What are the external effects of US economic fluctuations?¹

Giancarlo Corsetti
*European University Institute, University of Rome III and CEPR*

Luca Dedola
*European Central Bank and CEPR*

Sylvain Leduc
*Board of Governors of the Federal Reserve System*

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Abstract

This paper investigates the external effects of productivity and demand shocks in the US using sign restrictions based on robust predictions by standard theory. Identifying shocks to US manufacturing — our measure of tradables — we find that positive productivity shocks boost US overall consumption and investment, relative to the rest of the world, and real imports, thus deteriorating net exports; US net foreign assets also decrease. These shocks, however, appreciate the US real exchange rate and the US terms of trade. Shocks to the demand for US manufacturing appear to be less persistent in the data, and have much smaller effects on absorption and on trade and capital accounts. However, they also lead to a delayed dollar appreciation.

These findings question the textbook view that supply driven domestic expansions should deteriorate the terms of trade of a country, and provide conditional evidence of a low degree of international risk sharing.

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1 Introduction

The well-established evidence of an international business cycle has long raised issues in the sources of world-wide fluctuations in economic activity. One view is that the international business cycle is driven by common shocks, possibly affecting different regions asymmetrically and with variable lags. Another view is that disturbances originated in one region are transmitted abroad through a variety of channels, both real and financial, including import demand, assets returns and portfolio reshuffling. As a prerequisite to discriminate between competing views, a good framework to quantify the empirical content of different channels of transmission of business cycle impulses across borders is needed.

As a contribution towards this goal, in this paper we document empirically the effects of productivity and demand shocks in the US on absorption, trade, international relative prices, asset prices and international portfolios. Using structural VARs, we identify productivity and demand shocks via the sign-restriction methodology adopted by Uhlig [2005], Canova and De Nicoló [2002], and Dedola and Neri [2007]. Namely, we impose intuitive theory-based restrictions, consistent with a large class of models, on the sign of impulse responses of a small set of variables — in order to assess the performance of our identification strategy, we also carry out Monte Carlo experiments on simulated time series data from a standard open economy model.

Two features of our study are worth stressing. First, since we are interested in understanding the key channels of the international transmission, we focus on the effects of asymmetric shocks, i.e. shocks affecting US variables relatively more than their counterparts abroad. Specifically, following the standard methodology in empirical open-economy (e.g Glick and Rogoff [1995]), we measure US variables (but net exports and domestic relative prices) relative to an aggregate of other major industrial countries.

Second, we focus on shocks to manufacturing rather than shocks to the US economy as a whole. Here, we take advantage of the fact that many theoretical predictions are clear-cut for macro shocks concentrated in the tradable sector of the economy — whereas the alternative of studying directly economy-wide shocks would raise difficult identification issues. We thus proceed by assuming that manufacturing captures a large fraction of tradables produced in the economy.¹ We will nonetheless assess whether our

¹Economy-wide disturbances can have vastly different effects on domestic and interna-
identified shocks have economy-wide effects, by estimating the response of US macro variables like aggregate consumption and investment.

In our findings, productivity shocks to US manufacturing do have aggregate effects on the US economy: they persistently increase US aggregate consumption and investment, i.e. US absorption, relative to the rest of the world, thus raising imports and worsening the US trade balance — the trade deficit turns out to be quite persistent over time. Productivity shocks also cause real appreciation, rather than depreciation, in all our measures of the international relative prices of US goods, namely, a CPI-based, a PPI-based and an export-deflator-based real exchange rate — the latter being constructed to proxy for the terms of trade. These findings imply that, similarly to Engel [1999], movements in traded goods and manufacturing prices are major drivers of the dollar real exchange rate. In other words, the real dollar appreciation triggered by a positive productivity shock to tradables is not exclusively due to the Harrod-Balassa Samuelson effects raising the relative price of US nontradables, but also to an improvement in the US terms of trade.²

Concerning the effects on asset prices and foreign assets and liabilities, we also document that productivity shocks significantly raise the US stock market relative to an aggregate index of foreign markets, an effect which we do not detect in response to demand shocks. Over time, these shocks also open a positive nominal interest differentials in favor of the US, which peaks 10 to 15 quarters after the shock. Based on the dataset of valuation-adjusted US Foreign assets and liabilities computed by Gourinchas and Rey [2008], we show that asymmetric positive productivity disturbances worsen the net foreign asset position of the US — complementing our early result

²In the textbook version of the HBS hypothesis, an increase in the supply of tradable is linked to a real appreciation of the exchange rate. Here, we emphasize that this is not necessarily the case when countries are specialized in the production of different tradable goods. Whether or not the increase in the relative price of nontradables across countries also transpires into an appreciation of the real exchange rate depends on the sign and relative strength of the terms of trade movement. Standard models typically predict a large enough worsening of the terms of trade that outweighs the HBS effect and leads to a real exchange rate depreciation.
of a deterioration of net trade. However, we also find that both gross assets and liabilities increase at the same time.

Conversely, we find that demand shocks to US manufacturing, which are orthogonal to productivity shocks, have the expected qualitative effects, but quantitatively tend to be less persistent and less consequential for macroeconomic variables, relative to productivity shocks. Specifically, in response to a relative increase in demand for US manufacturing, all US international relative prices strengthen, though with some delay; aggregate investment rises somewhat, but the effects on consumption, external accounts and financial positions, and asset prices, are generally quite subdued.

Our results square well with several standard theoretical predictions that are robust across different models, providing them with empirical support. However, they also question key aspects of the international transmission of productivity shocks typically postulated by textbook open-economy models. Most notably, our estimates of the responses of international relative prices imply an extra benefit to US residents of favorable US productivity shocks: a higher supply of tradables is accompanied by an increase in their purchasing power.

This result has consequential but subtle implications for the nature of international transmission and cross-country risk sharing. Namely, as pointed out by Cole and Obstfeld [1991], a fall in international relative prices partly offsetting productivity and output differentials would be a key channel to provide ex-ante consumption risk insurance, by containing differences in national wealth, and substituting for the benefits of international capital markets. Conversely, our estimated response of US international relative prices acts to magnify the ex-ante consumption risk of US productivity fluctuations, thus hindering, rather than facilitating, international risk sharing. In this respect, our empirical results provide conditional evidence of substantial departures from efficient cross-country risk sharing, thus complementing the important (unconditional) findings in Backus and Smith [1993].

Our findings lend broad support to the international transmission mechanism highlighted by recent open-economy models with incomplete markets (see Ghironi and Melitz [2006] or Corsetti, Dedola and Leduc [2008]). These works have emphasized that, following a technology shock to tradables production, pronounced asymmetric wealth effects and/or firms entry can drive the response of domestic absorption (demand) to such an extent that the home currency appreciates in real terms, the terms of trade improve, and the
trade balance turns into a deficit, at least over the business cycle. The international spillovers from these relative price movements, while hampering risk sharing, also cause output to co-move more than consumption — thus addressing a feature of the international transmission of technology shocks at the root of the famed “quantity puzzles” in international macroeconomics (see Obstfeld and Rogoff [2001]).

Our work relates to a small but significant empirical literature. In notable early work, Clarida and Galí [1994] used long run restrictions to identify aggregate demand and aggregate supply shocks and their effects on the real exchange rate, and cross-country GDP and inflation differentials for the US vis-à-vis the other G7 countries. In previous work by us (Corsetti, Dedola and Leduc [2006]), we also used long-run restrictions to identify technology shocks in the manufacturing sector in a sample of five G7 countries, finding that permanent productivity differentials in the US have effects broadly similar to those of productivity shocks above. Corsetti and Mueller [2006] and Monacelli and Perotti [2007] study the external effects of real demand shocks, in the form of shocks to US government spending, finding mixed evidence on the response of net trade and international relative prices. Finally, Canova, Ciccarelli and Ortega [2006] carefully characterize the empirical features of business cycle comovements among the G7 countries. In this paper we instead trace the detailed external effects of identified US shocks, constituting the key channels of the international transmission mechanism.

The paper is organized as follows. Section 2 briefly reviews the international transmission mechanism in standard theoretical and quantitative models, identifying alternative views and empirical predictions on which we base our sign restrictions and define the key questions our empirical analysis will address. Section 3 describes the data and the empirical methodology. Section 4 presents and analyzes in detail our main findings, while Section 5 presents some sensitivity analysis. Section 6 explores whether our identified impulse responses can correctly reproduce the international transmission in Monte Carlo experiments with model-generated data. Section 7 concludes, also deriving some directions for future research. Appendix 1 describes the data in detail, while Appendix 2 specifies the model used in the Monte Carlo experiments in Section 5.

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3In a closed-economy context, strong effects on current demand of current and anticipated endogenous productivity gains are derived for instance by Comin and Gertler [2006].
2 From theory to the identification of productivity and demand shocks

In this section we motivate and lay out the theoretical underpinnings of our identification of shocks to productivity and demand in the manufacturing sector. The idea underlying identification via sign restrictions is to focus on a minimal set of predictions on the direction of the response of key macroeconomic variables to specific shocks, which are implied by standard theoretical models encompassing the most general analytical frameworks. Specifically, in our approach, identification should only hinge on restrictions on variables whose behavior in the international transmission of shocks is quite uncontroversial. Conversely, the response of variables for which theory presents a fairly wide range of predictions should be left unconstrained — as to reconsider theoretical and empirical controversies in light of the analysis results.

2.1 Alternative views of the international transmission

The conventional view in policy and market circles is that US output booms, associated with consumption and investment expansions, lead to real dollar appreciation and deteriorate the external balance. This view appears to fit well important recent episodes of high US output and productivity growth, accompanied by large real dollar appreciation and trade imbalances. Moreover, intriguing empirical evidence consistent with it is provided by several studies documenting that positive news on the US business cycle tends to lead to dollar appreciation, negative news to depreciation — e.g., see Andersen et al. [2003] and the recent survey by Engel et al. [2007].

