Trade Wedges, Inventories, and International Business Cycles*

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Preliminary

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Abstract
The large, persistent fluctuations in international trade that can not be explained in standard models by either changes in expenditures or relative prices are often attributed to trade wedges. We shows that these trade wedges can reflect the decisions of importers to change their inventory holdings. We find that a two country model of international business cycles with an inventory management decision can generate trade flows and wedges consistent with the data. We find that modelling trade in this way alters the international transmission of business cycles. Specifically, real net exports become less procyclical and consumption becomes less correlated across countries.
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1. Introduction

The recent global collapse and rebound of international trade in the 2008-09 global recession has renewed interest in understanding both the determinants of the cyclical fluctuations of international trade and the role of international trade in transmitting business cycles across countries. A key feature of international trade documented by Levchenko, Lewis, and Tesar (2010) is that international trade tends to fluctuate much more than can be explained by either changes in expenditures on traded goods or relative prices as predicted by standard trade models. This is true even once one carefully controls for the different composition of the goods that are being consumed and traded. This casts some doubts on previous studies of international business cycles, since nearly all utilize models suffering from the flaw that LLT highlight. In this paper, we consider a model of international trade and inventory management that can generate both the fluctuations in trade that standard models can and those they cannot explain. We use our model to reconsider the role of trade in propagating business cycles internationally.

There are strong empirical and theoretical reasons for studying role of inventory management decisions in shaping fluctuations in international trade flows. First, the idea that imports might not be consumed immediately is quite intuitive since we know trade takes time and so imports must first be added to inventory and then drawn out of inventory. Second, empirically in our previous work (AKM 2010b), we show that at the height of the trade collapse US imports of automobiles fell more dramatically than final sales of imported autos in the US. Similarly, during the rebound of US trade, US imports of autos grew much faster than final sales of imported autos. During the collapse in US auto imports, US auto importers were able to maintain their sales pace by lowering their inventory of autos. Likewise, during the rebound in US auto imports, US auto importers rebuilt their inventory of autos. Given data restrictions, measuring this effect for the whole economy is more challenging and so we develop a general equilibrium model that allows us to quantify the role of inventories on trade.[1]

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[1] Our earlier work lacked capital investment, and so it was not fully generally equilibrium nor fully appropriate for thinking quantitatively about international business cycle properties, where investment plays a key role.

Our first goal is then to see whether a plausibly calibrated model of inventory management and international trade can generate volatile and persistent fluctuations in international trade that are largely attributed to movements in a trade wedge. We find with the inventory mechanism we propose our model can indeed generate most of the fluctuations in international trade and the trade wedge. However, while we get the trade wedge to move about right relative to imports and relative prices, the movements in imports and the trade wedge are not as persistent as in the data. At this point, we attribute this failure to the inability of our model of inventory management to generate persistent fluctuations in net inventory investment.

Our second goal is to explore whether a model with the appropriate fluctuations in international trade can generate international business cycles like in the data. Specifically, we consider two well known failures of standard international business cycle models. First, as Raffo (2008) points out, standard models do not generate countercyclical real net exports. The key in the Raffo analysis is to constrain the movements in investment to match the data. With this constraint, exports expand more than imports and net exports are procyclical. Second, BKK (1994) show that in standard trade models there is a consumption-output anomaly in that the models predict consumption is more correlated across countries than output, while in the data it is output that is more correlated. This is true in models with complete markets and models with incomplete markets and persistent shocks. With incomplete markets and permanent shocks this can change (see Baxter-Crucini, 1995).

With respect to the properties of net exports, our model with inventories generate net exports that are close to acyclical while remaining consistent with investment dynamics. With inventories, following a good shock, imports expand more strongly and exports are dampened as domestic firms build their inventories of both goods. These dynamics reflect the different dynamics of net inventory investment and investment in equipment. In the data and the model, net inventory investment movements are sharp but not very persistent while investment in equipment has smaller more persistent fluctuations.

In terms of the consumption-output anomaly, we find that the puzzle is weakened slightly as inventories reduce the correlation of consumption across countries. The idea is simple. It is cheaper to consume from the stock of goods held locally than from goods that

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must be shipped internationally. Thus, consumption will depend on both the shocks and the stock of goods available. Since the stocks can move differently across countries this allows for consumption to be less correlated across countries. For the same reasons, we also find that inventories tend to reduce the synchronization of production in real business cycles, particularly production involving foreign inputs.

Our paper is related to many papers that study trade dynamics and business cycles empirically and theoretically.[2] In terms of quantitative work, our paper is closely related to the work by Backus, Kehoe and Kydland (1995) and Stockman and Tesar (1995). BKK show that standard trade models imply a very tight link between relative quantities and relative prices and that given this tight link it is impossible for equilibrium business cycle models to generate relative prices and quantities that match the data. Stockman and Tesar (1995) show that shocks to tastes can break the link between relative quantities and prices and create a trade wedge. They consider the role of these shocks in the propagation of business cycles. Unlike their work, which takes the wedge as exogenous, we focus on understanding the source of the wedge. Lastly, this paper is related to our own work on inventories and trade. Similar to Alessandria, Kaboski, and Midrigan (2010b) we also develop a general equilibrium model of international trade and inventory adjustment. The model is used to study the fluctuations in trade in the global downturn in 2008-09. The model lacks capital and only considered transition dynamics following aggregate shocks. In contrast, here we work with a slightly simpler two country GE model of inventory holdings and trade with capital accumulation. We also extend this model to allow for production to involve the use of domestic and foreign intermediates. This model is linearizable and is thus quite tractable for considering business cycle fluctuations.

The paper is organized as follows. In the next section, we discuss some evidence on the cyclical behavior of international trade. In Section 3 we build a model of international trade and inventory management. In Section 4 we calibrate the model. In Section 5 we discuss the properties of the model, while Section 6 concludes.

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[2]Husted and Kollintzas (1984) study import dynamics in the the presence of inventory dynamics in a partial equilibrium model.

2. Theory and Evidence

In this section, we provide clear evidence of an important role of inventory adjustment for import dynamics, define the trade wedge, and summarize the key cyclical properties of trade for the US.

A. Evidence from Japanese Autos

First, to clearly establish that net inventory investment influences imports, we consider the dynamics of US imports of autos from Japan from January 2007 to November 2011 (October for import data). The data is normalized relative to the 2007 average. This data is useful because we can separately measure imports and sales of imported Japanese autos (as opposed to transplant production). This period is interesting since it includes two major events. The collapse and rebound of trade in the global recession as well as the collapse and rebound in trade following the Japanese Tsunami.

Figure 1 shows that US imports and sales of light vehicles from Japan tracked each other quite well in 2007. Starting in January 2008, US imports increased above sales in the first half of 2008 and then gradually fell for the next 5 months of 2008. The gradual decline in imports tracked sales. But because imports were relatively high initially, the stock of Japanese autos in the US was growing in much of this period. Starting in December of 2008 though the declines in imports intensified just as sales stabilized a bit. In February 2009, imports plunged almost 70 log points. In total, from January to July 2009 US imports of Japanese light vehicles were substantially below the levels of US sales of imported Japanese light vehicles. Only from August 2009 through December 2009 were sales and imports of comparable size. The relative large drop in trade relative to sales is accounted for by a period of rapid inventory reduction. The rebound in imports is also associated with a period of inventory buildup rather than a large expansion in sales. Indeed sales of imported Japanese light vehicles grew gradually from August 2009 onwards.

Following the Tsunami in March 2011, imports of Japanese light vehicles fell precipitously in April while sales and inventory fell less. It is interesting to note that the pace of sales of Japanese light vehicles, which had been growing strongly, began to decline in March prior to the decline in imports. Clearly, retailers anticipated a sustained period in which

inventories would be low and adjusted their sales rate immediately. Relative to their 2011Q1 levels, in 2011Q2 imports were down 81 log points while sales were down only 27 log points as retailers drew down their stocks by 44 log points. In 2011Q3 imports recovered and were down only 10 log points while sales were still down on average 26 log points. The strong imports meant that importers were able to rebuild their stocks to a level only 15 percent below the levels when the Tsunami hit. The data on light vehicle imports and sales from Japan show that inventory investment will affect imports. Now we show how to link these changes in inventories with the traditional way of measuring trade wedges.

B. Trade Wedges and Cyclical Properties of Trade

Trade wedges measure the departures in trade flows from those predicted by theory. This approach involves deriving a simplified aggregate import demand equation, calibrating its parameters, and then measuring deviations from predicted imports given fundamentals. Stockman and Tesar (1995) take this approach. Recently, Levchenko, Lewis, and Tesar (2010) use this approach to document large deviations in trade flows, m_t^D, from the predictions of the theory, m_t^T. These deviations, or wedges, in import demand might be interpreted as changes in tastes (as in Stockman and Tesar), trade barriers, export participation by producers (Alessandria and Choi, 2007, and Melitz and Ghironi, 2005), or the inventory adjustment decision of exporters and importers (AKM 2011). We show, however, that inventory adjustment is important for both the magnitude and the interpretation of these wedges.

To motivate our analysis, consider the following accounting identity:

(1) $$M_t = S_{mt} + I_{mt} - I_{mt-1},$$

where M_t are imports, S_{mt} are sales of imported goods, and I_t is the inventory stock of imported goods so that $I_t - I_{t-1}$ is inventory investment. We also assume a constant elasticity demand for imported goods:

(2) $$S_{mt} = (P_{mt}/P_t)^{-\gamma} S_t,$$

where P_{mt} is the price of imported goods, P_t is the price of the composite bundle and S_t

denotes total sales (or absorption). Equation (1) is an accounting identity, while (2) characterizes a large class of models of international trade in which preferences or production is Armington (CES) over imported and local goods.

