The Great Trade Collapse of 2008-09: An Inventory Adjustment?*

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January 2010

Abstract

This paper examines the role of inventories in the decline of production and trade in the economic crisis of late 2008 and 2009. Empirically, we show that international trade declined more drastically than trade-weighted production or absorption, and that inventory dynamics show a sizable adjustment, especially for imported goods. This is most clearly evident for autos, the industry with the largest drop in trade. We develop a two country general equilibrium model with endogenous inventory holdings in response to frictions in domestic and foreign transactions costs. Quantitatively, in response to a global productivity shock, the calibrated model shows a larger decline in output, and an even larger decline in international trade, relative to a more standard model without inventories. The magnitudes of output, trade, and inventory responses are similar to those observed in the recent recession.

JEL classifications: E31, F12.

Keywords: Fixed costs, delivery lags, inventory.

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*This paper is very preliminary. Comments are welcome. Please do not cite.

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1. Introduction

A key feature of the economic slowdown in the latter half of 2008 and early 2009 was a widespread and massive collapse in international trade. For example, from August 2008 to January 2009, US non-petroleum real imports and exports fell 18 percent and 22 percent respectively.[1] The decline in trade was much larger than the fall in overall economic activity as industrial production in manufacturing fell only 10.8 percent in the same period. In a global economy, the downturn in trade is a potentially important mechanism for the propagation of shocks and crises, and whether or not the downturn is long- or short-lived can have important consequences for predictions of the timeline for recovery.

Many possible explanations for the large change in trade relative to production have been proposed. Some have attributed the decline to an increase in the costs of trade either from trade financing drying up (ICC, 2008, Economist, 2009a, Dorsey, 2009, Dougherty, 2009, Auboin, 2009, Amiti and Weinstein, 2009), while others argue that the decline is actually commensurate with the decline in economic activity (Eaton, Kortum, Nieman, and Romalis, 2009, and Levchenko, Lewis, and Tesar, 2009).[2] Both explanations would lead to a decline in trade that is as persistent as the underlying shock. A third potential explanation, which we pursue, is that the decline in trade is driven by inventory adjustments in response to underlying shocks. This explanation would lead to a drop in trade that is steep, but shorter-lived relative to underlying shocks. That is, if inventories play an important role in the downturn, once the inventory adjustment is over, trade should recover quite rapidly. In the paper, we empirically evaluate the inventory channel in the drop in U.S. trade, model and quantify this channel, and finally use the model to predict future dynamics.

Our empirical analysis establishes a special role for international trade and inventories

[1] Including petroleum-based goods, which experienced very large terms of trade fmovements over this period, exports fell 22 percent and imports fell 12 perecnt.

[2] Other potential explanations include a collapse of global supply chains in multi-stage production (Yi, 2009) or an increase in protectionist policies (Baldwin and Evenett, 2009, Economist 2009b).

in the economic downturn.[3] Specifically, we show that the observed decline in trade is indeed large compared to the decline in economic activity, with a drop in trade roughly four times the drop in output, and fifty percent more than the drop in industrial production or trade-weighted demand (i.e., real sales) of tradable goods. Real sales are a proxy for demand for U.S. production, and so without inventory adjustment, a pure demand shock for U.S. goods should move one-for-one with exports. Similarly, a simple shock to demand for U.S. consumers should move imports one-for-one with real sales. Instead, we document that across the seven most recent (i.e., post-1970) recessions, both exports and imports are about 50 percent more volatile than industrial production or demand for tradables.

The drop in imports relative to sales leads naturally to an adjustment of inventory-to-sales ratios, and indeed we believe this is their primary aim. Indeed, inventories play an important role in recessions and the inventory-to-sales ration is strongly countercyclical. We document this well-known fact, and show that the current recession is no exception. From August, 2008 through April, 2009 inventory-to-sales ratios rose 5 percent overall, 6 percent in (non-auto) consumer goods and 19 percent in capital goods.

To gain some perspective on the dynamics of trade and inventory, it is useful to consider their behavior in the current recession, which began in the fourth quarter of 2007, and deepened substantially in September 2008. Focusing on just the period beginning in September 2008, when the collapse in trade also accelerated, we find that in the 12 months ending in August 2009, total real imports declined by $238 billion compared to annualized level in the 3 months ending in August 2008, and exports fell $202 billion. At the same time, the stock of US business inventories fell approximately $102 billion from August 2008 to August 2009. Thus, there is a substantial adjustment of inventories that coincided with the collapse in trade.

[3] We also observe similar dynamics in past recessions. Thus, inventory management concerns appear to be important for business cycle dynamics more generally.

For one quantitatively important industry, we show that the inventory adjustment responses are stark, and are closely linked to international trade dynamics. Specifically, for motor vehicles we have data on foreign and domestic sales and inventories. Both imports and sales of foreign automobiles began dropping in mid-2008, and inventory-sales ratios rose roughly 45 percent over six months. Over the first three months of 2009, sales began to recovers somewhat, but imports continued to fall precipitously, while inventory-sales ratios adjusted downward by 40 percent. The fall in auto imports began to level off only in the 2nd quarter of 2009, after this adjustment. These dynamics do not appear to be peculiar to the recent recession. We show similar dynamics in the U.S. auto market in the 1970s, and also similar dynamics in Japan in its last four recessions. Moreover, given that trade in autos fell first and most spectacularly in the current recession, we believe that any explanation of the aggregate trade collapse must be able to explain the dynamics of this industry.