This popular characterization of the open-economy consequences of cyclical expansions is well in line with traditional models stressing real demand disturbances — such as the Mundell-Fleming-Dornbusch (MFD) model. Indeed, in the MFD framework, a real ('IS') demand boom appreciates the currency in nominal and real terms and increases imports, while exports are ‘crowded out’. As a result, in an open economy demand booms have smaller effects on domestic output than in a closed economy — due to exter-

\footnote{4On average, US cyclical output and consumption expansions are indeed positively correlated with trade deficits, real exchange rate appreciation and terms of trade improvement, a point implied by the findings by Backus and Smith [1993] and Corsetti, Dedola and Leduc [2008].}
nal ‘leakages’ of domestic demand. Conversely, the conventional view seems more difficult to reconcile with the international transmission as envisioned by the modern open-economy literature placing emphasis on supply driven expansions.

The reason is that seminal contributions to this literature — not only the international real business cycle (IRBC) literature (e.g. see Backus, Kehoe and Kydland [1994] and Stockman and Tesar [1995]), but also the sticky price literature (e.g., see Obstfeld and Rogoff [1995] and Chari, Kehoe and McGrattan [2002]) — have been developed either under the assumption of complete markets or using specifications implying a high degree of international risk sharing. As shown in detail below, in this case positive technology shocks to tradable output that raise a country’s overall consumption, cannot but worsen that country’s real exchange rate and terms of trade — the international relative price of domestic tradables. Under incomplete markets, however, recent work shows that the same models can predict the opposite: because of large relative wealth and demand movements, tradables productivity and output expansions cause the terms of trade and the real exchange rate to appreciate. Remarkably, the short-run impact of (persistent) technology shocks is thus similar to that of demand shocks according to the MFD framework.\footnote{See e.g. Ghironi and Melitz [2006] and Corsetti Dedola and Leduc [2008].}

2.2 A theoretical perspective on the transmission of demand and supply shocks

The discussion above suggests that the response of international relative prices to shocks to the tradables sector should be placed at the core of our empirical work on the transmission mechanism. In what follows, we further clarify the different role of these prices in the theory of international transmission, using a stylized two-country endowment economy. In spite of its simplicity, this model captures important economic mechanisms at play in much larger, fully developed models, such as the one we use to carry out our Montecarlo experiments in Section 6. As regard notation, we express all prices in the same currency, and denote foreign variables with a star ‘*’.

According to standard theory, productivity gains in the domestic tradable sector raise the price of non-tradables relative to tradables ($P_N/P_T$) — this is the key prediction of the HBS theory; in addition, they can be expected
to move the country’s terms of trade \((TOT)\), i.e. the relative price of domestic exports in terms of imports. The overall response of the real exchange rate \((RER)\) — defined as the relative price of national consumption baskets \((P/P^*)\) — will thus depend on the sign and relative magnitude of the movements in these two prices. For given terms of trade, the HBS effect tends to appreciate the real exchange rate; the terms of trade response may or may not offset this appreciation.

To see this point most clearly, consider the following standard decomposition of the real exchange rate as a function of the relative price of tradables \((P_T/P^*_T)\) — in turn depending on the terms of trade — and the relative price of nontradables at home \((P_N/P_T)\) and abroad \((P^*_N/P^*_T)\):

\[
RER \equiv \frac{P}{P^*} = \frac{P_T}{P^*_T} \cdot \frac{P/P_T}{P^*_N/P^*_T} = f(TOT) \cdot \frac{g \left( \frac{P_N}{P^*_T} \right)}{g \left( \frac{P^*_N}{P^*_T} \right)}.
\]

Positive productivity shocks to tradables do increase the relative price of home nontradables \(\frac{P_N}{P_T}\): ceteris paribus, this tends to appreciate the real exchange rate, captured above by an upward movement in \(RER\). However, whether productivity gains in the tradable sector ultimately appreciates or depreciates a currency in real terms clearly depends on the equilibrium response of the terms of trade.

Now, the equilibrium response of international prices is largely determined according to the degree of risk sharing in the economy. As is well understood, full consumption-risk insurance implies that the ratio of marginal utility of consumption across any two countries, \(\frac{U'(C)}{U'(C^*)}\), is proportional to the bilateral real exchange rate between these countries:

\[
RER \equiv \frac{P}{P^*} = \kappa \frac{U'(C)}{U'(C^*)}.
\] (1)

Under standard assumptions about preferences, this condition implies that domestic consumption can rise relative to foreign consumption only if its relative price, the real exchange rate, simultaneously depreciates — namely, if it falls according to the above expression.

The above condition, and its failure, have far-reaching implications for the international transmission mechanism via terms of trade movements. Full
international risk insurance does not affect the HBS mechanism: positive productivity shocks to tradables do increase the relative price of home non-tradables \( \frac{P_N}{P_T} \) whether or not international financial markets are complete, contributing to real appreciation. But this means that, under complete markets, domestic consumption can rise with a domestic productivity shocks to tradables, only if the terms of trade depreciate, up to outweighing the change in the relative price of domestic nontradables — i.e. up to the point of causing an overall depreciation of the real exchange rate.\(^6\) Similar considerations also apply to models assuming incomplete markets, yet implying allocations that are arbitrarily close to the perfect risk sharing — i.e. predicting a counterfactual positive and high correlation between relative consumption and the real exchange rate — see Cole and Obstfeld [1991], Chari, Kehoe, McGrattan [2002], and our discussion in Corsetti, Dedola and Leduc [2008]. In either case, a positive shock to tradables necessarily worsens a country’s terms of trade.

When asset markets are incomplete and/or departures from full risk sharing substantial, instead, the response of international prices to productivity shocks in the tradables sector can go either way. Under incomplete markets, the condition (1) does not hold in general: home consumption can increase relative to foreign consumption even if the real exchange rate does not depreciate — as is the case when productivity gains drive a wedge between domestic and foreign wealth, causing asymmetric effects on relative aggregate demand. When this (endogenous) wedge is substantial, large movements in relative domestic absorption can actually cause the terms of trade to improve, changing the sign of their response relative to the complete market allocation. A terms of trade appreciation is clearly in violation of the full risk sharing condition discussed above, but consistent with the large body of empirical evidence following the work of Backus and Smith [1993].

The degree of risk-sharing also shapes the behavior of international relative prices in response to shocks to the demand for domestic tradables. Relative to the case of productivity disturbances, a shift in demand for these goods appreciates their price relative to the price of nontradables. For given terms of trade, this tends to depreciate the real exchange rate. With incom-

\(^6\)It is easy to verify that a similar argument goes through also in models without nontradables, but home bias in consumption. In this case, the real exchange rate is only a direct function of the terms of trade. Then, a productivity shock raising domestic consumption cannot but depreciate both international prices.
plete markets, it is possible that such demand shift also increases the price of domestic tradables in terms of foreign goods — thus improving the country’s terms of trade. However, if markets are complete (as long as the shock raises domestic relative to foreign consumption, without otherwise shifting marginal utilities), it must be the case that the real exchange rate depreciate: the domestic relative price movement cannot be outweighed by the terms of trade movement.

These theoretical results provide a tight framework for our empirical identification strategy. On the one hand, they qualify domestic relative price of manufacturing goods — our measure of tradables — as a natural candidate for identification via sign restrictions. For a large class of models, this price unambiguously falls in response to positive productivity shocks to tradables (the HBS effect), and unambiguously increases in response to sector specific demand shocks — this is so independently of the degree of international risk sharing. Indeed, the HBS effect will provide the keystone to our empirical model, complementing restrictions on productivity and output in US manufacturing. On the other hand, the same discussion qualifies both the real exchange rate and the terms of trade as natural candidates for the list of variables, including net exports, consumption and investment, which should be left unconstrained in our analysis, with the goal of gaining empirical insights into the anatomy of the international transmission mechanism of US fluctuations.

**Advantages of identifying asymmetric shocks to a country tradables**

Our theoretical results so far also illustrate the clear advantage of focusing our analysis of the international transmission mechanism on shocks specific to the tradable sector, rather than to the economy as a whole. Namely, in response to shocks to tradables, the behavior of domestic relative prices and quantities is quite similar across different theoretical models; theoretical predictions on the behavior of the terms of trade, the real exchange rate and other external variables instead vary across models, but for exactly this reason an empirical characterization of their behavior is potentially quite valuable. Theory predictions are instead less clear-cut for economy-wide shocks to productivity and demand. In response to these disturbances, the behavior of many macro variables, and especially of domestic and international relative prices, can differ vastly, depending on the (unknown) distribution of these
shock across the tradable and nontradable sectors.\textsuperscript{7} Identifying shocks and interpreting empirical results would then be exceedingly difficult — namely, it would require strong auxiliary assumptions about the relative importance of aggregate shocks in each sector. As theory’s predictions are sharper for sectoral shocks, both identification and interpretation require a much smaller and less controversial set of maintained hypotheses.