We assume that in the long-run sales of foreign goods equals imports, $\bar{S}_m = \bar{M}$, so that inventory investment, is zero. Then we have:

$$\frac{M_t - \bar{M}}{\bar{M}} = \frac{S_{mt} - \bar{S}_m}{\bar{S}_m} + \frac{\bar{I}_m}{\bar{S}_m} \frac{I_{mt} - I_{mt-1}}{\bar{I}_m},$$

where $\bar{I}_m$ is the long-run stock of imported inventories and $\bar{I}_m/\bar{S}_m$ is the inventory-to-sales ratio of imported goods. Combining (1) and (2), using a log approximation for small deviations, and letting lower-case variables denote log-deviations from trend, yields:

$$(3) \qquad m_t^T = -\gamma\,(p_{mt} - p_t) + s_t + \frac{\bar{I}_m}{\bar{S}_m}(i_{mt} - i_{mt-1}).$$

Setting inventory adjustment to zero yields a standard Armington demand equation:

$$(4) \qquad \hat{m}_t^T = -\gamma\,(p_{mt} - p_t) + s_t$$

Assuming a conventional value of the Armington elasticity of $\gamma = 1.5$, we can contrast the time-series of U.S. imports with those predicted by the theory and define $\hat{\omega}_t = m_t^D - \hat{m}_t^T$ as the implied trade wedge when ignoring inventory adjustment. We call this the import wedge. Note that the import wedge that ignores inventories can be split into two terms

$$\hat{\omega}_t = \left(m_t^D - s_t\right) + \gamma\,(p_{mt} - p_t)$$

The first term on the right hand side is the ratio of imports to expenditures. The second term is the contribution of relative price fluctuations to the import wedge.

To calculate the import wedge, we measure the relative price of imports, $(p_{mt} - p_t)$, as the ratio of the non-petroleum import price index relative to a price index on final expen-

ditures of goods. Specifically, we measure the price of goods as

$$p_t = \alpha p_{gt} + (1 - \alpha) \, p_{xt}$$

where p_{gt} is the price of consumer goods and p_{xt} is the price of investment in equipment and software (from the BEA). We assume $\alpha = 0.75$. Our measure of aggregate expenditure, S_t, is real domestic consumption of goods plus investment in equipment and software. We focus on the period 1995q1 to 2010q4.

Figure 1 plots the deviations from an HP filtered trend (with a smoothing parameter of 1600) of the US imports, the import wedge, the import ratio, and the contribution of the relative price of imports. In the left panel, we plot imports and the import wedge. While imports are more volatile than the wedge, clearly, a substantial fraction of the fluctuations of imports are explained by the fluctuations in the wedge. The second panel plots the wedge as well as movements in the import ratio and the relative price term. From this figure, we see that most fluctuations in the wedge are accounted for by fluctuations in the ratio of imports to expenditures. Relative price fluctuations seem to play a minor role and actually tend to amplify the wedge slightly.

Table 1 summarizes the fluctuations in trade variables over the business cycle. Imports are about 1.4 times as volatile as US manufacturing industrial production (IP). Imports are strongly procyclical with a correlation with IP of 0.92. The import wedge slightly more volatile than IP and is also procyclical with a correlation with IP of 0.86. Imports and the import wedge are persistent with an autocorrelation of 0.86 and 0.78 respectively. The price of imports relative to final goods is about 1/3 as volatile as production and is not very correlated with either the import wedge or imports.

We next consider how inventories might alter our view of trade wedges. Note that we can define $\omega_t = m_t^D - m_t^T$ as the wedge predicted by a theory that allows for inventory adjustment. To distinguish from the import wedge, we just call this the actual import wedge. Comparing (3) with (4), the actual import wedge subtracts out inventory adjustment from the import wedge, $\omega_t = \hat{\omega}_t - (\bar{I}/\bar{S})(i_t - i_{t-1})$.

To measure the actual import wedge requires a measure of the inventory-to-sales ratio

of imported goods as well as the changes in imported inventory. Unlike autos, we lack direct measures of imported inventories and thus use the entire stock of U.S. inventories as a proxy. Consistent with the micro evidence in Alessandria, Kaboski and Midrigan (2010a) that importers hold about double the inventory of non-importers, we set $\bar{I}/\bar{S}$ equal to 2.25, about twice the average inventory-to-sales ratio since 1997. We assume that fluctuations in imported inventories are perfectly correlated with fluctuations in aggregate inventories. Alternatively, we can just use equation 1 to calculate S_{Mt} and then measure the actual import wedge as

$$\omega_t = (s_{mt} - s_t) + \gamma (p_{mt} - p_t)$$

Figure 3 shows that fluctuations in the actual import wedge, ω_t, are generally smaller than fluctuations in the wedge that ignores inventory adjustments, $\hat{\omega}_t$. Indeed, in the current recession, nearly one-third of the decline and all of the increase in the import wedge disappears and the size of the actual import wedge appears less unusual. Thus, inventory adjustments made a sizable contribution to recent trade fluctuations.

In the last line of Table 1 we report the cyclical properties of the actual import wedge. With this adjustment, the actual wedge is 30 percent less volatile, 10 percentage points less persistent and 10 percentage points less correlated with imports than the import wedge. This clearly suggest that adjusting for the inventory management decisions of importers should help to explain some of the fluctuations in international trade. However, a key shortcoming of our approach to estimating the role of inventory adjustment in fluctuations in trade is that it requires a very strong assumption that imported inventories move one for one with total inventories. This is likely to not be the case in the data (it certainly isn't the case for autos). Thus, we require a model of optimal inventory adjustment to accurately estimate the role of inventory adjustments in trade flows. That is what we do next.

3. Model

We now develop a two-country general equilibrium model of international trade with inventories, by extending Backus, Kehoe, and Kydland (1994) to include a monopolistic retail sector that holds inventories of both domestic and imported intermediates. Inventories are introduced through a friction, orders must be placed before idiosyncratic demand is

realized. This gives retailers a stockout avoidance motive for holding inventories and allows for straightforward linearization. Specifically, in each country, a continuum of local retailers buy imported and domestic goods from a competitive intermediate goods sector in each country, and each retailer acts as a monopolist supplier in selling its particular variety of the good. Consumers purchase these varieties and then use an aggregation technology to transform home and foreign varieties into final consumption. Intermediate goods firms also purchase from retailers, since they use an aggregate of the continuum of varieties as materials in their own production.

A. Environment

Formally, consider an economy with two countries, Home and Foreign. In each period, t, the economy experiences one of finitely many states η_t. Let $\eta^t = (\eta_0, ..., \eta_t)$ be the history of events up to date t, with the initial state η_0 given. Denote the probability of any particular history η^t as $\pi(\eta^t)$.

The commodities in the economy are labor, a continuum of intermediate goods (indexed by $j \in [0,1]$) produced in Home, and a continuum of intermediate goods produced in Foreign. These intermediate goods are purchased and sold as retail goods to consumers. Finally, consumers combine intermediate goods to form final goods (consumption and capital), which are country-specific because of a bias for domestic intermediates. We denote goods produced in the Home with a subscript H and goods produced in Foreign with a subscript F. (Allocations and prices for the foreign country are denoted with an asterisk.) In addition, there are a full set of Arrow securities.

Consumers

The consumer's preferences over final consumption $c(\eta^t)$ and leisure $l(\eta^t)$ are as follows:

$$(5) \qquad \sum_{t=0} \sum_{\eta^t} \beta^t \pi\left(\eta^t\right) U\left[c\left(\eta^t\right) - hC\left(\eta^{t-1}\right), l\left(\eta^t\right)\right].$$

The consumer chooses its own consumption, utility can also depend on past aggregate consumption $C(\eta^{t-1})$ for $h \neq 0$, which allows for habit formation. The habit formation is external

in that the consumer treats past aggregate consumption as given.

Using Home consumers as an example, both the final consumption $c(\eta^t)$ is produced by aggregating purchases of a continuum of domestic retail goods $c_H(j, \eta^t)$ and a continuum of imported retail goods $c_F(j, \eta^t)$, (where $j \in [0, 1]$ indexes the good in the continuum).

$$
(6) \qquad c\left(\eta^t\right) = \left[\begin{array}{c} \left(\int_0^1 v_H\left(j, \eta^t\right)^{\frac{1}{\theta}} x_H(j, \eta^t)^{\frac{\theta-1}{\theta}} dj \right)^{\frac{\theta}{\theta-1}\frac{\gamma-1}{\gamma}} \\ + \tau_c^{\frac{1}{\gamma}} \left(\int_0^1 v_F\left(j, \eta^t\right)^{\frac{1}{\theta}} x_F(j, \eta^t)^{\frac{\theta-1}{\theta}} dj \right)^{\frac{\theta}{\theta-1}\frac{\gamma-1}{\gamma}} \end{array} \right]^{\frac{\gamma}{\gamma-1}}
$$

The weights $v_H\left(j, \eta^t\right)$ and $v_F\left(j, \eta^t\right)$ are subject to idiosyncratic shocks that are iid across j and t. These stochastic idiosyncratic demand shocks are essential in leading to the precautionary stockout avoidance motive for holding inventories. The parameter $\tau_c \in [0, 1]$ captures the lower weight on Foreign goods (i.e., a Home bias).

The aggregator for investment $x\left(\eta^t\right)$ is analogous with only the weight on foreign goods τ_x potentially differing:

$$
(7) \qquad x\left(\eta^t\right) = \left[\begin{array}{c} \left(\int_0^1 v_H\left(j, \eta^t\right)^{\frac{1}{\theta}} x_H(j, \eta^t)^{\frac{\theta-1}{\theta}} dj \right)^{\frac{\theta}{\theta-1}\frac{\gamma-1}{\gamma}} \\ + \tau_x^{\frac{1}{\gamma}} \left(\int_0^1 v_F\left(j, \eta^t\right)^{\frac{1}{\theta}} x_F(j, \eta^t)^{\frac{\theta-1}{\theta}} dj \right)^{\frac{\theta}{\theta-1}\frac{\gamma-1}{\gamma}} \end{array} \right]^{\frac{\gamma}{\gamma-1}}
$$

For simplicity, we make the innocuous assumption that the shocks to retail varieties identical across consumption and investment. The Foreign consumer uses analogous technologies except that the lower weights τ_x and τ_c multiply the Home goods.

