tr>
<tr>
<td>q=2</td>
<td>0.9341</td>
<td>0.9776</td>
<td>0.9344</td>
<td>0.9160</td>
</tr>
<tr>
<td>q=3</td>
<td>0.9458</td>
<td>0.9768</td>
<td>0.9409</td>
<td>0.9586</td>
</tr>
<tr>
<td>q=4</td>
<td>0.9340</td>
<td>0.9771</td>
<td>0.9631</td>
<td>0.9555</td>
</tr>
</tbody>
</table>

Table 6: Persistence of Terms of Trade - Sum of AR coefficients

<table>
<thead>
<tr>
<th></th>
<th>Full Sample</th>
<th></th>
<th>Limited Sample</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$AR(5)$</td>
<td>$AR(2)$</td>
<td>$AR(8)$</td>
<td>$AR(3)$</td>
</tr>
<tr>
<td>Data Raw</td>
<td>0.9958</td>
<td>0.9928</td>
<td>0.8800</td>
<td>0.9165</td>
</tr>
<tr>
<td></td>
<td>0.6951</td>
<td>0.7357</td>
<td>0.6629</td>
<td>0.7339</td>
</tr>
<tr>
<td>Models q=0</td>
<td>0.9634</td>
<td>0.9709</td>
<td>0.9522</td>
<td>0.9611</td>
</tr>
<tr>
<td>q=1</td>
<td>0.9754</td>
<td>0.9796</td>
<td>0.9685</td>
<td>0.9720</td>
</tr>
<tr>
<td>q=2</td>
<td>0.9712</td>
<td>0.9841</td>
<td>0.9719</td>
<td>0.9719</td>
</tr>
<tr>
<td>q=3</td>
<td>0.9704</td>
<td>0.9842</td>
<td>0.9664</td>
<td>0.9787</td>
</tr>
<tr>
<td>q=4</td>
<td>0.9741</td>
<td>0.9841</td>
<td>0.9575</td>
<td>0.9784</td>
</tr>
</tbody>
</table>

results are compared to their empirical counterparts coming from the series of the US terms of trade over 1975:1-2010:4.

3.4 Volatility

So far we have concentrated our analysis on persistence. However, the inability of models to generate enough variability in relative prices has also troubled researchers (Backus, Kehoe and Kydland 1994, Chari, Kehoe and McGrattan 2002, Heathcote and Perri 2002, Rabanal et al 2008). In this section we analyse how the outcomes
Table 7: Volatility of the terms of trade - Standard Deviations (percent)

<table>
<thead>
<tr>
<th></th>
<th>sd($TT$)</th>
<th>sd($y1$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full sample</td>
<td>14.65</td>
<td>25.68</td>
</tr>
<tr>
<td>Limited sample</td>
<td>5.034</td>
<td>16.08</td>
</tr>
<tr>
<td>Lags of news</td>
<td></td>
<td></td>
</tr>
<tr>
<td>q=0</td>
<td>1.3614</td>
<td>30.8712</td>
</tr>
<tr>
<td></td>
<td>(0.2846)</td>
<td>(13.5152)</td>
</tr>
<tr>
<td>q=1</td>
<td>1.3201</td>
<td>29.8641</td>
</tr>
<tr>
<td></td>
<td>(0.2834)</td>
<td>(12.9767)</td>
</tr>
<tr>
<td>q=2</td>
<td>1.2838</td>
<td>28.9594</td>
</tr>
<tr>
<td></td>
<td>(0.2818)</td>
<td>(12.4932)</td>
</tr>
<tr>
<td>q=3</td>
<td>1.2520</td>
<td>28.1715</td>
</tr>
<tr>
<td></td>
<td>(0.2798)</td>
<td>(12.0905)</td>
</tr>
<tr>
<td>q=4</td>
<td>1.2244</td>
<td>27.4695</td>
</tr>
<tr>
<td></td>
<td>(0.2773)</td>
<td>(11.7077)</td>
</tr>
</tbody>
</table>

Numbers in brackets represent standard deviations.
Data derived from 100 simulations, 244 periods each.

of our benchmark model change on this front when allowing for news-shocks in the technology processes.

Overall, our results indicate that the volatility of relative price drops with news-shocks, but the difference in magnitude is not that big. For this reason, the relation between terms of trade volatility and news-shocks is not necessarily monotonic, even though this is what it looks like in the table, but due to large standard errors relative to the values themselves it might be the case that in a different simulation-attempt this monotonicity breaks down. Nevertheless, we can be confident enough that economies driven by unexpected shocks imply higher volatility in the terms of trade compared to economies where shocks are known four periods in advance.

The intuition for the above is simple and comes as a consequence of all complete-market models of the international business cycle, as well explained by Chari, Kehoe and McGrattan (2002) and Heathcote and Perri (2002) among others. In brief, in a world of perfect international risk sharing, the relative price of goods across countries
Table 8: Volatility of the terms of trade - HP-Filtered Data - Standard Deviations (percent)