For a similar reason, our interest in isolating the channels of international transmission suggests that our identification strategy should focus on shocks hitting the US asymmetrically vis-à-vis the rest of the world. Global shocks, i.e. shocks that are strongly correlated across countries, affecting the US symmetrically relative to the rest of the world, would raise issues in interpretation which are similar to the one discussed above, in relation to economy-wide shocks. The interpretation of the international repercussions of global shocks would again require auxiliary assumptions on their distribution and consequences across countries.\textsuperscript{8}

A common way to deal with this issue in the empirical literature — well in the tradition of empirical open-economy macroeconomics — is to measure variables taking cross-country differentials — e.g. see Clarida and Galí [1994] and Glick and Rogoff [1995]. One potential issue in this approach is that it implicitly imposes symmetry across economic areas. In our study, however, this assumption can be defended on two grounds. First, a symmetry assumption is not obviously consequential in studies comparing the US, a very large country, against a large aggregate of OECD countries. Second, alternative approaches, such as expanding the empirical system to include the level of some US variables, soon run against the constraint imposed by data availability, quickly exhausting any degree of freedom in the empirical analy-

\textsuperscript{7}For instance, suppose that we find a positive association between the level of the US economy-wide labor productivity and a real exchange rate depreciation. This could be driven by the fact that productivity gains also hit the nontradable sector — thereby depreciating the domestic relative price of nontradables by a reverse HBS effects irrespective of the response of the terms of trade to shocks to tradables. It would be quite difficult to infer depreciation is evidence in favor of a particular transmission mechanism without knowing whether the productivity increase is concentrated in tradables or nontradables, and the extent to which the distribution of shocks is stable over time.

\textsuperscript{8}For instance, suppose that we find a positive association between the level of US labor productivity and the US trade deficit. Could we infer that this is evidence in support of the intertemporal approach to the current account? Unfortunately, the answer to this question is ‘No’. Without controlling for movements in foreign productivity we could not reach this conclusion, as e.g. forcefully argued by Glick and Rogoff [1995].
sis. Thus, as the focus of our analysis and its emphasis is on international variables like the trade balance and the real exchange rate, in our baseline empirical models we consider cross-country differentials. We then conduct robustness exercises enlarging our benchmark specification to include some country variables in level.

2.3 Sign restrictions in our identification

In this subsection, we define the theory-based sign restrictions that we adopt in our analysis, analyzing productivity and demand shocks in turn.

**Productivity in US manufacturing** The first shock under consideration consists of supply shocks increasing labor productivity in the US manufacturing, relative labor productivity in the rest of the world. To identify these shocks we postulate a set of four restrictions. Positive supply shocks should:

1. Raise manufacturing output relative to aggregate output in the US \((YT-Y)\); (2) Lower the relative price of manufacturing \((PT-P)\) — the HBS effect; (3) Raise US manufacturing output relative to Foreign manufacturing output \((YT-Y^\ast)\); and (4) Raise US labor productivity relative to Foreign labor productivity in manufacturing.

Restrictions (1) and (2) reflect the theoretical underpinning that supply shifts should move price and quantity in opposite direction (rather than in the same direction, as is the case for demand shocks); restriction (3) isolates US-specific shocks (or US-specific components of global shocks). The last restriction ensures that our identified supply shocks are associated with an increase in relative labor productivity, as it would be the case with standard technology shocks analyzed by the IRBC literature. All other variables included in our analysis, namely, aggregate consumption and investment, trade variables and international relative prices, are left unconstrained, so that the external consequences of productivity shocks can be traced in the data.

**Demand for US manufacturing** The second shock under consideration consists of possibly global demand shifts in favor of US manufacturing goods, relative to all other goods and services produced in the US. The identification of these shocks is based on a set of three restrictions. Positive demand shocks specific to US manufacturing goods should: (1) Raise manufacturing output relative to aggregate output in the US \((YT-Y)\); (2) Raise the relative price
of manufacturing in terms of other goods in the economy (PT-P); and (3) Raise US manufacturing output relative to Foreign manufacturing output (YT-YT*).

The first and second restriction capture the theoretical prior that demand shifts should move price and quantity in the same direction. The third one instead isolates shocks that are specific to US tradable production, relative to the other countries in our sample. All other variables included in our analysis are, again, left unconstrained, as to trace the external consequences of demand shocks in the data.

For instance, a key textbook prediction is that, as long as there is home bias in domestic spending, positive demand shocks should raise domestic absorption and appreciate the currency, causing some expenditure-switching effect in favor of imports and possibly resulting in a deterioration of the trade balance. Note that “crowding-out” effects on net exports are predicted by both traditional MDF frameworks, and modern choice-theoretic open economy models. Our empirical strategy will allow us to estimate these effects for an important category of demand shocks, and test conditional predictions by theory.

**Caveats and qualifications** The two sets of restrictions defined above, one for productivity, the other for demand shocks, can be derived from a vast majority of models in the literature. One example which, building on Corsetti and Pesenti [2001], can be solved in closed-form is provided by the stochastic model by Obstfeld and Rogoff [2000]. Other examples are provided by standard IRBC models like that in Stockman and Tesar [1995], or in related work of ours (Corsetti, Dedola and Leduc, [2008]).

Obviously, we are very aware of the fact that no identification scheme is ironclad. For instance, our productivity shocks clearly capture exogenous shifts in the production function due to technology improvements. Yet, to the extent that measured labor productivity is endogenous, e.g. because of labor hoarding, these shocks could also correspond to other supply disturbances which do not immediately shift the production function, like embodied capital shocks or labor supply shocks.

This consideration points to the risk that our analysis would yield no significant results. Namely, if different supply shocks with similar consequences on restricted variables elicit opposite responses of unconstrained variables, we may find that our identified shocks end up having no significant estimated
effects on external variables. The lack of detectable effects would then raise serious interpretation issues. However, to the extent that we do recover some significant responses, our results would still provide model builders with useful evidence documenting key properties of the transmission of productivity and demand shocks. For a candidate shock to be the main driver of our results, it should be able to account for the estimated increase in labor productivity, as well as the response of all other variables which characterize the transmission mechanism we find in the data.

In this respect, an important part of our analysis will consist of robustness checks. In one of these checks we will remove restriction (4) from our identification scheme above. We will show that the assumption of relative manufacturing productivity increases is indeed crucial to estimate substantial external repercussions of supply shocks, driving US manufacturing relative quantity and prices in opposite directions.

As similar considerations obviously apply to demand shocks, we will also check whether imposing the additional restriction that consumption increase, will affect the estimated responses to a demand shock. The idea underlying this experiment is to isolate more clearly the effects of demand shocks with a dominant domestic origin.

3 The empirical framework


The US is analyzed vis-à-vis an aggregate of the other G7 countries (Japan, Germany, the UK, and Italy, Canada and France) and three other OECD countries (Australia, Sweden and Ireland) for which we were able to obtain quarterly data on hourly labor productivity in manufacturing. We refer to this aggregate as the 'Rest of the World', in short ROW. All ROW's variables are built as an aggregate of the above mentioned countries (ex-

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9 These 10 countries add up to roughly half of world GDP at PPP values, so they represent a substantial sample of the global economy. Moreover, trade flows among them also amount to over a half of their respective total trade, on average. For instance, the US trade share with the other 9 countries in our sample is around 60 percent of US total trade.
cluding the US), weighted according to their respective (time-varying) GDP shares at PPP values. We examine the effects of productivity and demand shocks to the US manufacturing sector (our proxy for traded goods), on relative consumption and investment, net exports, the real exchange rate and the terms of trade — we leave a detailed description of the data sources to the data appendix. The sample period is 1973 - 2004.

We estimate several specifications of the following reduced form VAR model (omitting the constant):

\[ Y_t = B (L) Y_{t-1} + U_t, \]  

where the vector \( Y \) includes the \( n \) variables of interest in levels and \( B (L) \) is a lag polynomial of order \( p \). The covariance matrix of the vector of reduced-form residuals \( U_t \) is denoted by \( \Sigma \). In our specifications (unless stated otherwise), the vector \( Y_t \) is 6x1. Following a common practice in open-economy VAR studies, we deal with the curse of dimensionality (due to including too many variables with relatively short samples), by keeping the first five variables in \( Y_t \) fixed, while changing the sixth and last variable across specifications.

The first five variables in \( Y_t \) are as follows: (i) (the log of) quarterly labor productivity in US manufacturing, in deviation from quarterly labor productivity in manufacturing in the ROW; (ii) the US index of manufacturing production and (iii) aggregate private consumption, both in deviation from the same variable for the ROW; (iv) (the log of) the relative US domestic producer price index over the services consumer price index; and (v) (the log of) real US manufacturing output over US real GDP.

The sixth and last variable in \( Y_t \) is, in turn, real private investment in the US relative to ROW; the ratio of nominal net export over nominal GDP for the US and real imports and exports of goods; and three measures of international relative prices:

\[ RER_i = \frac{P_i}{P_i^*}. \]

The price indexes \( P_i \) and \( P_i^* \) are alternatively (the log) of the CPI, PPI and export-deflator in dollars. Note that \( P_i^* \) is built as a PPP, GDP-weighted aggregate of prices for the countries included in ROW.\(^{11}\)

\(^{10}\) We use GDP shares as trade weights were not available for all countries going back to 1973.

\(^{11}\) This is meant to capture the following well-known decomposition of the CPI-based...
3.1 Identification with sign restrictions

Following Uhlig [2005], we now briefly describe our empirical strategy. As is well-known, the reduced form (2) can be estimated consistently using ordinary least squares (OLS), which, conditional on Gaussian innovations $U_t$ and initial conditions, amount to maximum-likelihood (ML) estimation.