Investment yields a standard law of motion, where country-specific capital depreciates at rate δ:

$$
(8) \qquad k(\eta^{t+1}) = (1 - \delta)\, k(\eta^t) + x(\eta^t)
$$

The consumer purchases domestic and imported retail goods at prices $p_H\left(j, \eta^t\right)$ and $p_F\left(j, \eta^t\right)$, respectively, supplies labor at a wage $\tilde{W}\left(\eta^t\right)$, and earns capital income at the rental rate $R(\eta^t)$ and profits $\Pi\left(\eta^t\right)$ (from retailers).

In addition, it trades Arrow securities $B\left(\eta^{t+1}\right)$ that are purchased at time t and pay off one unit next period in state η^{t+1}. We denote the price of the security in state η^t at time

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t as $Q\left(\eta^{t+1}|\eta^{t}\right)$. The consumer's period t budget constraint is therefore:[3]

$$\sum_{i=\{H,F\}} \int_0^1 p_i\left(j,\eta^t\right)\left[c_i(j,\eta^t) + x_i(j,\eta^t)\left[1 + \xi\left(\frac{x\left(\eta^t\right)}{k(\eta^t)} - \delta\right) + \frac{\xi}{2}\left(\frac{x\left(\eta^t\right)}{k(\eta^t)} - \delta\right)^2\right]\right]dj$$

$$+ \sum_{\eta^{t+1}} Q(\eta^{t+1}|\eta^t)B\left(\eta^{t+1}\right) = \tilde{W}\left(\eta^t\right)l\left(\eta^t\right) + R(\eta^t)k\left(\eta^t\right) + \pi\left(\eta^t\right) + B\left(\eta^t\right)$$

The left-hand side of the budget constraint shows that investment is subject to quadratic adjustment costs, parameterized by ξ. Foreign consumer are analogous except that prices and profits are those in the Foreign country. The prices of Arrow securities $Q(\eta^{t+1}|\eta^t)$ are the same in both countries, since they can be traded internationally at no cost.

The consumer takes prices and profits as given and maximizes (5) by choosing a series labor supply, retail purchases, investment, and Arrow securities subject to (6), (7), (8), and (??).

Producers

For each country, we model a single representative producer that supplies to both the Home and Foreign markets. Intermediate goods in the Home country are produced by competitive firms using the following technology:

$$(9) \qquad M\left(\eta^t\right) = a\left(\eta^t\right)\left[\left(K\left(\eta^t\right)^\alpha L\left(\eta^t\right)^{1-\alpha}\right)^{s_m} N\left(\eta^t\right)^{1-s_m}\right]$$

where $M\left(\eta^t\right)$ is output of intermediates, $K\left(\eta^t\right)$ is aggregate capital and $L_m\left(\eta^t\right)$ is aggregate labor used for intermediates production. The materials used in production $N\left(\eta^t\right)$ are formed using an aggregator that is identical to the consumption aggregator:

$$N\left(\eta^t\right) = \left[\left(\int_0^1 v_j^H\left(\eta^t\right)^{\frac{1}{\theta}} n_j^H(\eta^t)^{\frac{\theta-1}{\theta}}di\right)^{\frac{\theta}{\theta-1}\frac{\gamma-1}{\gamma}} + \tau_c^{\frac{1}{\gamma}}\left(\int_0^1 v_j^F\left(\eta^t\right)^{\frac{1}{\theta}} n_j^F(\eta^t)^{\frac{\theta-1}{\theta}}di\right)^{\frac{\theta}{\theta-1}\frac{\gamma-1}{\gamma}}\right]^{\frac{\gamma}{\gamma-1}}$$

leading to analogous expressions for the demand for retail goods as materials.

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[3]We also need to set a borrowing limit in order to rule out Ponzi schemes, $B(\eta^t) > \underline{B}$, but this borrowing limit can be set arbitrarily large, i.e., $\underline{B} << 0$.

Aggregate productivity in Home evolves according to

$$\log\left(a\left(\eta^t\right)\right) = \rho\log\left(a\left(\eta^{t-1}\right)\right) + \varepsilon\left(\eta^t\right)$$

Finally, we assume an analogous production function for Foreign-produced intermediates with a country specific aggregate productivity shock. Producers are competitive, maximizing static profit taking prices as given.

Retailers

In Home there is a unit mass of retailers selling goods that were produced in Home, and another unit mass of retailers selling goods that were produced in Foreign. Retailers purchase intermediates from producers and sell them to consumers as consumption or investment goods and to producers as intermediates. For a Home retailer of good j produced in Home, retail sales are denoted $y_H\left(j, \eta^t\right)$, while purchases from intermediate goods producers are denoted $z_H\left(j, \eta^t\right)$. We focus on Home retailers operating in Home, retailers operating in Foreign face an identical problem, as do Foreign retailers operating in Home. (The subscript F continues to distinguish goods *produced* in Foreign, while an asterisk continues to denote the corresponding arguments for the *retailers* in the Foreign market.)

The key friction motivating the holding of inventories is that retailer must choose the amount of goods to the amount of inventories to have in its store at time t *before* learning $v_H\left(j, \eta^t\right)$. We denote this stock on hand as $z_H\left(j, \tilde{\eta}^t\right)$, where $\tilde{\eta}^t$ signifies the history up to date t excluding the retailer's demand realization at t.However, the retailer chooses its price $p_H\left(j, \eta^t\right)$ *after* learning $v_H(j, \eta^t)$. We also allow the retailer to return the unsold stock, but only at $t+1$ so he will be able to sell it at next period's price $\omega\left(\eta^{t+1}\right)$ after incurring the inventory carrying costs: depreciation as well as a physical cost of storing the good, payable in units of labor.

The discounted expected profit maximization problem of the domestic retailer selling

goods produced in home is therefore:

$$\max_{z_H(j,\tilde{\eta}^t),\, p_H(j,\eta^t)} \sum_{t=0}^{\infty} \sum_{\eta^t} Q\left(\eta^t\right) \left[\left(p_H\left(j,\eta^t\right) y_H\left(j,\eta^t\right) - \omega\left(\eta^t\right) \left[z_H\left(j,\tilde{\eta}^t\right) - s_H\left(j,\eta^{t-1}\right) \right] - \xi_s \omega_t s_H\left(j,\eta^{t-1}\right) \right) \right]$$

$$\text{s.t.} \quad y_H\left(j,\eta^t\right) = \min\left[q_H\left(j,\eta^t\right), z_H\left(j,\tilde{\eta}^t\right) \right]$$

$$s_H\left(j,\eta^t\right) = (1 - \delta_s)\left[z_H\left(j,\tilde{\eta}^t\right) - y_H\left(j,\eta^t\right) \right]$$

where $Q\left(\eta^t\right) = Q\left(\eta^t|\eta^{t-1}\right) Q\left(\eta^{t-1}|\eta^{t-2}\right) ... Q\left(\eta^1|\eta^0\right)$ is the date 0 Arrow-Debreu price of 1 unit of the numeraire to be delivered at in state η^t, and $q_j^H\left(\eta^t\right)$ is the demand the retailer faces at price $p_j^H\left(\eta^t\right)$. Unsold inventory $z_H\left(j,\tilde{\eta}^t\right) - y_H\left(j,\eta^t\right)$ can be carried forward, but this entails two costs: physical depreciation, captured by δ_s and an additional cost of carrying inventories, captured by ξ_s, which, to avoid introducing an additional relative price term, is assumed denominated in units of the intermediate good. The end-of-t stock of inventories of undepreciated inventories is denoted $s_j^H\left(\eta^t\right)$.

The Home retailer that sells Foreign goods faces a similar problem, except for its wholesale cost is $\omega^*\left(\eta^t\right)$. Foreign retailers also face analogous problems.

B. Equilibrium

We first define and then show some preliminary characterization of the equilibrium, which will be solved numerically.

Definition

In this economy, an equilibrium is defined as (i) an allocation of aggregate and individual quantities $\{C\left(\eta^t\right), c\left(\eta^t\right),\, l\left(\eta^t\right),\, m\left(\eta^t\right),\, y\left(\eta^t\right), B\left(\eta^t\right),\, \Pi\left(\eta^t\right)\}_{t=0}^{\infty}$,and disaggregate goods $\{c_i\left(j,\eta^t\right), s_i\left(j,\eta^t\right), z_i\left(j,\tilde{\eta}^t,\xi^{t-1}\right)_{i=H,F}\}_{t=0}^{\infty}$ for both Home and Foreign, and (ii) prices of goods $\left\{ \{p_i\left(j,\eta^t\right)\}_{i=H,F},\, \omega\left(\eta^t\right), \right\}$ and factors in $\{W\left(\eta^t\right), R\left(\eta^t\right)\}_{t=0}^{\infty}$ for both Home and Foreign, and (iii) Arrow security prices $\{Q\left(\eta^{t+1}|\eta^t\right)\}_{t=0}^{\infty}$, such that:

- Given prices, the allocations satisfy the consumers' problems, the intermediate producers' problems, and retailers' problems in Home and Foreign;
- Individual consumption $c(\eta^t)$ equals aggregate consumption, $C\left(\eta^t\right)$; and
- The retail goods, labor, and capital markets clear in each country, and the intermediate

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goods markets and Arrow security markets clear for the world economy.