<table>
<thead>
<tr>
<th></th>
<th>sd(TT)</th>
<th>sd(TT) / sd(y1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Sample</td>
<td>2.4676</td>
<td>153.3219</td>
</tr>
<tr>
<td>Limited Sample</td>
<td>2.4401</td>
<td>171.4169</td>
</tr>
<tr>
<td>q=0</td>
<td>0.4695</td>
<td>33.4681</td>
</tr>
<tr>
<td></td>
<td>(0.0562)</td>
<td>(4.3817)</td>
</tr>
<tr>
<td>q=1</td>
<td>0.4159</td>
<td>28.0162</td>
</tr>
<tr>
<td></td>
<td>(0.0555)</td>
<td>(3.9925)</td>
</tr>
<tr>
<td>q=2</td>
<td>0.3717</td>
<td>23.9876</td>
</tr>
<tr>
<td></td>
<td>(0.0539)</td>
<td>(3.7219)</td>
</tr>
<tr>
<td>q=3</td>
<td>0.3372</td>
<td>21.0846</td>
</tr>
<tr>
<td></td>
<td>(0.0517)</td>
<td>(3.4945)</td>
</tr>
<tr>
<td>q=4</td>
<td>0.3120</td>
<td>19.0701</td>
</tr>
<tr>
<td></td>
<td>(0.0489)</td>
<td>(3.2680)</td>
</tr>
</tbody>
</table>

Filtering parameter, $\lambda = 1600$.
Numbers in brackets represent standard deviations.
Data derived from 100 simulations, 244 periods each.

are tied down by the processes of consumption[7]. With complete markets, both at
the domestic and at the international level, agents smooth consumption in space
(between countries) and time (between periods). The arrival of good news about
the future is not going to change dramatically peoples’ consumption patterns and
the use of intermediate goods. In other words, the demand shifts sparked by news
are not likely to be large in magnitude because of forward-looking agents’ desire to
smooth the wealth effect. For this reason, movements in the terms of trade during the
interim period are largely driven by the response of investment, as in our economy
intermediate goods are used to produce a single, homogeneous final good that can
be used for both consumption and investment purposes. Nevertheless, it is known
that in news-driven environments investment is not very responsive when compared
to actual shocks[8]. Investment falls in light of news about higher productivity in the

[7] A very good analysis of the relative consumption - real exchange rate relation is given in the
classic Backus and Smith (1993).

[8] Counter-intuitively, and in contrast to empirical evidence (positive correlation of economic ag-
gregates within and across countries, see BDP), investment falls following positive news about the

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future, but falls by less the more in the distant future this change will occur because of discounting\textsuperscript{9}. For this reason, the demand for the home-intermediate good falls, but falls by less the longer the intermediate period is. Therefore, the adjustment in relative prices is less pronounced and the implied variability in the terms of trade is lower.

Overall, our results suggest that the inability of complete-market, neoclassical models to replicate the observed variability of the terms of trade is not likely to be resolved by allowing technology improvements to be perfectly predictable. If anything, the latter seems to be worsening these models’ performance. Note that restricting the asset structure alone is not a panacea to issues of variability in the terms of trade, as the allocations under complete and incomplete markets are likely to be very similar and in some cases identical (Cole and Obstfeld 1991, Baxter and Cruccini 1995). Nevertheless, augmenting incomplete markets models with other frictions has been helpful towards this direction (Corsetti et al 2008).

\textsuperscript{9}Investment falls because people want to postpone it for the period when the marginal product of capital will be higher. This strategy obviously increases their income. However, the more in the future productivity will change, the less profitable this strategy is. Nevertheless, some investment is postponed no matter the length of the interim period (see figure 11).
4 Conclusion

In this exercise we have augmented a standard, frictionless model of the international business cycle with news shocks. In a world where technology disturbances are forecastable, movements in relative prices reflect changes in relative demands. We have emphasised the role of wealth effects generated by news shocks in explaining both the direction and the magnitude of terms of trade movements. Moreover, our simple analysis has shown that news can add persistence to the terms of trade, especially when looking at autocorrelation coefficients of order higher than one, half-lives of impulse responses and roots of lag-polynomials. In terms of volatility, whether technology improvements come as pure surprises or are expected does not alter the results match, and all models fail substantially to match the observed variability in the terms of trade. Indeed, the fact that the fall in relative demand is lower for longer interim periods implies - if anything - a lower variance in the terms of trade; making one of the most puzzling features of international data even more difficult to address.

References


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5 Appendix

Following BKK, we define the empirical US terms of trade series as “the ratio of the implicit price deflator for imports to the implicit price deflator for exports, with deflators computed as the ratios of current-price imports and exports to base-year-price imports and exports”. Our source is the same as the authors, that is the OECD’s Quarterly National Accounts database.
Figure 10: World recession generated by one standard-deviation expected technology shock in country one, long interim period, $q = 20$. Percentage deviations from steady-state. Solid-lines: Country one. Dashed-lines: country two.

Figure 11: IRFs of Consumption, Investment and Domestic Absorption in country one at different lengths of the interim period. Percentage deviations from steady state. Solid-lines: two quarters. Dashed-lines: four quarters. Crosses: twenty quarters.
Figure 12: The transition of Consumption and Capital in country one for long interim period. Percentage deviations from steady state.

Figure 13: The terms of trade for US, logs, Raw and HP-Filtered - Full Sample
Figure 14: The terms of trade for US, logs, Raw and HP-Filtered - Limited Sample

Figure 15: IRFs to one-unit reduced-form innovation, estimated from an AR with five lags (AIC) - Full Sample.
Figure 16: IRFs to one-unit reduced-form innovation, estimated from an AR with eight lags (AIC) - Limited Sample.

Figure 17: IRFs to one-unit reduced-form innovation, estimated from an AR with five lags. Model-generated data. Full Sample.
Figure 18: IRFs to one-unit reduced-form innovation, estimated from an AR with eight lags. Model-generated data. Limited Sample.