In the structural VAR literature, identification amounts to providing enough restrictions as to solve uniquely for the following decomposition of the $n \times n$ estimated covariance matrix of the reduced-form VAR residuals $\Sigma$ (up to an orthonormal transformation $Q$ such that $QQ^t = I$):

$$\Sigma = A_0 A_0^t.$$ 

This matrix equation defines a one-to-one mapping from the vector of orthogonal structural shocks $V$ to the reduced form residuals $U$, $U = A_0 V$. Because of the orthogonality assumption, and the symmetry of $\Sigma$, at least $\frac{n(n-1)}{2}$ restrictions on $A_0$ need to be imposed.\(^\text{12}\)

The $j$-th column of the identification matrix $A_0$, $A_{0,j}$, is called an impulse vector in $\mathbb{R}^n$, as it maps the innovation to the $j$-th structural shock $v_j$ into the contemporaneous, impact responses of all the $n$ variables, $\Psi_{0,j}$. With the structural impulse vector $A_{0,j}$ in hand, the set of all structural impulse responses of the $n$ variables up to the horizon $k$, $\Psi_{1,j}, \ldots, \Psi_{k,j}$ can then be computed using the estimated coefficient matrix $B(L)$ of the reduced form VAR, $B_1, B_2, \ldots B_p$:

$$\Psi_{s,j} = \sum_{h=0}^{s} B_{s-h} \Psi_{h,j}, \quad s \geq 1, B_{s-h} = 0, s - h \geq p;$$

$$\Psi_{0,j} = A_{0,j}.$$

Proposition 1 in Uhlig [2005] shows that any structural impulse vector $A_{0,j}$ arising from a given identifying matrix $A_0$ can be represented as $Pq$, for

real exchange rate between a first component due to the relative price of tradables across countries, and a second component due to the relative price of tradables in terms of nontradables within countries (see Engel, 1999):

$$\log RER \approx \log \frac{P_T}{SP_T^*} + (1 - \gamma^*) \log \left( \frac{P_T^*}{P_N^*} \right) + (1 - \gamma) \log \left( \frac{P_N}{P_T} \right),$$

where $\gamma$ is the share of traded goods in consumption.

\(^{12}\)E.g., see Hamilton [1994], chapter 11.
an appropriate vector $q$ belonging to the hypersphere of unitary radius $S^n \subset \mathcal{R}^n$, and an arbitrary matrix $P$ such that $PP^t = \Sigma$. For instance, natural candidates for the orthogonal decomposition $P$ are either the eigenvalue-eigenvector or the Cholesky decomposition of $\Sigma$.

The basic idea of sign restrictions can thus be described as follows. A-priori, a non-zero probability is attributed only to structural impulse vectors $A_{0,j}$ which, for a given reduced-form estimate of the VAR, yield impulse-responses whose signs are consistent with the assumed restrictions. Formally, this could be operationalized to characterize the set of all consistent impulse responses by using the algorithm suggested by Uhlig [2005]: for a given estimate of the VAR reduced-form matrices $\Sigma$ and $B(L)$, and the associated decomposition $P$, draw (a large number of) candidate $q$ vectors from a uniform distribution over $S^n$; compute the associated impulse vector $A_{0,j}$ and impulse response matrix $\Psi$, discarding those that do not satisfy the assumed sign restrictions. In practice, the $q$ vectors are drawn from a multivariate standard normal and normalized with their Euclidean norm to make sure they have unitary length.

As argued by Uhlig [2005], the fact that the Bayesian approach views the VAR parameters as random variables, makes it particularly suited to interpreting and implementing sign restrictions. From a Bayesian point of view, on the one hand, the approach amounts to attributing zero probability to reduced-form parameter realizations for which impulse responses contravene the assumed set of sign restrictions. On the other hand, all the impulse responses from the same reduced-form realization that satisfy those restrictions are attributed the same posterior probability. We can thus use standard Bayesian methods for estimation and inference, obtaining measures of the uncertainty about estimated impulse responses.

As shown by Uhlig [2005], under a standard diffuse prior on the VAR reduced form parameters $B(L)$ and $\Sigma$, and assuming a Gaussian likelihood for the data sample at hand, the posterior density of the reduced-form VAR parameters with the type of restrictions we implement will be proportional to a standard Normal-Wishart — whose parameters are known functions of the OLS-MLE estimates of the VAR reduced form. Therefore, it is possible to simulate the posterior distribution of impulse responses consistent with our sign restrictions by jointly drawing from the Normal-Wishart posterior for $\Sigma$, $B(L)$ and the uniform for $q$ over $S^n$, discarding the impulse responses that violate the restrictions. It should be kept in mind that, as stressed by Uhlig [2005], the sign restriction approach amounts to estimating simultaneously
the coefficients of the reduced-form VAR and the impulse vector. Draws of the VAR parameters from their unrestricted posterior which do not admit any impulse vector satisfying the imposed sign restrictions are discarded as they have zero prior weight.

The procedure outlined above allows one to obtain estimates of impulse responses consistent with a given set of assumed sign restrictions. Economic theory can then be brought to bear, as in Uhlig [2005] or Dedola and Neri [2007], to attribute all the probability mass to the event that the responses of \( m \leq n \) variables (e.g., relative labor productivity, relative output and so on) to the specific structural shock of interest have a given (positive or negative) sign for \( s \leq k \) quarters. Clearly, this must also be the only shock that satisfies the sign restrictions. For instance, Uhlig [2005], by appealing to standard monetary theory, assumes that a contractionary monetary policy shock in the US uniquely brings about a hike in the Federal Fund rate, a drop in the price level and a contraction in money demand (non-borrowed reserves).

Similarly, in the previous section we argued that our sign restrictions are consistent with a broad class of predictions over sectoral quantity and prices that most participants in the literature would accept, claiming that productivity and demand shocks uniquely satisfy the set of sign restrictions we use in the estimation.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Horizon in quarters</th>
<th>Variable</th>
<th>Horizon in quarters</th>
</tr>
</thead>
<tbody>
<tr>
<td>( l p_{T,k} - l p_{T,k}^* &gt; 0 )</td>
<td>( k = 1, \ldots, 20 )</td>
<td>( y_{T,k} - y_{T,k}^* &gt; 0 )</td>
<td>( k = 1, \ldots, 20 )</td>
</tr>
<tr>
<td>( y_{T,k} - Y_k &gt; 0 )</td>
<td>( k = 1, \ldots, 20 )</td>
<td>( y_{T,k} - Y_k &gt; 0 )</td>
<td>( k = 1, \ldots, 20 )</td>
</tr>
<tr>
<td>( p_{T,k} - p_{N,k} &lt; 0 )</td>
<td>( k = 5, \ldots, 20 )</td>
<td>( p_{T,k} - p_{N,k} &gt; 0 )</td>
<td>( k = 5, \ldots, 20 )</td>
</tr>
</tbody>
</table>

As summarized in Table 1, operationally we require that a persistent US-specific positive productivity shock to manufacturing increases labor productivity and output relative to the rest of the world, and output relative to US real GDP for the first 20 quarters, and decreases the PPI over the services CPI from the 5th to the 20th quarter. The response of the other variables included — US net exports over GDP, relative consumption and investment, and of all international relative prices — is left unrestricted.
Likewise, a persistent US-specific positive demand shock to manufacturing increases output relative to the rest of the world and output relative to US real GDP for the first 20 quarters, and the PPI over the services CPI from the 5th to the 20th quarter. The response of the labor productivity differential and the other variables included — US net exports over GDP, relative consumption and investment, and of all international relative prices — is left unrestricted.

The choice of an horizon of 5 years over which the restrictions are imposed reflects the prior that these shocks be mildly persistent — e.g. in the case of an AR(1) with autoregressive coefficient of 0.75 a 1% shock will have all but died out after 20 quarters — but is somewhat arbitrary. Therefore, we will also experiment with restrictions over horizons of 28 and 12 quarters as well.

4 The international transmission of productivity and demand shocks to US tradables production

In this and the next section, we report our empirical findings. We consider the sample period 1973-2004, covering the developments in the international monetary system after the collapse of Bretton Woods (and the longest period for which we have data). In what follows, we first report results for each shock considered in isolation, based on a specification in which all variables are in levels and the sign restrictions are the one specified in Table 1. In addition, we also discuss results lengthening and shortening the time horizon over which restrictions are imposed. Second, we estimate the effects of the two shocks simultaneously, thus imposing orthogonality between them in a straightforward generalization of the methodology presented in Section 3. Sensitivity analysis on other dimensions is carried out in the next section.

In our experiments below we typically consider 1000 draws from the posterior, and 5000 rotations each. Table 2 reports the percentage of accepted reduced form draws for which we find at least one vector $\mathbf{q}$ satisfying our restrictions. In our experiments, this percentage is well above 95 percent, except for the case of longer restriction horizons shown in the second panel of the table. The percentage of overall draws which satisfy restrictions varies between 0.5 and 7 percent.
4.1 Productivity shocks

Figures 1 through 3 display the impulse response functions to a positive productivity shock for the specification in Table 1, along with 68 percent pointwise posterior credible intervals. By way of example, Figure 1 displays the response of US relative productivity, manufacturing output (YT-YT*), and aggregate consumption (C-C*), all in log differential with ROW, along with (the log of) manufacturing output over real GDP (YT/Y), the (log of the) PPI relative to the services CPI, and nominal net trade over GDP (NX/Y). Each figure shows the median (the red solid line) and the 16th and 84th percentiles (the blue dashed lines) of the posterior distribution of the responses satisfying our restrictions in Table 1 for a productivity shock, multiplied by 100.

Our main results are as follows. First, as shown in Figure 1, the median effect of the productivity shock on relative manufacturing output and labor productivity is of the order of 1% and 0.5%, respectively and quite persistent, well beyond the 20 quarters over which the sign restriction is imposed; the increase of manufacturing output over real GDP is slightly smaller and less persistent. Interestingly, the response of (relative) manufacturing output display a marked hump shape peaking after the first year following the shock. Second, the productivity shock leads to a prolonged, statistically significant fall in the relative price of domestic tradables already from the second quarter after the shock. The latter corresponds to the assumed HBS effect, reflecting the conventional wisdom on the relative price implications of productivity gains in manufacturing. Third, the response of aggregate consumption and net trade, both unrestricted variables, is already significant after a couple of quarters and very persistent: it remains significantly positive for the entire period (10 years) displayed in the Figure. Aggregate relative consumption increases, peaking after a couple of years at 0.5%; the fall in net exports gradually reaches 0.1% of GDP after 4 years.\(^{13}\)

This prolonged fall in net exports may be surprising, in light of some applied and policy literature postulating that a productivity increase in tradables should bring about an improvement in net trade. To investigate the

\(^{13}\)Note that, if our identification scheme was picking just an (offsetting) measurement error in manufacturing labor productivity, output and the PPI, it would be quite far-fetched that this measurement error be also positively correlated with very persistent increases in relative aggregate consumption (and investment), and a deterioration of net exports.
source of the trade deterioration, Figure 2 reproduces the responses of relative consumption (C-C*) and net trade, along with relative private investment (I-I*) and the CPI-based real exchange rate (RER); Figure XXX reproduces the response of real imports and real exports.