We briefly describe the market clearing conditions. First, Arrow securities are in zero net supply, so bond market clearing requires $B(\eta^t) + B^*(\eta^t) = 0$. Second, all capital and labor is used in intermediate goods production.

$$
\begin{aligned}
L(\eta^t) &= l(\eta^t) \\
K(\eta^t) &= k(\eta^t)
\end{aligned}
$$

Next, the resource constraint for intermediate goods requires that production is equal to orders plus the goods used to cover inventory carrying costs.:

(10) $$m_H(\eta^t) = \int_0^1 \left[z_H(j, \eta^t) - \left[1 - \xi_s \omega(\eta^t)\right] s_H(j, \eta^t) \right] dj +$$

(11) $$\int_0^1 \left[z_H^*(j, \eta^t) - \left[1 - \xi_s \omega(\eta^t)\right] s_H^*(j, \eta^t) \right]$$

Notice that intermediate goods produced in Home, $M(\eta^t)$, have two uses: they go to domestic retailers of Home goods, $z_j^H(\eta^t)$, and to exporters of Home goods, $z_H^*(j)$. The resource constraint for individual retail goods $y_H(j, \eta^t)$ involves those sold as consumption goods $c_H(j, \eta^t)$, investment goods $x_H(j, \eta^t)$, and materials for production. $n_H(j, \eta^t)$:

$$y_H(j, \eta^t) = c_H(j, \eta^t) + x_H(j, \eta^t) + n_H(j, \eta^t)$$

A parallel set of market clearing constraints holds for foreign goods.

Preliminary Characterization

We briefly offer a preliminary characterization of the features of the equilibrium. Perfectly competitive producers simply pay factors their marginal products and price at marginal cost:

$$\omega(\eta^t) = \frac{\left[r(\eta^t)^\alpha w(\eta^t)^{1-\alpha} \right]^{1-s_n} p_n^{s_n}}{a(\eta^t)}$$

The consumer's maximization can be solved step-wise, with the consumer choosing an allocation of retail purchases $c_H(j, \eta^t)$ and $c_F(j, \eta^t)$ to minimize the expenditure necessary to

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deliver $C\left(\eta^t\right)$ units of consumption. With respect to aggregates, the consumer's optimization conditions are standard. The zero net supply condition on Arrow securities leads to the following pricing $Q\left(\eta^t\right) = \beta^t \pi\left(\eta^t\right) \frac{U_c\left(\eta^t\right)/P\left(\eta^t\right)}{U_c(\eta^0)/P(\eta^0)}$.

The cost-minimizing first-order conditions define the demand for the consumption of retail varieties (analogous expressions hold for demand for investment):

$$c_H(\eta^t) = v_H\left(j, \eta^t\right) \left(\frac{p_H(j, \eta^t)}{P_H(\eta^t)}\right)^{-\theta} \left(\frac{P_H\left(\eta^t\right)}{P_c\left(\eta^t\right)}\right)^{-\gamma} c\left(\eta^t\right)$$

(12) $$c_F\left(j, \eta^t\right) = v_F\left(j, \eta^t\right) \tau_c \left(\frac{p_F(j, \eta^t)}{P_F(\eta^t)}\right)^{-\theta} \left(\frac{P_F\left(\eta^t\right)}{P_c\left(\eta^t\right)}\right)^{-\gamma} c\left(\eta^t\right)$$

where we have defined the following aggregate price indexes for Home-produced output, Foreign-produced output, and output overall:

(13) $$P_H\left(\eta^t\right) = \left(\int_0^1 v_H\left(j, \eta^t\right) p_H\left(j, \eta^t\right)^{1-\theta} dj\right)^{\frac{1}{1-\theta}}$$

(14) $$P_F\left(\eta^t\right) = \left(\int_0^1 v_F\left(j, \eta^t\right) p_F\left(j, \eta^t\right)^{1-\theta} dj\right)^{\frac{1}{1-\theta}}$$

(15) $$P_c\left(\eta^t\right) = \left[P_H\left(\eta^t\right)^{1-\gamma} + \tau_c P_F\left(\eta^t\right)^{1-\gamma}\right]^{\frac{1}{1-\gamma}}$$

The total (i.e., including consumption, investment, and materials) demand for an individual retailer's goods can therefore be expressed:

$$q_H\left(j, \eta^t\right) = v_H\left(\eta^t\right) \left(\frac{p_H(j, \eta^t)}{p_H(\eta^t)}\right)^{-\theta} \left[\left(\frac{p_H\left(\eta^t\right)}{p_c\left(\eta^t\right)}\right)^{-\gamma} \left(c\left(\eta^t\right) + n\left(\eta^t\right)\right) + \left(\frac{p_H\left(\eta^t\right)}{p_x\left(\eta^t\right)}\right)^{-\gamma} x\left(\eta^t\right)\right].$$

The retailer's pricing decision rules therefore take the following form:

$$p_H\left(j, \eta^t\right) = \begin{cases} \frac{\theta}{\theta-1} \sum_{\eta^{t+1}} \left(1 - \delta_s - \xi\right) \frac{Q\left(\eta^{t+1}\right)}{Q(\eta^t)} \omega\left(\eta^{t+1}\right) & \text{if } q_H\left(j, \eta^t\right) \le z_j\left(\eta^t\right) \\ \left(\frac{z_j\left(\eta^t\right)}{v_H(j,\eta^t)\left(\frac{1}{p_H(\eta^t)}\right)^{-\theta}\left[c(\eta^t)+\left(\frac{p_H(\eta^t)}{p(\eta^t)}\right)^{-\gamma}x(\eta^t)\right]}\right)^{-\frac{1}{\theta}} & \text{if } q_H\left(j, \eta^t\right) > z_j\left(\eta^t\right) \end{cases}$$

That is, for sufficiently high demand shock, the retailer sells at the price to just sell its

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entire inventory. For a low demand shock, it sets the price at the $\theta/(\theta-1)$ markup over its marginal shadow cost, the expected discounted value of carrying the inventories forward. The analytical expression for the implied threshold value of $v_j^H(\eta^t)$ follows trivially. Given this pricing policy, the optimal stock-on-hand depends on the distribution of these idiosyncratic shocks. For the parameterization given below, this policy has an analytical solution. The aggregate stock of inventories held in Home is given by

$$S\left(\eta^t\right) = \int_0^1 s_H\left(j,\eta^t\right) dj + \int_0^1 s_F\left(j,\eta^t\right)$$

Finally, a nice feature of this equilibrium is that it has no occasionally-binding constraints that lead to strong non-linearities in the decision rules or laws of motion of aggregates. The aggregate equilibrium is therefore easily linearizable.

4. Calibration

We now describe the functional forms and parameter values considered for our benchmark economy. The parameter values used in the simulation exercises are reported in Table 2. Similar to Raffo (2008) we use a GHH instantaneous utility function. Unlike Raffo we allow for habit persistence in consumption.

$$U(C,L) = \log\left(\left(C - hC_{-1}\right) - \frac{\psi}{1+\eta}L^{1+\eta}\right).$$

For simplicity we consider the case of external habit.

We also choose a simple parameterization for the idiosyncratic demand shocks, assuming the distribution of taste shocks differs for domestic/imported goods. Domestic taste shocks are drawn from $G^D(v) = 1 - \frac{1}{v^{\phi_D}}$ and imported taste shocks are drawn from $G^F(v) = 1 - \frac{1}{v^{\phi_F}}$. Allowing ϕ_D and ϕ_F to differ is essential in calibrating to evidence on the inventory holdings of foreign and domestic holdings as explained below.

First, we discuss the calibration of several parameters that are relatively standard in the international real business cycle literature, however. For these, we assign typical values. These parameters include the preference parameters $\{\beta, \gamma, \psi, \eta\}$ and technology parameters $\{\delta, \alpha\}$. Our period is a quarter so $\beta = 0.99$. We set the depreciation rate of capital to

$\delta = 0.025$ and the capital share to $\alpha = 0.33$. We choose ψ, the relative weight on leisure in the utility function in order to match a labor supply of $1/3$. We set η so that the Frisch elasticity is 2. We assign the elasticity of substitution between domestic and imported goods $\gamma = 1.5$, a standard value.

The remaining parameters $\{\theta, \delta_s, \chi_s, \phi_D, \phi_F, \omega, s_n\}$ are particular to our inventory/retailing set-up. We start by assigning $\theta = 3$, a typical estimate in industrial organization studies. We choose ϕ_D, ϕ_F, and ω to generate three moments. First, imports are 15 percent of sales. Second, inventory holdings are equal to 1.3 times sales. The third target is that importing firms hold twice the inventory (relative to sales) as firms that source domestically. This ratio is consistent with inventory-sales ratios for importers vs. domestic firms that we observe for Chilean plants and for US manufacturing industries. We set the total costs of managing inventories to 1.5 percent. This is split between depreciation of $\delta_s = 0.0035$ and a physical cost of managing inventory of $\chi = 0.0115$. Lastly, we set $s_n = 0.5$ so that intermediate inputs represent half of manufacturers' production costs.

For the technology shock process, we follow much of the literature and assume the persistence of national productivity shocks is 0.95 and the correlation of innovations across countries is 0.25. We choose the size of the shocks to match the volatility of industrial production.

The investment adjustment costs and cyclicality of inventory holding costs are chosen to target the volatility of investment in equipment and overall investment. Recall that we allowed for productivity shocks to improve the efficiency with which workers manage inventory as well. We allow this to depend flexibly on the business cycle by letting $\chi_t = \chi/A^\mu$. To get total investment of the right magnitude requires that the cost of managing inventories to be countercyclical (specifically we need $\mu = 2.5$). Finally, we set our habit parameter to match the autocorrelation of consumption in our benchmark model. This requires habit of 0.25.

To clarify the role of inventories, we also consider the properties of models with no inventories. In the models with no inventory we set the investment adjustment cost so that total investment, which includes net inventory investment, is 2.89 times as volatile as production, as in the data. To explore the role of habit and the input-output structure we consider a model with neither (column No Habit, No IO) and one with just the IO structure

and no Habit (results are in the columns No Habit). We do this for the inventory and no inventory models. In the case of the no inventory model, we choose the habit parameter in the full model to decrease the persistence of consumption by the same amount in the inventory and no inventory models when going from the Benchmark to no Habit model.