The mechanism we propose is an economic shock, which raises inventory-to-sales ratios above desired levels, causing a more precipitous drop in economic activity, especially international trade. To quantitatively evaluate such an interpretation, we follow Alessandria, Kaboski, and Midrigan (2009a,b), and calibrate a model of international real business cycles augmented to include a distribution sector that holds inventories. Inventory holdings are microfounded in that distributors face an increasing returns transaction-level technologies, shipping lags, and overall uncertainty drive inventory management considerations.

We discipline the model using both aggregate and microdata on trade and inventories. The quantitative traction of the model comes from these frictions being particularly strong for importers.[4] We calibrate the frictions to match time-averaged aggregate inventory-to-sales ratios, and evidence on the lumpiness of transactions and the relative importance of

[4] Alessandria, Kaboski, and Midrigan (2009a) document the severity of these frictions and their relative importance for importers. Their partial equilibrium model performs relatively well in explaining the quantitatively large and short-lived drops in imports experienced in developing countries (e.g., Argentina) during recent financial crises.

inventories for importers vs. non-importers.

We then perform several experiments to quantify the model's predictions for trade, inventory, and sales dynamics. First, we consider the role of the global recession, modelled as a synchronized negative productivity shock in both countries. Our model with inventories shows a substantially deeper (33 percent larger) drop in trade relative to the drop in production. Inventory-to-sales ratios increase substantially but then decline (and actually overshoot) before stabilizing. Moreover, the magnitudes of responses are comparable to those observed in the recent recession. Second, to better understand the role of inventories in the propagation mechanism, we consider the propagation of a single negative productivity shock to Home. Again, the model with inventories has lower levels of production on impact in both Home and Foreign than the model without. Hence, both output and trade are more responsive to shocks and volatile when inventories are important. Finally, we also consider the role of finance on trade flows by considering an increase in the inventory carrying costs. Such a shock reduces economic activity but affects trade relatively more since importers hold more inventory than non-importers. However, the overall impact is small, accounting for no more than a fifth of the drop in total trade.

The rest of the paper is organized as follows. The next section documents the empirical evidence on trade and inventories in the most recent crisis. Section 3 develops the model, while Section 4 presents the calibration and quantitative results.

2. Empirics

Here we document two key features of trade flows. First, in downturns trade tends to fall much more than measures of income, production, or expenditure. That is, there is a relatively high income elasticity. The relatively high volatility of trade is well-known (see Backus, Kehoe and Kydland, 1992, for instance) and often attributed to the traded basket being comprised primarily of durables (see Boileau, 1999, or Engel and Wang, 2007). While this is clearly part of the story, even when using final expenditures on traded goods rather than income, we still find a relatively high elasticity of trade. By these measures, we find that the reduction in trade in the current recession is not unusual. Indeed, what is unusual is the magnitude of the US recession. Second, we provide evidence that there is an important role for inventory holdings in downturns, particularly for trade dynamics. We show that aggregate inventory dynamics in the current recession are also not unusual. We focus further on autos because trade in autos fell the most in the current recession, and, for autos, we can separately measure domestic sales of imported autos and imports of autos. These data show substantial differences between domestic sales of imported autos and auto imports that must be filled by inventory holdings. The auto data suggests that the high elasticity of trade may not reflect substantial variation in final purchase of imports, but rather reflect substantial inventory adjustments.

A. Trade Response

We now describe the cyclical properties of trade (exports and imports) in the US. A key feature of trade flows is that they are more volatile than production or absorption of traded goods.

Table 1 presents key summary moments for U.S. business cycles for the years 1967-2009, where the data have been HP filtered with a smoothing parameter of 1600. We focus on this recent period, since the inventory series is first available in 1967. In any case, trade is most relevant for this recent period.[5]

Trade is about 1.5 times more volatile than manufacturing industrial production (measured by the ratio of standard deviations). Because income (measured by GDP) is less volatile

[5] The ratio of exports plus imports to GDP fluctuated between 4 and 6 percent from 1947 to 1967, but rose from 6 to over 20 percent between 1967 and 2009. There have also been changes in inventory management that have occurred recently, including movement to just in time management principles. The increase in international trade has likely led to increased importance of inventories while these practices may have reduced their quantitative importance. In aggregate, the inventory/sales ratios have been relatively stable, rising from about 1.4 in the late 1960s to above 1.5 in the 1980s before falling to 1.3 in the 2000s.

than industrial production, trade is even more volatile relative to income, with roughly a relative volatility of 3.5 (1.49/0.43=3.47 for imports and 1.64/0.43=3.81 for exports).