Two findings are worth stressing. First, relative investment rises persistently with a hump shape which mimics that of consumption, though it responds more strongly. Relative investment peaks at around 2%, and reaches back its previous long-run level already after 6 years. The deterioration of the trade balance is basically driven by a rise in real imports: real exports do not respond significantly. Therefore, the deterioration in net exports is seemingly consistent with an increase in US absorption relative to the rest of the world, driven by the productivity shock, as predicted by the standard intertemporal approach to the current account (with capital accumulation). Second, the CPI-based RER persistently appreciates (an increase is an appreciation) in the aftermath of the shock, and then shows sign of a long-run depreciation as it falls below its initial level.14

Together with the response of relative consumption, the response of the CPI-based RER is at odds with standard conditions for efficient consumption risk sharing — but consistent with the unconditional evidence in Backus and Smith [1993]. This result is noteworthy in light of the observation, often made in the literature, that a positive correlation in the data between relative consumption and real appreciation could be perfectly consistent with the risk sharing condition (1) to the extent that taste shocks weaken the link between relative marginal utility and consumption. Remarkably, our results document that the full risk sharing condition (1) still fails to hold when measured conditional on productivity shocks only.

The determinants of the striking response of the real exchange rate are further investigated in Figure 3. This figure shows the response of three alternative measures of international relative prices, based on the CPI, the PPI and the export deflator, respectively — the latter denoted as terms of trade (TOT) — together with the response of the export deflator for goods

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14Here we note that Basu, Fernald, and Kimball (2006) find that positive technology shocks, identified via "purged Solow residuals," tend to depreciate the real exchange rate. In contrast to their analysis, our positive productivity shock is not necessarily due to an improvement in technology. Moreover, our procedure identifies an increase in US relative to foreign manufacturing productivity, while they study the impacts of an economy-wide shock to the level of US technology. As we mentioned in the introduction, these differences can play an important role in the international transmission.
relative to the domestic manufacturing PPI (EXPDEF/PPI). Remarkably, all our measures of international relative prices display the same appreciation pattern. As two of our measures are built using PPIs (i.e., price indexes including a larger share of tradable goods than the CPI) and export deflators (including only the price of traded goods), our results suggest that the CPI-based RER appreciation reflects more than the classical HBS hypothesis (i.e., a rise in the price of nontradables) — in line with the unconditional evidence in Engel [1999]. As shown in the Figure, real appreciation also reflects substantial fluctuations in the relative price of US tradables relative to ROW tradables. However, deviations from the law of one price (LOP) in US manufacturing goods do not appear to contribute to the RER appreciation: the response of the US export deflator relative to the PPI (though negative) is only marginally significant, for just a couple of quarters. To complete the analysis, Figure XXX shows the probability of RER appreciation and of a TOT improvement, calculated as the frequency of impulse responses recording a strengthening of these relative prices.

This evidence lends support to the hypothesis that terms-of-trade movements play a crucial role in driving the CPI-based real exchange rate dynamics in the aftermath of a productivity shock to manufacturing, consistent with standard international business cycle models with incomplete markets featuring strong wealth/demand effects of productivity shocks. An instance of model specifications with this characteristics is provided in related work of ours (Corsetti Dedola Leduc [2008]): when productivity shocks are persistent, and the long-run price elasticity of exports is high enough, the demand for tradables rises above supply in the short run, and appreciates the price of domestic tradable goods relative to Foreign ones. As investment raises the capital stock, output rises over time, reversing the movements in relative prices.\textsuperscript{15}

Finally, we document that our identified productivity shocks significantly raise the US stock market relative to an aggregate index of foreign markets, an effect which we do not detect in response to demand shocks. Over time,

\textsuperscript{15}In our previous work, we stressed the crucial role of a high trade elasticity as a precondition for this dynamic response. A high elasticity contains the adverse movements in the price of Home tradables when their quantity rises. This means that, other things equal, the present discounted value of future output is higher, so is the increase in wealth. Note however that according to our findings, short-run TOT and RER volatility appears more consistent with relatively low short-run elasticities, raising interesting issues in possible differences in trade elasticities over different horizons.
these shocks also open a positive nominal interest differentials in favor of the US, which peaks 10 to 15 quarters after the shock. Based on the dataset of valuation-adjusted Foreign assets and liabilities calculated by Gourinchas and Rey (2008), we show that asymmetric positive productivity disturbances worsens the net foreign asset position of the US — complementing our early result of a deterioration of net trade. However, we also find that these shocks raise both gross liabilities and gross assets at the same time. The additional imports are not financed by running down gross assets.

These results are virtually unchanged when we re-estimate the VAR model imposing our set of restrictions over an horizon which is either shorter or longer than in our baseline specification. First, we assume that the productivity shock raise US labor productivity and output relative to the rest of the world, and output relative to US real GDP for the first 12 quarters, and reduce the PPI over the services CPI from the 5th to the 12th quarter, while the response of the other variables included — US net exports over GDP, relative consumption and investment, and of all international relative prices — is left unrestricted. The only detectable effects of shortening the restriction horizon is that the response of all variables to the productivity shock is now marginally less persistent — we do not report figures to save space.

Alternative, we assume that our restrictions bind for up to 28 quarters — i.e. 8 quarters more than our baseline case. Beside increasing marginally the persistence of the estimated effects of productivity and demand shocks, this change makes it more difficult to find productivity shocks in the data. As shown by Table 2, we end up rejecting a larger fraction of draws from the reduced form posterior of our VAR.

4.2 Demand shocks

Figures 4 through 6 display the impulse response functions to a positive demand shock for our benchmark specification, with the same format as Figures 1 to 3 above — each figure reports the median (the red solid line) and the 16th and 84th percentiles (the blue dashed lines) of the posterior distribution of the responses satisfying our restrictions in Table 1 for a demand shock.

Consider Figure 4, presenting the same variables as in the baseline in Figure 1 — US relative productivity, manufacturing output (YT-YT*), and aggregate consumption (C-C*), all in log differential with ROW, along with (the log of) manufacturing output over real GDP (YT/Y), the (log of the)
PPI relative to the services CPI, and nominal net trade over GDP (NX/Y). Comparing Figures 1 and 4 makes it clear that the estimated effects of demand shocks on YT-YT* and YT/Y are smaller and less persistent than those of productivity shocks. Consumption and net exports are not significantly affected by the shock. Relative labor productivity slightly rises on impact — a possible interpretation of this result could be in terms of short-run variations in capacity utilization. We shall return on this point below.

Figure 5 shows that the response of investment, though still much smaller than its counterpart after a productivity shock, is stronger and more significant than that of consumption. The CPI-based RER is not significant on impact — the point estimate actually depreciates. However it significantly appreciates after three years, around the peak of the investment response. This is so despite the pressure towards real depreciation due to the persistent increase in the price of manufacturing output relative to nontradables displayed in Figure 4. Figure 6 confirms our previous result, that the response of international relative prices has common determinants going beyond and even countervailing the HBS effect of the US relative price of nontradables: all measures of international prices show the same pattern, significantly appreciating between 3 and 4 years after the shock. Finally, observe that the relative price of export goods does not fall significantly, which is consistent with the presumption that the origin of the demand shock is mainly domestic.

Changing the horizon over which we impose our restrictions, as for productivity shocks, once again does not affect significantly our results. As for productivity shocks, the effects of demand shocks estimated with our specification in Table 1 are reasonably robust to changing the assumed persistence of the shocks by plus or minus two years.

4.3 Orthogonal productivity and demand shocks

In the analysis above, we do not impose orthogonality between the two shocks. However, recall that we require them to have opposite effects on the US relative price of tradables vis-à-vis CPI services, while always increasing US manufacturing output relative to real GDP. Thus our identification strategy contains the risk that our results confound their effects. Nonetheless, as we identify productivity and demand shocks individually, without requiring that both be present in the data and be orthogonal to each other, our estimated effects of either shock could be potentially biased — for instance, if the
two shocks happen to be negatively correlated with each other. Specifically, in the case of the demand shock, it may happen that some of the estimated responses, while picking up the assumed positive demand shock, could be contaminated by a (weaker) negative productivity shock. This would have the effect of strengthening the positive response of the relative price of tradables, while attenuating that of other variables, like relative output or consumption.

Clearly, orthogonality has potentially important consequences for our results. Since the number of restrictions imposed simultaneously is larger, it may be more difficult to find the two shocks in the data, leading us to reject a much higher number of reduced forms in our estimation procedure. This could affect our findings, that each shock individually is very likely to be present in the data.

The change in the procedure described in Section 3 needed to produce two sets of candidate impulse responses which are orthogonal on impact is straightforward. We now need to find two vectors, $q_1$ and $q_2$, both belonging to the hypersphere of unitary radius $S^n \subset \mathbb{R}^n$, which also satisfy the additional orthogonality condition $q_1^\top q_2 = 0$; then, we can compute the two impulse vectors $Pq_1$ and $Pq_2$ and the related impulse responses, verifying that they satisfy the sign restrictions for productivity and demand shocks. In practice, the vectors are again drawn from a multivariate standard normal, then orthogonalized and normalized with their Euclidean norm to make sure they have unitary length.