5. Results

We now discuss the properties of our benchmark model economy. Table 3 reports the size of fluctuations. Table 4 reports the correlation with industrial production and other cross-correlations. Table 5 reports autocorrelations. To make the benefit of modelling inventories concrete, we compare the results in the benchmark models with and without inventories. Figures 4 and 5 plot the impulse response of key variables in the benchmark model with inventories and without inventories, respectively. In short, we find that our benchmark model can capture some key features of trade dynamics without doing too badly on the new inventory dimensions.

Specifically, we find that trade is now about 20 percent more volatile than production or total sales (compared to 45 percent in the data and 3 percent less volatile than production with no inventories). These fluctuations in trade generate an import wedge of 0.88 vs. 1.08 in the data. With inventories, imports are slightly more procyclical than without inventories (0.67 vs. 0.65). In both models imports are not as procyclical as in the data where the correlation with production is 0.92. The wedge is not quite as procyclical as in the data either (0.54 vs 0.86) but it is about as correlated with imports as in the data (0.85 vs 0.88).

In terms of real net exports, the inventory model generates considerable larger fluctuations in net exports (0.3 vs 0.17) and these are about in line with the data (0.28). With inventories, net exports are considerably less procyclical (0.10 vs 0.38) but still no countercyclical as in the data (-0.42). These movements in net exports primarily arise because inventories make exports considerably less procyclical. The correlation of production is 0.77 vs. 0.96 with no inventories.

In terms of comovement of business cycles, we find that there is actually less synchronization of business cycles in the inventory model than the no inventory model. For instance, the cross-correlation of production is 0.44 in the inventory model and 0.56 in the no inventory

model. Similarly, the cross correlation of consumption in the inventory model is 0.68 and 0.79 in the no inventory model. One reason for the weaker comovement is that inventories provide another way to smooth production (and consumption).

The key problem with the inventory model though is that it generates fluctuations in trade that are not persistent enough. For instance, the autocorrelation of imports is 0.54 vs 0.66 with no inventories and 0.85 in the data. Also the wedges are not persistent enough, with an autocorrelation of 0.22 vs 0.78. These temporary fluctuations in trade lead to temporary fluctuations in net exports. The autocorrelation is only 0.22 vs 0.41 with no inventories and 0.76 in the data. One key reason that these fluctuations are so fleeting is that net inventory investment is fleeting with an autocorrelation of 0.29 vs 0.61. This clearly points to a need to fine-tune our model of inventory management perhaps introduce either a micro founded adjustment cost as in AKM (2010b).

The source of these transitory fluctuations are clear from Figures 4 and 5. Following a productivity shock at home, the need to build up inventory in the more productive location leads to a jump in imports for one period and a very weak export response. Consequently, initially net exports goes into deficit and that deficit is reversed in the second period when imports fall sharply and exports expand sharply.

6. Sensitivity

In this section, we examine the sensitivity of our findings to our assumptions. Specifically, we discuss the role of habit and the input-output structure for our main findings.

A. Habit

Introducing habit persistence allows consumption to be as persistent as in the data. The persistence of consumption leads to more persistent movements in international trade. With habit the volatility of imports falls from 1.28 to 1.20 in our benchmark formulation and the autocorrelation rises from 0.47 to 0.54. The less volatile imports lead to less volatile and more procyclical net exports. Without inventories, adding habit increases the volatility of trade. Overall the impact of habit is relatively minor.

B. Input-Output Structure

Eliminating the input-output structure has a fairly large impact on the nature of trade in the inventory model and a relatively minor impact in the no inventory model. With inventories, trade becomes very volatile. Imports are now 2.15 times as volatile as output and the wedge is 1.99 times as volatile as production. Net exports are very volatile and slightly countercyclical. These movements are very temporary and driven by the need to reallocate quickly inventories across countries. Net inventory investment and net exports are now fully 3 times as volatile as the data. With no inventory, trade becomes a bit less volatile (0.88 vs 0.97 in benchmark) and imports and exports tend to commove together more strongly.

The input-output structure increases the comovement of economic activity substantially with and without inventories. With inventories, the input-output structure raises the consumption correlation by more than the output correlation. Without the input-output structure, the correlation of consumption with inventories is about 9 percentage points below the correlation of consumption without inventories while the output correlation gap is only three percentage points. Thus, the consumption-output anomaly that BKK identify is a bit weaker with inventories. This is intuitive since the economy with inventories can use local inventories to smooth consumption. These inventories are less useful for smoothing consumption across countries. However, when we add the input-output structure, output and consumption correlations are now both about 11 percentage points lower in the inventory model than the no inventory model. With the input-output structure, inventories allow producers more ways to smooth production as well. Consequently, with inventories we get less synchronization of business cycles for a given shock process.[4]

One question to ask is: given the same amount of comovement in output, do inventories lead to less correlated consumption? To explore this we lower the correlation of shocks in the no inventory benchmark until the output correlation is the same as in our benchmark inventory model. The results are reported in the final column of the tables. Given a certain amount of synchronization in output, we find that with inventories the consumption correlation is lower with inventories than without (0.72 vs 0.68).

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[4]A key question that comes up is: does the the measurement of shocks depend on the presence of inventories? At this point, we suspect yes, but have not been able to measure the differences.

C. More sensitivity

To be completed [Elasticity of substitution, Incomplete Markets, Demand Shocks]

7. Conclusions

Over the business cycle, fluctuations in international trade involve substantial, persistent departures from theory in that the movements in trade that generally can not be explained by either movements in final expenditures or relative prices. We argue that an important reasons for the failure of standard models to explain these trade flows is that they ignore the inventory management decisions of importers. We show a two country GE model with an inventory management decision can generate some of the explained and unexplained movements in international trade over the business cycle.

In terms of the propagation of business cycles, we find that bringing trade flows more in-line with the data alters some features of international business cycles. Specifically, with inventories net exports are substantially less procyclical than without them. Following a good shock, the home country has a stronger desire to import and a weaker desire to export. Moreover, we find that consumption becomes less correlated across countries. However, in our benchmark formulation with an input-output structure this effect is dampened and inventories actually lead to less synchronization of business cycles. However, for a given amount of comovement in production, we find the model with inventories generates a lower consumption correlation. This occurs because the stock of inventories is local and influences the consumption decision. Reallocating inventories across countries is costly so consumption commoves less. With the input-output structure, inventories affect production in the same way across countries and thus lead firms to less synchronization in production.

While our benchmark model with habit and an IO structure looks good in many dimensions it also misses on some important dimensions. First, trade is not persistent enough. This partly reflects the transitory nature of net inventory investment. It is likely that adding some costs of adjusting inventories will substantially improve the fit of the model. Second, net inventory investment is not correlated enough with investment in equipment. This seems to arise because investment is not procyclical enough. It is likely that net inventory investment is crowding our equipment investment and again including the adjustment cost will help

improve the fit. Third, we have focused on business cycles driven by technology shocks solely. There is much debate about the source of business cycle fluctuations so it may be useful to study the impact of other types of shocks in our model. For instance, demand shocks are likely to have a much stronger impact on business cycle synchronization in our framework given the needs to build up inventory in good times. Finally, other sources of wedges are likely to be important and may have interesting interactions with inventory management decision. We are pursuing all of these avenues.

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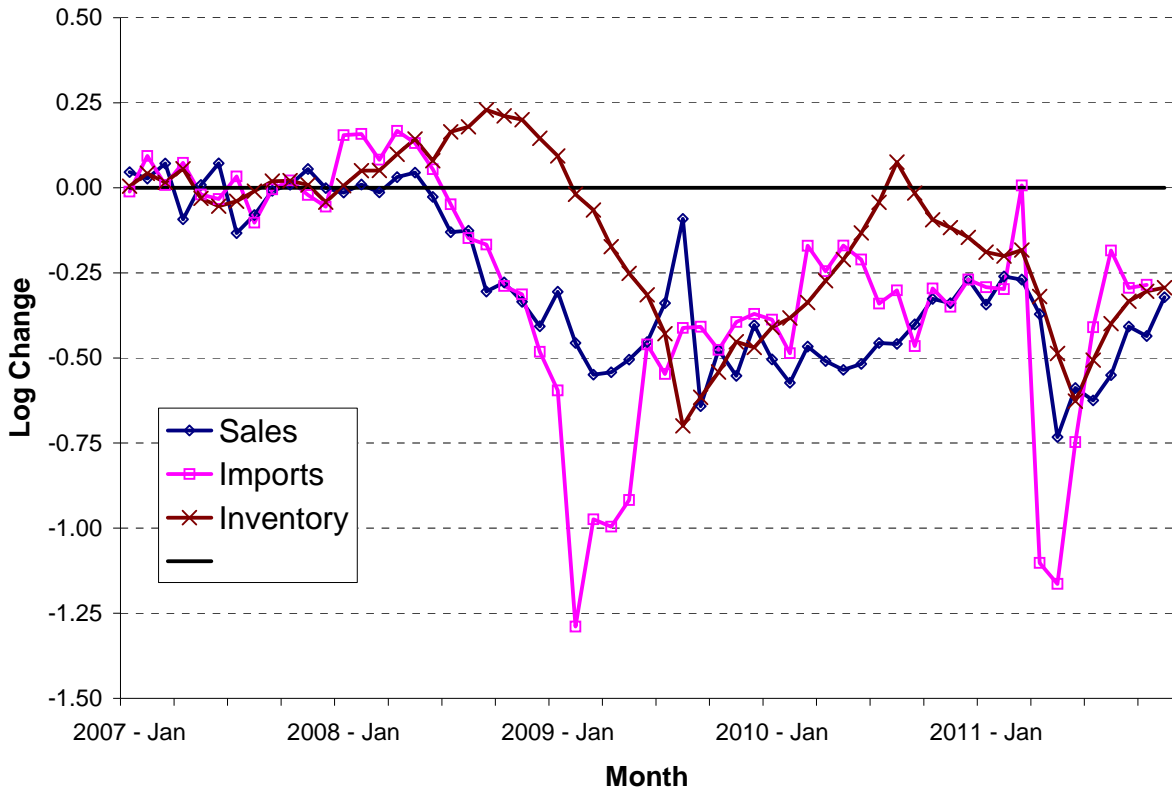
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Appendix

Data

Here is the data we used along with the mneumonics from Haver.

1. Output: Industrial Production: Manufacturing [SIC] (SA, 2007=100)
2. Investment = NII + I$_E$

   (a) NII = Real Change in Private Inventories (SAAR, Bil.Chn.2005$)
   (b) I^{eqs} =Real Private Nonresidential Investment: Equipment & Software (SAAR, Bil.Chn.2005$)

3. Real Exports of Goods (SAAR, Bil.Chn.2005$)
4. Real Imports of Goods (SAAR, Bil.Chn.2005$)
5. Aggregate Hours: Nonfarm Payrolls, Manufacturing (SAAR, Bil.Hrs)
6. Real Personal Consumption Expenditures: Goods (SAAR, Bil.Chn.2005.$)
7. Real Manufacturing & Trade Inventories: All Industries (EOP, SA, Mil.Chn.2005$)
8. Real Manufacturing & Trade Sales: All Industries (SA, Mil.Chn.2005$)
9. Real Broad Trade-Weighted Exchange Value of the US$ (Mar-73=100)
10. Terms of Trade: Price of Exports of nonagricultural goods/Price of Imports of nonpetroleum goods from the BEA
11. Price of Goods = PCE$^{0.75}$P$_I^{0.25}$

   (a) Personal Consumption Expenditures: Goods: Price Index (SA, 2005=100)
   (b) Private Nonresidential Fixed Investment: Chain Price Index (SA, 2005=100)

US Car Sales, Imports, and Inventory of Japanese cars (2007 -2011)

Legend:
- Sales
- Imports
- Inventory

Y-axis: **Log Change** (0.50, 0.25, 0.00, -0.25, -0.50, -0.75, -1.00, -1.25, -1.50)

X-axis: **Month** (2007 - Jan, 2008 - Jan, 2009 - Jan, 2010 - Jan, 2011 - Jan)
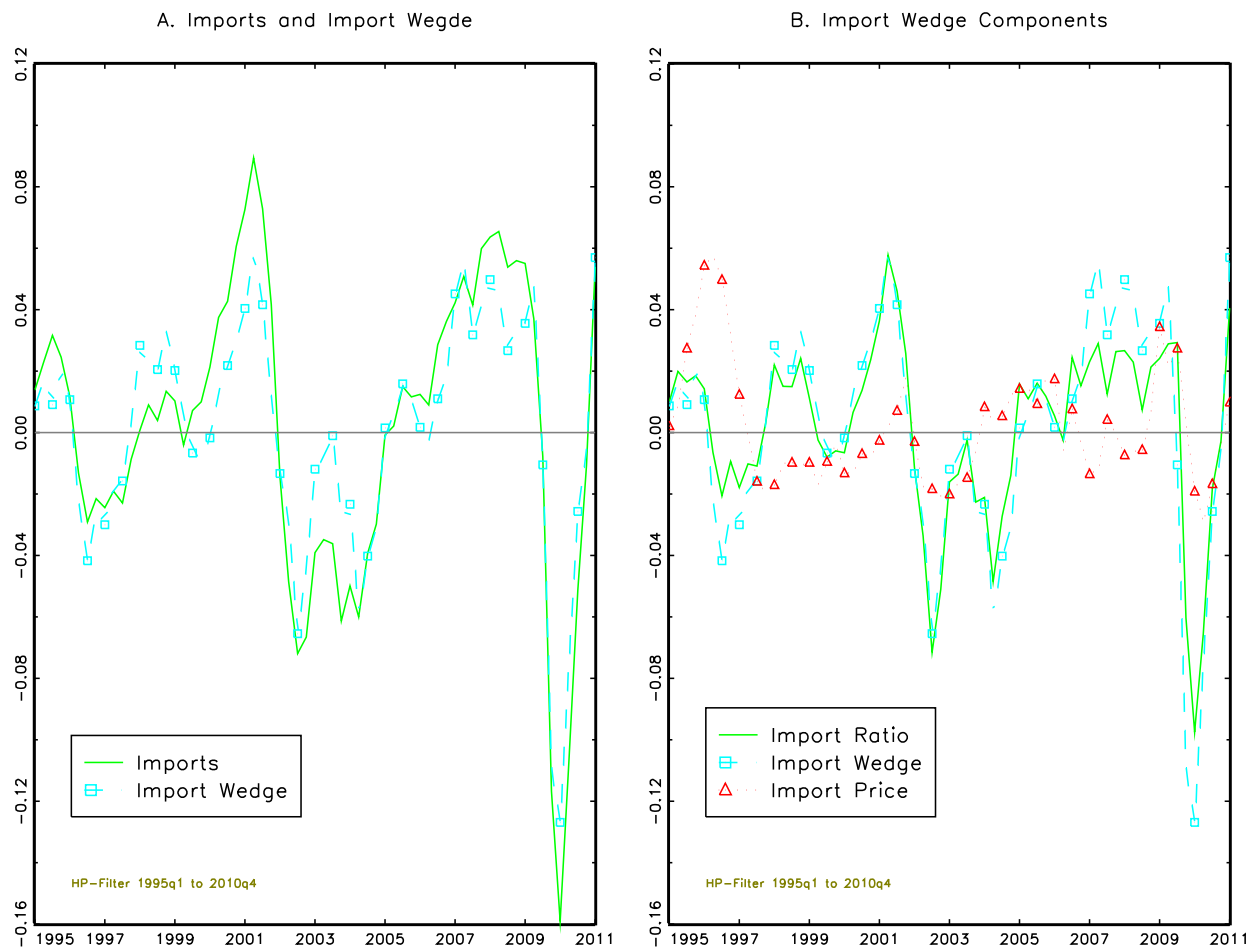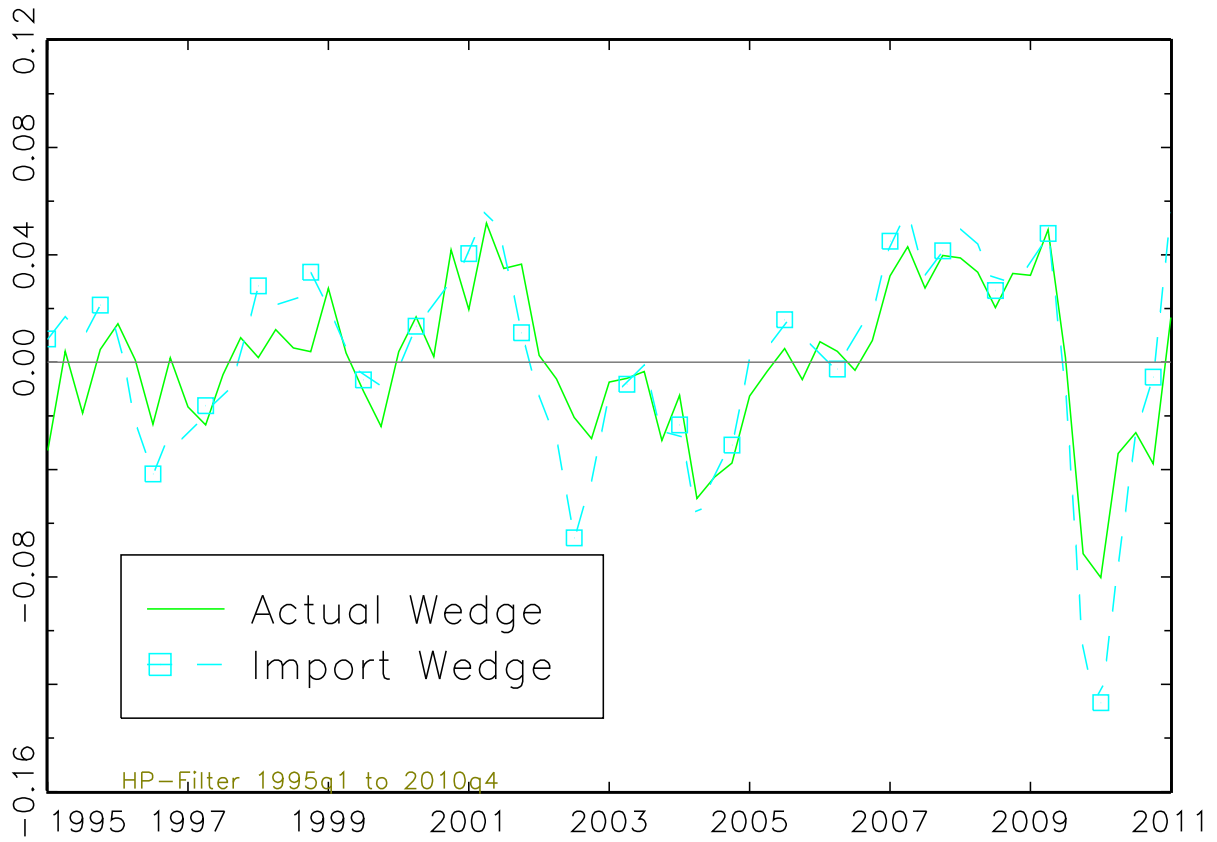
Figure 2: Deviations from trend of US Imports, Wedge, and Import Price