We estimate orthogonal productivity and demand shocks applying this approach to our six variables VARs, imposing the same restrictions as in Table 1 contemporaneously. As expected, the fraction of accepted reduced forms drops for all specifications of our VARs, well below 50%. But the specific reason for this drop provides a first important result. The fall in accepted reduced forms is mainly due to the fact that persistent demand shocks orthogonal to productivity shocks are very difficult to find in the data. Namely, after imposing orthogonality, for a given draw from the VAR posterior of our baseline system, we find a productivity shock in 96% of all reduced forms; conditional on finding the productivity shock, our algorithm finds a suitable demand shock only for 21% of the accepted reduced forms. Conversely, conditional on finding a suitable demand shock — which happens for only 23% of all reduced form draws — the algorithm finds a suitable productivity shock for 90% of the accepted reduced forms. This is evidence that persistent demand shocks are not a very likely feature of the data at the same time as persistent, orthogonal supply shocks.
Most notably, however, the acceptance rate rises again above 90% when we shorten the horizon over which we impose our identification restrictions for the demand shock. In Figures XX13XX to XX14XX we report results for the case in which productivity shocks are still identified according to the restrictions in Table 1, but demand shocks are assumed to have effects for a maximum of 8 quarters — namely, US manufacturing output relative to the rest of the world, and relative to US real GDP is assumed to be positive for the first 8 quarters, while the PPI over the services CPI rises from the 5th to the 8th quarter.

The estimated responses to the productivity shock, shown in Figures XX13XX and XX14XX, are virtually identical to their counterparts reported in Figures 1 to 3. Conversely, the estimated effects of demand shocks in Figures XX15XX and XX16XX are now quite different from their counterparts in Figures 4 to 6. As expected, this shock has now much less persistent effects. It also elicits smaller and less significant responses on all variables: specifically, the delayed increase in aggregate investment is no longer significant. Yet, the real exchange rate and the terms of trade still show a significant appreciation in the third year after the shock.

5 Sensitivity analysis

In this section, we report results about the sensitivity of our analysis along several dimensions.\textsuperscript{16}

We considered a large set of alternative specifications of the model. We included different measures of international relative price — the PPI- instead of the CPI based real exchange rate. We estimated our model in first differences. These alternative specifications did not have any significant impact on our benchmark results as reported in the Figures above.

An important robustness check consists of testing whether the symmetry assumption implicit in estimating VARs in cross-country differences leads to relevant biases. We proceeded as follows. We regressed the residuals from the baseline six variable specification on levels of all US and ROW variables. It turn out that only manufacturing productivity is significant in these auxiliary

\textsuperscript{16}We also considered alternative specifications of the model when, for instance, including a different international relative price — the PPI- instead of the CPI based real exchange rate, or estimating our model in first differences. These alternative specifications did not have any significant impact on our benchmark results as reported in the Figures above.
regressions. Then we re-estimated productivity shocks in 7 variable VARs, including also this variable in levels and leaving it unconstrained. Our results are broadly similar to those reported above.

We also verified the sensitivity of our results to changing our identification scheme in two ways. First, in the case of the productivity shock we removed the requirement that relative manufacturing productivity increase. Second, in the case of the demand shock we additionally required that relative consumption increase for 2 years. Our results show that in order to have substantial external repercussions, it is crucial that supply shocks be accompanied by strong relative productivity effects. Moreover, demand shocks associated with an increase in relative consumption tend to generally have stronger and significant effects on trade variables, but weaker effects on investment and international relative prices.

6 Can sign restrictions correctly recover the international transmission of productivity shocks?

(preliminary and incomplete)

In this section we examine whether our identification strategy is able to detect the true effects of productivity and demand shocks on the variables that we leave unconstrained, like the terms of trade and the real exchange rate, when our identifying assumptions are satisfied by the underlying structural model.

We pursue our goal by drawing on the recent VAR literature, aiming at assessing the ability of a given set of identifying restrictions to recover the true impulse responses when applied to data simulated using stochastic general equilibrium models. In line with this literature we run the following experiment. First, we simulate time series from a version of the standard DSGE model with traded and non-traded goods and incomplete markets as specified in previous work of ours (see Appendix 2 for more detail). Second, for each realized set of time series, we estimate a reduced form VAR with 4 lags with the same variables as in our baseline specification in Section 4, and

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17See, among others, Erceg, Guerrieri and Gust [2003], Chari, Kehoe and McGrattan [2004], Giannone, Reichlin and Sala [2006], and Christiano, Eichenbaum and Vigfusson [2006].
apply the identification scheme described in Section 3 above to estimate the effects of productivity shocks to the tradable sector.

We emphasize that the aim of our exercise is not to provide a broad assessment of the general properties of sign restrictions with simulated data from models which are estimated from actual macroeconomic data — thus giving a complete description of the latter (see e.g. Christiano, Eichenbaum and Vigfusson [2006] for such an investigation concerning long-run restrictions). Such an ambitious goal is clearly beyond the scope of this paper.

More modestly, we ask whether the set of model’s conditional moments (impulse responses) computed by applying VARs with sign restrictions to simulated data does a good job in detecting the patterns of the international transmission, when simulated data are produced by calibrated open-economy models which satisfy our identifying assumptions for sectoral productivity shocks, as reported in Table 1. This seems a desirable condition for impulse responses from identified VARs from the data to be useful in providing guidance in validating different open-economy models.

The artificial economy we use as a laboratory is characterized by home bias in domestic spending on tradables and by the presence of distribution services produced with the intensive use of local inputs; this model therefore draws a distinction between the PPI and CPI tradable prices and generates realistic departures from purchasing power parity. We describe the main building blocks of the model in Appendix 2; a more detailed analysis of the model’s properties can be found in Corsetti, Dedola, and Leduc [2008].

6.1 Productivity shocks

As discussed in Section 2, the international transmission of productivity shocks to tradables — especially the response of the terms of trade and the exchange rates — can vary significantly, depending on shock persistence and price elasticities. To be consistent with our identification procedure, we simulate our model under a parameterization which gives rise to impulse responses satisfying the sign restrictions in Table 1. While we refer again to Appendix 2 for details on the model’s calibration, we stress here that we assume that the technology shocks are fairly persistent, and set the trade elasticity equal to 4. This value is in line with the estimates typically used by international trade studies; with this value the international transmission follows the pattern described above and close to our empirical results. In order to avoid stochastic singularity problems when estimating the VARs
with 6 variables, in the simulations we add other shocks hitting the economy, namely persistent shocks to productivity in the nontradable sector in each country and taste shocks to the utility function, as in Stockman and Tesar [1995] and Corsetti, Dedola and Leduc [2008]. All shocks’ innovations have the same standard deviation, set to 0.7 percent.

We generate 100 artificial datasets of 128 time periods; as in our empirical VARs, each simulated dataset includes the following variables: relative labor productivity and output in the tradable sector, aggregate relative consumption and investment (all in log differential with ROW, namely the other country), along with nominal net exports over GDP and real tradable output over real GDP, and the relative price of tradables over nontradables expressed as the PPI over the CPI of nontradables, the terms of trade (the relative price of exports in terms of imports) and the CPI-based real exchange rate.

Figure 17 and 18 report preliminary results from applying sign restrictions to simulated data from the above economy. In Figure 17 we report the theoretical responses (the blue line), while in Figure 18 we report the median response estimated by the VAR across all simulations (the red line), along with a set of 68% pointwise confidence bands (the dotted blue lines). The estimated impulse responses were obtained similarly to Section 3, namely by estimating for each of the 100 model’s simulations a reduced form VAR and the associated posterior, then randomly sampling 100 realizations from each of the latter and computing impulse responses for 100 rotations for each realization — therefore the bands report the 16th and 84th percentile over all the accepted impulse responses.

Consider first the theoretical responses in Figure 17: in line with our sign restrictions, a positive technology shock in the tradable sector leads to a persistent rise in relative labor productivity, relative tradable output, the tradable-output-to-GDP ratio, and to a fall in the relative price of tradables to nontradables. Concerning the unconstrained variables in our VARs, the shock causes a persistent rise in relative consumption and investment, and a deterioration of net exports. Moreover, because the permanent productivity shock induces sizeable wealth effects that raise Home demand for domestic products, the terms of trade persistently appreciate following the shock, with the real exchange rate moving together with the terms of trade.

Turning to the estimated impulse responses, it is clear that our identification procedure captures fairly well the qualitative features of the international transmission mechanism. The estimated impulse responses uncover the correct pattern of each variable’s response; the VAR median impulse re-
sponse is in most cases not far from to the true impulse response. The VAR correctly predicts a very persistent increase in relative consumption and investment as well as the short run net trade deterioration. More strikingly, it correctly uncovers an appreciation of the terms of trade and real exchange rate. Notably, it detects that this appreciation is persistent but not permanent. However, the VAR has some difficulty uncovering with precision the theoretical response of relative consumption in the first few quarters and the time profile of net exports. For the former variable, the VAR displays some bias toward zero, whereas for the latter one it predicts a quicker return to a surplus — this being the only instance in which the true impulse response falls outside of the estimated confidence bands.  

To sum up, the preliminary results discussed in this section suggest that, if our identifying assumptions are correct, our empirical findings are unlikely to be driven by some bias inherent in our approach. We view this result as supporting our approach — our methodology appears to lead to a correct inference of the international transmission of productivity shocks to tradables.

6.2 Demand shocks
(to be completed)

7 Conclusions

In this paper, we provide empirical evidence on the international transmission of US productivity and demand shocks. Relative to the literature, our contribution is novel in at least two respects. First, it applies time series methods with minimal identifying assumptions but strong theoretical underpinnings to international data. Second, we jointly study the dynamics of the international transmission and international relative prices, distinguishing between the relative price of nontradables, the real exchange rate and the terms of trade.