WEDGES

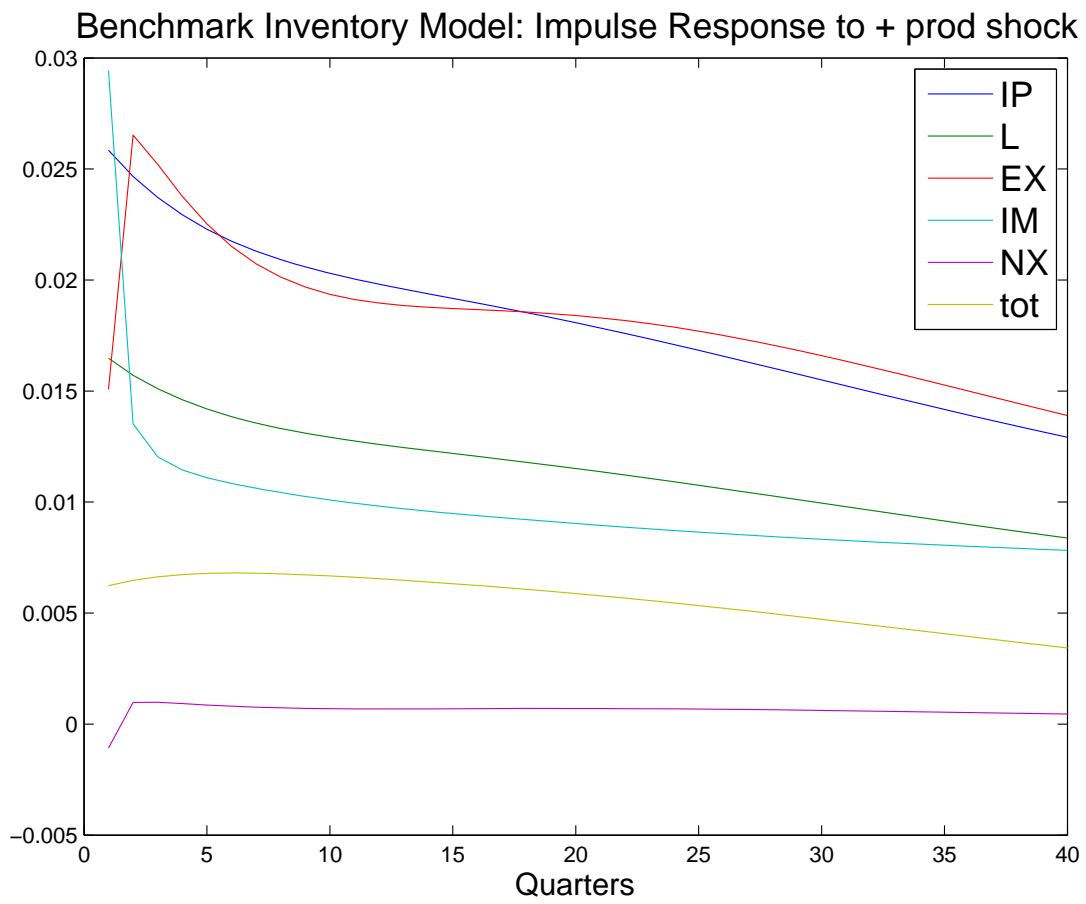Figure 3: Actual Wedge and Import Wedge

Figure 4: Impulse Response in Benchmark Inventory Model
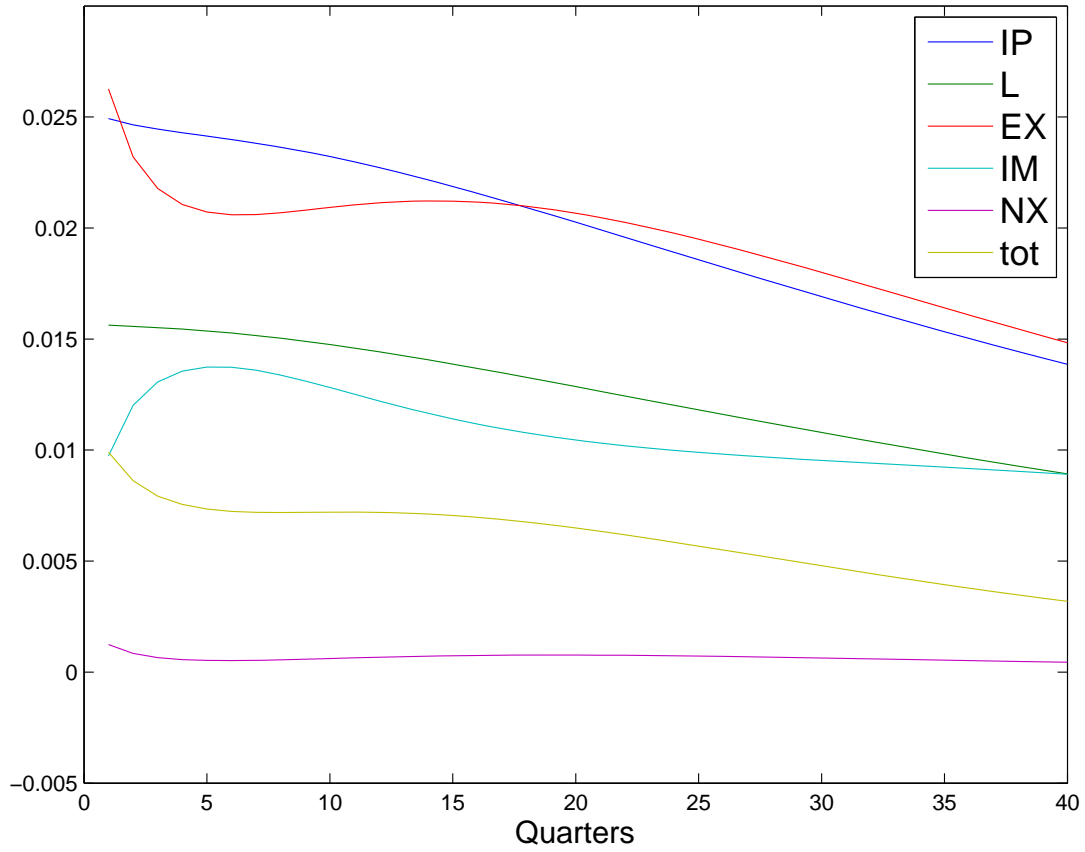
Figure 5: Impulse Response in Benchmark Inventory Model
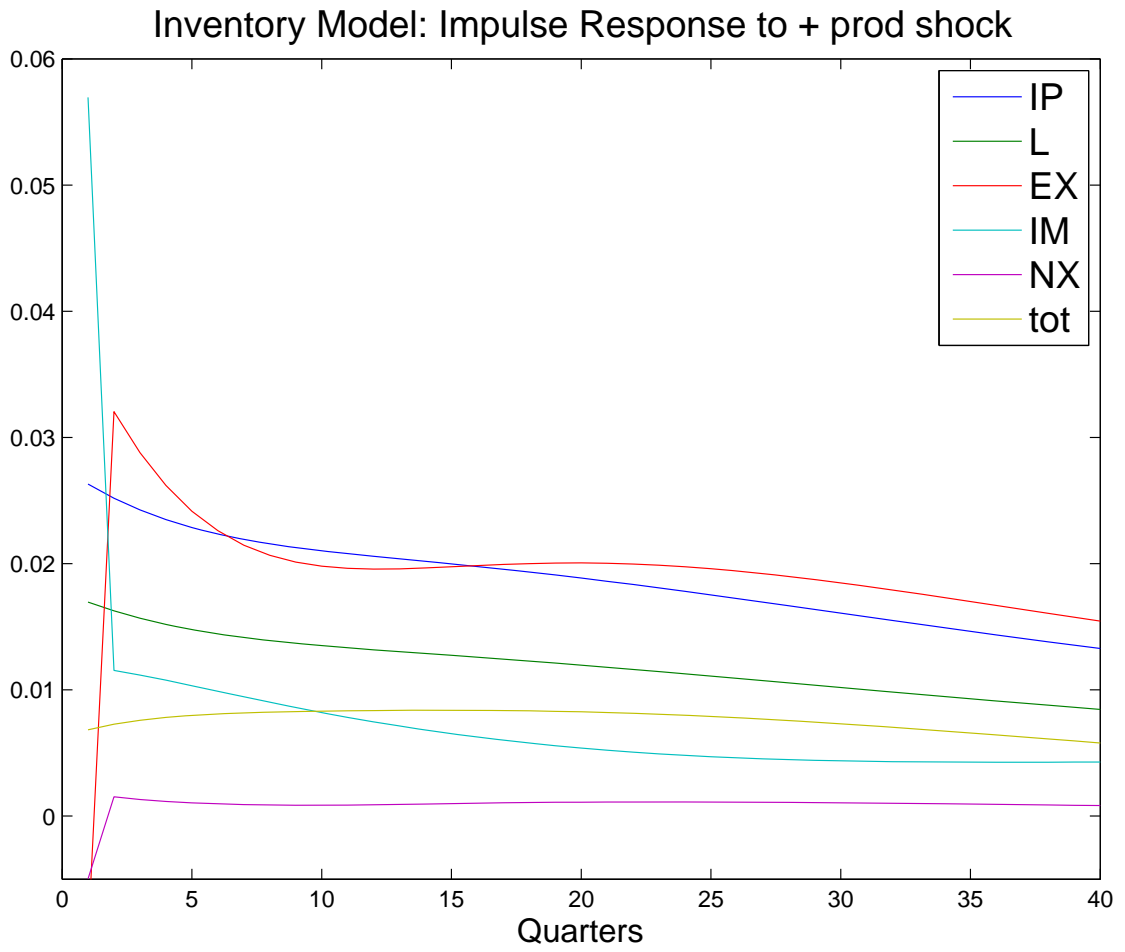
Figure 6: Inventory Model with No IO and No Habit
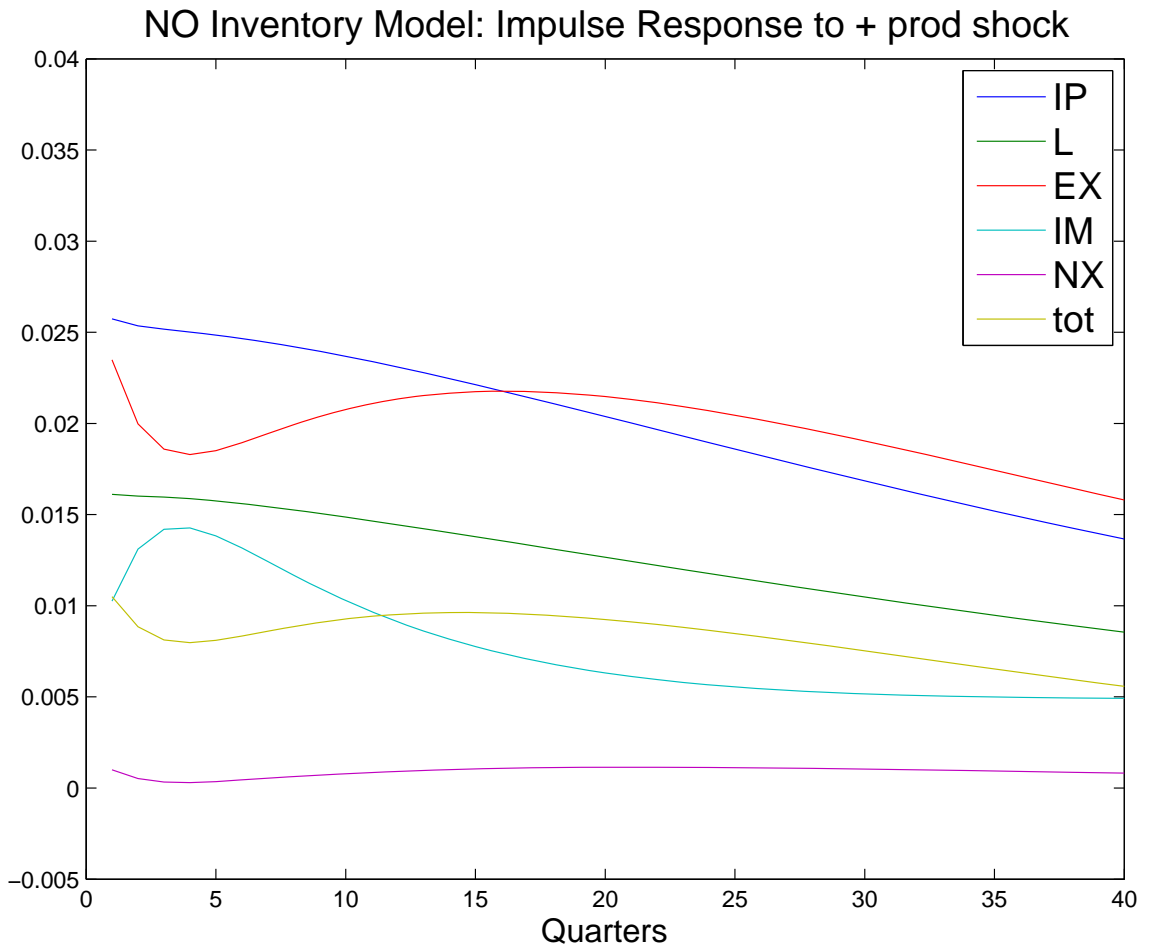
Figure 7 No Inventory Model with No IO and No Habit