Finally, note that, as apparent from Figures 13 and 14, the procedure adopted in Section 3 to compute confidence bands (corresponding to the dotted blue lines), is fairly conservative — as it typically encompasses the true degree of sampling uncertainty (corresponding to the dotted green lines). These results therefore suggest that an econometrician using our procedure would be unlikely to infer incorrectly that a response is significant when the true response is not.
Our main result is that the international transmission of productivity shocks in US manufacturing — which we identify with the tradable sector — squares remarkably well with the main predictions of standard general equilibrium models of the international economy. Productivity shocks are identified by restricting relative labour productivity in manufacturing, relative manufacturing output, the ratio of US manufacturing output over US GDP to rise, and the price of these goods to fall relative to nontradable goods. For these variables, the horizon over which they are significantly positive exceeds the one we impose in the model: in other words, the data appear to pick greater persistence of shocks and their effects that we assume as identifying restrictions. In our results, shocks so identified raise US absorption relative to foreign absorption: relative consumption and relative investment rises significantly and persistently over time. Correspondingly, US net trade deteriorates: the trade deficit is significant, and highly persistent. The increase in US wealth driving US consumption above the foreign counterpart is quite strong. In fact, all our measures of international relative prices, CPI-based, PPI-based and export-deflator based exchange rates, appreciate on impact. Over time, as capital is accumulated and productivity growth keeps being high, US international relative prices tend to depreciate, falling below their initial levels.

Conditional on productivity shocks, the correlation between relative consumption and the real exchange rate is consistent with the Backus-Smith puzzle, pointing to lack of efficient consumption risk sharing vis-à-vis productivity fluctuations, hence to the importance of relative wealth effects from persistent changes in supply. These wealth effects maps into strong aggregate demand fluctuations, independently of other sources of uncertainty regarding tastes and/or expectations. Indeed, our results for the case of sectoral demand (taste) shocks show that these are much less likely in the data, and in any case quite inconsequential for the macroeconomic process.

These results for the US challenge a popular view of the core transmission mechanism in DSGE models of the international economy. They suggest that price movements may raise the international consumption risk of productivity fluctuations, as countries with larger supplies will also rip further gains from favorable terms of trade movements; by the same token, the sign of the spillovers from productivity shocks may be negative, with relevant policy implications. Namely, our results help understand the dynamics of the US terms of trade and real exchange rate when this country experienced a persistent increase in productivity growth in the second half of the 1990s — whereas
both the relative price of US exports and the US real exchange rate appreciated together. In this respect, the dynamics of international relative prices unveiled by our empirical analysis runs counter to the view that favorable price movements contain national wealth differences when countries experience (persistent) productivity growth differentials. In such circumstances, market forces may provide much less automatic stabilization of consumption and real income across borders than commonly believed.
Appendix 1  Data description and sources

United States
Labor productivity: Index of output per hour of all persons in manufacturing sector, seasonally adjusted, 1992 = 100 (Bank of International Settlements and Dept. of Labor).

Manufacturing output: Index of industrial production in manufacturing, seasonally adjusted, 2000 = 100 (Federal Reserve Board)

Consumption: Private final consumption expenditure, volume in national currency, seasonally adjusted (OECD, Economic Outlook Database).

Nominal GDP: Gross domestic product, value, market prices in national currency, seasonally adjusted (OECD, Economic Outlook Database)

Net exports: Net exports of goods & services, value in national currency, seasonally adjusted (OECD, Economic Outlook Database)

PPI index: Producer price index of manufactured products, seasonally adjusted, 2000 = 100 (OECD, Main Economic Indicators Database)

CPI total: Consumer price index all items, seasonally adjusted, 2000 = 100 (OECD, Main Economic Indicators Database)

CPI services: Consumer price index for services less energy services, seasonally adjusted; 1982-84 = 100, monthly converted to quarterly averages (BLS)

Export deflator: Exports of goods and services, deflator, seasonally adjusted, national accounts basis; 2000 = 100 (OECD, Economic Outlook Database)

CPI-based real exchange rate: Index of ratio of US CPI (total) to aggregate CPI (total) of 9 OECD countries, all in current US dollars, weighted with GDP shares at annual PPP values, 1970q1 = 100 (authors calculations based on OECD, Economic Outlook Database)

PPI-based real exchange rate: Index of ratio of US PPI (manufacturing) to aggregate PPI (manufacturing) of 9 OECD countries, all in current US dollars, weighted with GDP shares at annual PPP values, 1971q1 = 100 (authors calculations based on OECD, Economic Outlook Database)

Terms of trade: Index of ratio of US export deflator (goods and services) to aggregate export deflator (goods and services) of 9 OECD countries, all in current US dollars, weighted with GDP shares at annual PPP values, 1970q1
Rest of the world

The rest of the world comprises the other six G7 countries (alternatively US, Japan, Germany, UK, Italy, France, Canada) plus Australia, Sweden and Ireland. This choice was dictated by data availability regarding hourly productivity in manufacturing.

Individual country’s variables were aggregated by first taking quarterly growth rates to remove national basis effects; then cross-country average growth rates were computed with weights based on each country’s GDP share in the 9-country aggregate calculated at annual purchasing power parity (PPP) values. Average growth rates were then cumulated starting from the initial base year to obtain levels.

Annual PPP based GDP shares are from the IMF’s World Economic Outlook Database from 1980; before 1980 they were computed directly on the basis of annual GDP at PPP values form OECD’s Economic Outlook Database.

Labor productivity: Aggregate of country-specific indexes of output per hour of all persons in manufacturing sector, seasonally adjusted, 1970q1 = 100 (authors calculations based on national statistical sources, BIS and IFS)

Manufacturing output: Aggregate of country-specific indexes of industrial production, manufacturing, seasonally adjusted, 1970q1 = 100 (authors calculations based on national statistical sources, BIS and IFS)

Consumption and investment: Aggregate of country-specific private final consumption expenditure, volumes in national currency, seasonally adjusted, 1970q1 = 100 (authors calculations based on OECD, Economic Outlook Database).

Appendix 2  Model description

Our world economy consists of two countries of equal size, as before denoted H and F, each specialized in the production of an intermediate, perfectly tradable good. In addition, each country produces a nontradable good. This good is either consumed or used to make intermediate tradable goods H and
F available to domestic consumers. In what follows, we describe our setup focusing on the Home country, with the understanding that similar expressions also characterize the Foreign economy — whereas starred variables refer to Foreign firms and households.

The Firms’ Problem

Firms producing Home tradables (H) and Home nontradables (N) are perfectly competitive and employ a technology that combines domestic labor and capital inputs, according to the following Cobb-Douglas functions:

\[
Y_H = Z_H K_H^{1-\xi} L_H^\xi \\
Y_N = Z_N K_N^{1-\xi} L_N^\xi,
\]

where \(Z_H\) and \(Z_N\) are exogenous random disturbances, independent across sectors and countries. Consistent with our empirical methodology, we assume that \(Z_H\) follows a unit root process. In turn, \(Z_N\) follows an AR(1) process with autocorrelation coefficient equal to 0.95. We assume that capital and labor are freely mobile across sectors. The problem of these firms is standard: they hire labor and capital from households to maximize their profits:

\[
\pi_H = \bar{P}_{H,t} Y_H - W_t L_H - R_t K_H \\
\pi_N = P_{N,t} Y_N - W_t L_N - R_t K_N,
\]

where \(\bar{P}_{H,t}\) is the wholesale price of the Home traded good and \(P_{N,t}\) is the price of the nontraded good. \(W_t\) denote the wage rate, while \(R_t\) represents the capital rental rate.

Firms in the distribution sector are also perfectly competitive. They buy tradable goods and distribute them to consumers using nontraded goods as the only input in production. We assume that bringing one unit of traded goods to Home (Foreign) consumers requires \(\eta\) units of the Home (Foreign) nontraded goods.

The Household’s Problem

Preferences The representative Home agent in the model maximizes the expected value of her lifetime utility, given by:

\[
E \left\{ \sum_{t=0}^{\infty} U [C_t, \ell_t] \exp \left[ \sum_{\tau=0}^{t-1} -\nu (U [C_t, \ell_t]) \right] \right\}
\]
where instantaneous utility $U$ is a function of a consumption index, $C$, and leisure, $(1 - \ell)$. Foreign agents’ preferences are symmetrically defined. It can be shown that, for all parameter values used in the quantitative analysis below, these preferences guarantee the presence of a locally unique symmetric steady state, independent of initial conditions.\footnote{A unique invariant distribution of wealth under these preferences will allow us to use standard numerical techniques to solve the model around a stable nonstochastic steady state when only a non-contingent bond is traded internationally (see Obstfeld [1990], Mendoza [1991], and Schmitt-Grohe and Uribe [2001]).}

The full consumption basket, $C_t$, in each country is defined by the following CES aggregator

$$C_t \equiv \left[ a_T^{1-\phi} C_{T,t}^{\phi} + a_N^{1-\phi} C_{N,t}^{\phi} \right]^{\frac{1}{\phi}}, \quad \phi < 1,$$

where $a_T$ and $a_N$ are the weights on the consumption of traded and nontraded goods, respectively and $\frac{1}{1-\phi}$ is the constant elasticity of substitution between $C_{N,t}$ and $C_{T,t}$. The consumption index of traded goods $C_{T,t}$ including both domestically produced goods $C_H$ and goods produced abroad $C_F$, is given by

$$C = C_T = \left[ a_T^{1-\rho} C_H^{\rho} + a_N^{1-\rho} C_F^{\rho} \right]^{\frac{1}{\rho}}, \quad \rho < 1.$$

**Price indexes** A notable feature of our specification is that, because of distribution costs, there is a wedge between the producer price and the consumer price of each good. Let $\overline{P}_{H,t}$ and $P_{H,t}$ denote the price of the Home traded good at the producer and consumer level, respectively. Let $P_{N,t}$ denote the price of the nontraded good that is necessary to distribute the tradable one. With competitive firms in the distribution sector, the consumer price of the traded good is simply

$$P_{H,t} = \overline{P}_{H,t} + \eta P_{N,t}. \quad (B.3)$$

We hereafter write the utility-based CPIs:

$$P_t = \left[ a_T P_{T,t}^{\phi - 1} + a_N P_{N,t}^{\phi - 1} \right]^{\frac{\phi - 1}{\phi}}. \quad (B.4)$$

whereas the price index of tradables is given by

$$P = \left[ a_T P_H^{\rho - 1} + (1 - a_H) P_F^{\rho - 1} \right]^{\frac{\rho - 1}{\rho}}.$$
Foreign prices, denoted with an asterisk and expressed in the same currency as Home prices, are similarly defined. We take the price of Home aggregate consumption $P_t$ to be the numeraire.

**Budget constraints and asset markets** We assume that international asset markets are incomplete. Home and Foreign agents can only hold an international bond, $B_H$, which pays in units of Home aggregate consumption and is zero in net supply. Agents derive income from working, $W_t\ell_t$, from renting capital to firms, $R_tK_t$, and from interest payments, $(1 + r_t)B_{H,t}$, where $r_t$ is the real bond’s yield, paid at the beginning of period $t$ but known at time $t - 1$. The individual flow budget constraint for the representative agent in the Home country is therefore:\(^{20}\)

$$
P_{H,t}C_{H,t} + P_{F,t}C_{F,t} + P_{N,t}C_{N,t} + B_{H,t+1} + P_{H,t}I_{H,t} \leq (B.5)$$

$$W_t\ell_t + R_tK_t + (1 + r_t)B_{H,t}.$$  

We assume that investment is carried out in Home tradable goods and that the capital stock, $K$, can be freely reallocated between the traded ($K_H$) and nontraded ($K_N$) sectors:\(^{21}\)

$$K = K_H + K_N.$$  

As opposed to consumption goods, we assume that investment goods do not require distribution services. The price of investment is therefore equal to the wholesale price of the domestic traded good, $P_{H,t}$. The law of motion for the aggregate capital stock is given by:

$$K_{t+1} = I_{H,t} + (1 - \delta)K_t \quad (B.6)$$

The household’s problem then consists of maximizing lifetime utility, defined by (B.1), subject to the constraints (B.5) and (B.6).

---

\(^{20}\) $B_{H,t}$ denotes the Home agent’s bonds accumulated during period $t - 1$ and carried over into period $t$.

\(^{21}\) We also conduct sensitivity analysis on our specification of the investment process, below.


**Model calibration**

Note that we assume symmetry across countries. We assume a utility function of the form:

\[ U[C_t, \ell_t] = \frac{\left(\alpha C_t^{\alpha} (1 - \ell_t)^{1-\alpha}\right)^{1-\sigma} - 1}{1 - \sigma}, \quad 0 < \alpha < 1, \quad \sigma > 0, \quad \text{(B.7)} \]

where \( \zeta_t \) is a taste shock assumed to follow an AR(1) process with autocorrelation coefficient equal to 0.95 and standard deviation set to 0.7 percent. We set \( \alpha \) so that in steady state, one third of the time endowment is spent working; \( \sigma \) (risk aversion) is set equal to 2. Following Schmitt-Grohe and Uribe [2001], we assume that the endogenous discount factor depends on the taste shock, the average per capita level of consumption, \( C_t \), and hours worked, \( \ell_t \), and has the following form:

\[
\nu(U[C_t, \ell_t]) = \begin{cases} 
\ln \left(1 + \psi \left[(C_t)^\alpha (1 - \ell_t)^{1-\alpha}\right]\right) & \sigma \neq 1 \\
\ln \left(1 + \psi \left[\alpha \ln(C_t) + (1 - \alpha)(1 - \ell_t)\right]\right) & \sigma = 1
\end{cases}
\]

whereas \( \psi \) is chosen such that the steady-state real interest rate is 1 percent per quarter. This parameter also determines the speed of convergence to the unique nonstochastic steady state.

Because of the presence of a distribution sector in our model, the trade elasticity is given by \( \omega (1 - \mu) \). Following the calibration in Burstein, Neves and Rebelo [2003], we set distribution costs to 50 percent. We then set the elasticity of substitution \( \omega \) to either 2 or 8, implying a trade elasticity of 1 and 4, respectively.

The value of \( \phi \) is selected based on the available estimates for the elasticity of substitution between traded and nontraded goods. We use the estimate by Mendoza [1991] referred to a sample of industrialized countries and set that elasticity equal to 0.74. Stockman and Tesar [1995] estimate a lower elasticity (0.44), but their sample includes both developed and developing countries.

As regards the weights of domestic and foreign tradables in the tradables consumption basket \( (C_T) \), \( a_H \) and \( a_F \) (normalized to \( a_H + a_F = 1 \)) are chosen such that imports are 5 percent of aggregate output in steady state. This corresponds to the average ratio of U.S. imports from Europe, Canada and Japan to U.S. GDP between 1960 and 2002. The weights of traded and nontraded goods, \( a_T \) and \( a_N \), are chosen as to match the share of nontradables in the U.S. consumption basket. Over the period 1967-2002, this share is
equal to 53 percent on average. Consistently, Stockman and Tesar [1995] suggest that the share of nontradables in the consumption basket of the seven largest OECD countries is roughly 50 percent. Finally, we calibrate $\xi$ and $\zeta$, the labor shares in the production of tradables and nontradables, based on the work of Stockman and Tesar [1995]. We set the depreciation rate of capital equal to 2.5 percent quarterly.
References


als 2006.

[12] Clarida, Richard, and Jordi Galí [1994]. “Sources of Real Exchange Rate Fluctuations: How Important Are Nominal Shocks?” Carnegie- 
Rochester Series in Public Policy 41, 1-56


[14] Corsetti Giancarlo, Luca Dedola and Sylvain Leduc [2006], “Productiv-
ity, External Balance and Exchange Rates: Evidence on the Transmis-
sion Mechanism Among G7 Countries,” NBER Working Paper 12483, forthcoming in 

[15] Corsetti Giancarlo, Luca Dedola and Sylvain Leduc [2008], “Interna-
tional Risk-Sharing and the Transmission of Productivity Shocks,” Re-
view of Economic Studies 75, pp. 443-473.

[16] Corsetti, Giancarlo, Philippe Martin and Paolo Pesenti [2005]. “Produc-
tivity, aggregate demand and real exchange rate: lessons from a general equilibrium analysis of the ‘Home Market Effect’,” Journal of Interna-
tional Economics, forthcoming.

638.

[18] Corsetti, Giancarlo, and Paolo Pesenti [2001]. “Welfare and Macroe-
conomic Interdependence,” Quarterly Journal of Economics, 116 (2), 421-
446.


Monetary Economics, March, 512-549.


# Table 2

## Benchmark specification

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## Specification with 28 quarters

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## Specification in first differences

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Figure 1. Responses to a Productivity Shock under Benchmark Specification

- Response of LP-LP* to productivity shock
- Response of PPI/CPI to productivity shock
- Response of YT-YT* to productivity shock
- Response of C-C* to productivity shock
- Response of YT/Y to productivity shock
- Response of NX/Y to productivity shock
Figure 2. Responses to a Productivity Shock under Benchmark Specification
Response of labor productivity to productivity shock

Response of Y-Y* to productivity shock

Response of C-C* to productivity shock

Response of YT/Y to productivity shock

Response of PPI/CPI to productivity shock

Response of Real Goods Imports to productivity shock
Figure 3. Responses to a Productivity Shock under Benchmark Specification

- Response of CPI RER to productivity shock
- Response of PPI RER to productivity shock
- Response of EXPdef/PPI to productivity shock
- Response of TOT to productivity shock
Probability of an appreciation
Figure 4. Responses to a Demand Shock under Benchmark Specification

- Response of LP-LP* to demand shock
- Response of PPI/CPI to demand shock
- Response of YT-YT* to demand shock
- Response of C-C* to demand shock
- Response of YT/Y to demand shock
- Response of NX/Y to demand shock

quarters

quarters
Figure 5. Responses to a Demand Shock Under the Benchmark Specification

- **Response of I-I* to demand shock**
- **Response of C-C* to demand shock**
- **Response of NX/Y to demand shock**
- **Response of CPI RER to demand shock**
Figure 6. Responses to a Demand Shock Under the Benchmark Specification
Figure 13. Responses to a Productivity Shock: Orthogonal Specification
Figure 14. Responses to a Productivity Shock: Orthogonal Specification
Figure 15. Responses to a Demand Shock: Orthogonal Specification

- **Response of labor productivity to demand shock**
- **Response of Y-Y* to demand shock**
- **Response of C-C* to demand shock**
- **Response of YT/Y to demand shock**
- **Response of PPI/CPI to demand shock**
- **Response of NX/Y to demand shock**
Figure 16. Responses to a Demand Shock: Orthogonal Specification

- Response of C-C* to demand shock
- Response of I-I* to demand shock
- Response of RER to demand shock
- Response of TOT to demand shock
Figure 17. Theoretical Responses to Technology Shock to Tradable Sector
Figure 18. Estimated Responses to a Productivity Shock: Monte Carlo Experiment

- **Response of labor productivity to technology shock**
- **Response of PPI/CPI to technology shock**
- **Response of YT-YT* to technology shock**
- **Response of C-C* to technology shock**
- **Response of YT/Y to technology shock**
- **Response of NX/Y to technology shock**
- **Response of TOT to technology shock**
- **Response of RER to technology shock**
- **Response of I-I* to technology shock**

Each graph represents the response of various economic indicators to a productivity shock over 40 quarters.