Table 1: US Business Cycle Statistics of Imports

	Volatility relative to IP	Autocorrelation	Correlation with IPMFR	Correlation with Imports
IP*	3.44	0.91	1.00	
Imports Goods	1.40	0.86	0.92	1.00
Pm/P	0.36	0.83	0.08	0.21
Import Wedge	1.08	0.78	0.86	0.94
Import Ratio	0.84	0.73	0.78	0.93
Actual Wedge	0.80	0.67	0.81	0.85

* IP volatility is absolute not relative.

Table 2: Parameter Values

		Benchmark	No Habit	No Habit No IO
Assigned Parameters				
β	discount factor	0.99	0.99	0.99
γ	Armington elasticity of H vs. F	1.5	1.5	1.5
θ	elasticity across varieties in H & F	3	3	3
δ_s	inventory depreciation	0.0035	0.0035	0.0035
χ_s	inventory depreciation labor	0.0115	0.0115	0.0115
μ	Elasticity of inventory costs	2.1	2.1	4.5
η	Frisch Elasticity	0.5	0.5	0.5
h	Habit	0.25	0	0
δ	Capital Depreciation	0.025	0.025	0.025
α	Capital Share	0.33	0.33	0.33
sn	Input Share	0.50	0.5	0
Calibrated Parameters				
ϕ_d	home taste shocks	1.626	1.626	1.626
ϕ_f	foreign taste shocks	1.226	1.226	1.226
ω	home bias	0.835	0.835	0.835

Table 3: Business cycle statistics model and data

Standard Deviations:	Data	Inventory Model			No Inventory			
		No IO, No Habit	No Habit	Benchmark	No IO, No Habit	IO, No Habit	Benchmark	Benchmark (comovement fixed)
Production	3.44	3.28	3.22	3.24	3.35	3.28	3.29	3.21
NX/sales	0.28	0.91	0.38	0.3	0.16	0.18	0.2	0.22
NII/sales	0.45	1.37	0.65	0.66				
Standard Deviations (rel. to IP):								
Consumption, C	0.46	0.59	0.6	0.59	0.64	0.75	0.73	0.71
Employment, L	0.82	0.65	0.64	0.64	0.64	0.64	0.64	0.64
Total investment, X + Delta S	2.89	2.89	2.9	2.9	2.89	2.88	2.89	2.9
Investment, X	1.62	1.63	1.62	1.62	2.89	2.88	2.89	2.9
Inventory Stock	0.63	1.25	0.67	0.68				
Exports,	1.49	2.15	1.28	1.2	0.88	0.95	0.97	0.96
Imports,	1.4	2.15	1.28	1.2	0.88	0.95	0.97	0.96
RER	0.89	0.37	0.32	0.31	0.39	0.39	0.39	0.44
TOT	0.27	0.47	0.44	0.43	0.56	0.55	0.56	0.63
Inventory Sales Ratio	0.82	0.59	0.6	0.52				
Sales (incl Mfr)	0.72	0.82	0.87	0.87	0.99	0.98	0.98	0.98
Wedge	1.08	1.99	0.93	0.88				

Table 4: Business cycle statistics model and data: Cross Correlations

		Inventory Model			No Inventory			
	Data	No IO, No Habit	No Habit	Benchmark	No IO, No Habit	IO, No Habit	Benchmark	Benchmark (comovement fixed)
Correlation with IP:								
NX/sales	-0.42	-0.1	0.08	0.1	0.31	0.41	0.38	0.42
NII/sales	0.56	0.57	0.65	0.67	0.04	0.09	0.06	0.06
Consumption, C	0.8	0.99	0.98	0.95	0.98	0.98	0.98	0.98
Employment, L	0.91	1	1	1	1	1	1	1
Total investment, X + Delta S	0.86	0.82	0.88	0.91	0.96	0.91	0.95	0.94
Investment, X	0.92	0.57	0.57	0.58	0.96	0.91	0.94	0.93
Inventory Stock	0.81	0.81	0.77	0.81			0.42	0.42
Exports,	0.85	0.32	0.72	0.77	0.88	0.97	0.96	0.95
Imports,	0.92	0.5	0.62	0.67	0.66	0.66	0.65	0.56
RER	-0.38	0.57	0.51	0.51	0.55	0.47	0.46	0.51
TOT	0.69	0.57	0.51	0.51	0.55	0.47	0.46	0.51
Inventory-Sales Ratio	-0.03	-0.17	-0.73	-0.72				
Sales (incl Mfr)	0.97	0.99	1	0.99	1	1	1	1
Wedge	0.86	0.37	0.49	0.54				
Correlations:								
IP and IPs*	0.6	0.31	0.44	0.44	0.34	0.55	0.56	0.44
L and Ls*	0.39	0.39	0.52	0.53	0.47	0.67	0.68	0.58
C and Cs*	0.38	0.47	0.7	0.68	0.58	0.79	0.79	0.72
X and Xs*	0.33	0.17	0.45	0.45	0.18	0.43	0.44	0.31
IS and Sales	-0.13	-0.02	-0.68	-0.66				
X and NII	0.87	-0.1	-0.05	-0.07				
Exports and Imports	0.85	-0.47	0.25	0.46	0.75	0.71	0.66	0.57
TOT and RER	-0.16	1	1	1	1	1	1	1
NIIY AND I_eqpt	0.47	-0.1	-0.05	-0.07				
Wedge and TOT	0.09	0.12	0.05	0.05				
Wedge and Imports	0.88	0.96	0.87	0.85				

*Taken from Chari, Kehoe, and McGratten (2002) based on the US and Europe.

Table 5: Business cycle statistics model and data: Autocorrelations

AutoCorrelations:	Data	Inventory Model			No Inventory			
		No IO, No Habit	No Habit	Benchmark	No IO, No Habit	IO, No Habit	Benchmark	Benchmark (comovement fixed)
Production, IP	0.91	0.69	0.69	0.69	0.72	0.71	0.72	0.72
NX, NX/sales	0.76	-0.09	0.12	0.22	0.31	0.5	0.41	0.41
NII/salesM	0.61	0.15	0.24	0.29				
Consumption, C	0.82	0.73	0.73	0.81	0.64	0.62	0.69	0.69
Employment, L	0.91	0.7	0.7	0.69	0.73	0.72	0.72	0.73
Total investment, X + Delta S	0.79	0.29	0.4	0.42	0.85	0.89	0.85	0.85
Investment, X	0.9	0.96	0.96	0.95	0.85	0.9	0.87	0.88
Inventory Stock	0.92	0.86	0.89	0.89				
Exports,	0.85	0.11	0.47	0.54	0.67	0.68	0.66	0.65
Imports,	0.86	0.11	0.47	0.54	0.67	0.68	0.66	0.65
RER	0.76	0.76	0.77	0.76	0.59	0.65	0.62	0.62
TOT	0.71	0.76	0.76	0.76	0.59	0.65	0.62	0.62
IS2	0.78	0.72	0.59	0.59	0.29	0.48	0.21	0.21
Sales (incl Mfr)	0.91	0.74	0.72	0.74	0.74	0.72	0.74	0.74
Wedge	0.78	-0.03	0.13	0.22				