Given our emphasis on inventories, an equally relevant question is whether trade is more volatile than the demand for traded goods. In constructing a measure of final demand, it is important to realize that the durable/nondurable composition of trade itself differs starkly from overall output, and also differs from typically tradable goods (i.e., equipment, consumer durables, and consumer nondurables). When constructing our measure of the demand of expenditures on traded goods, Y_t^T, we therefore weight the expenditures on durables (investment in equipment, $I_{EQ,t}$, and consumer durables, $C_{D,t}$) plus expenditures on consumer non-durable, $C_{ND,t}$ appropriately:

$$Y_t^T = \alpha \left(\frac{I_{EQ,t} + C_{D,t}}{I_{EQ,0} + C_{D,0}} \right) + (1 - \alpha) \frac{C_{ND,t}}{C_{ND,0}},$$

Here the weight α is equal to the share of equipment and durables in trade flows (approximately 2/3, see the appendix for calculation details) and everything is measured relative to a base year. Notice that while Y_t^T is a measure of the absorption of traded goods, it does not distinguish between domestic and foreign traded goods. Because this measure of final demand for traded goods is slightly less volatile than industrial production, trade is roughly 1.75 times (1.49/0.88=1.69 for imports and 1.64/0.88=1.86 for exports) as volatile as corresponding final demand.

Using the HP filtered data, Figure 1 shows the drop in trade and our measures of economic activity relative to trend for the most recent recession (The analogs to Figure 1 are the previous six recessions are available in the appendix.). The dashed vertical line indicates the beginning of the recession according to NBER dating, and we normalize all series using the quarter prior to the recession. From the fourth quarter of 2007 through the second quarter of 2009, output had fallen five percent relative to trend, while industrial production and traded goods demand had fallen by almost fifteen percent. Still, the response in trade is substantially larger with exports and imports falling nearly 25 and 20 percent, respectively, relative to trend. The magnitude of these declines in trade are thus in line with the cyclical movements from Table 1.

Still, across recessions, the timing of imports and exports do not always line up with output or demand (see the Appendix). To make the declines in trade flows comparable across the diverse recessions, Table 2 reports the elasticity of trade relative to each measure of absorption in the quarter of the peak drop in trade (so that the peak drop in imports and exports may be in different quarters). The top two panels report the import and export elasticity. To take into account the fact that exports tend to rise after the start of a recession, the bottom panel reports the peak to trough drop in exports. Clearly, trade falls more than our measures of income, production or demand/absorption across recessions.

In terms of the elasticity of the import response, the recent recession does not appear atypical. While there is variation across recessions, the most recent recession actually yields an import elasticity of 1.72, below the import demand elasticity of 2.48. With regards to exports, the decline in exports relative to industrial production of 1.38 in the most recent recession is also the median relative decline. The nearly synchronized drop in trade suggests that very little of the drop is a result of a change in the global composition of absorption from foreign goods to US goods.

B. Inventory Response

We now return to the previous figures and tables to consider the comovement of inventory holdings and trade flows. As is well known, the inventory-to-sales ratio is strongly countercyclical (the correlation with industrial production is -0.70 in Table 1). The bottom panel of Table 2 shows that the response of the inventory-sales ratio is not atypical in this recession. Across the seven most recent recessions, the median log drop in the inventory-to-sales ratio relative to industrial production is 0.56, while that in the most recent recession is a slightly lower -0.41. With only seven recessions, it is difficult to discern a change in the cyclical properties of inventories over the cycle.

The peak in the inventory-sales ratio tends to precede the peak decline in imports or exports, however. In Figure 1, we see that the inventory-to-sales ratio rises at the aggregate level and peaks in the first quarter of 2009, prior to the peak decline in imports or exports. This pattern occurs in all the recessions we consider, except for the 1990 recession when the peak increase in inventory and declines in trade occurred in the same quarter.

One might be concerned that the 5 percent increase in the inventory-to-sales ratio from Figure 1 is too small relative to the declines in trade to account for much of the relatively large fall in trade. This is not the case since business inventories, a stock, are approximately equal to 10 months of imports, a flow, at the August 2008 rate of imports.[6] Indeed, using monthly data, we find that the stock of business inventory in the US fell approximately $100 billion from the end of August 2008 to the end of August 2009 while the cumulative drop in imports of goods over this period, relative to the average rate from June to August 2008, was $238 billion and for exports the drop was $202 billion.[7] Thus, potentially the inventory adjustment may account for nearly 40 percent of the decline of imports. Of course, inventory of both domestic and foreign inputs fell over this period suggesting perhaps a smaller role for inventories. However, without data that separates inventory holdings of imported goods from domestic goods as well as sales of domestic and imported goods, it is challenging to evaluate the inventory mechanism fully. Our subsequent empirical analysis of autos and our model-based quantitative analysis overcome this challenge.

[6] This is like saying that investment is not important for the business cycle because the capital stock does not change much in the short-run. One must be careful in comparing the change in stocks (inventories) against the change in a flow (trade).

[7] Comparing the twelve months ending in August, in 2008/9, exports fell about $146 billion and imports fell $278 billion. Constructing a measure of the drop in inventory holdings in the rest of the world is challenging, but there is clear evidence of inventory disinvestment in other countries in this period as well.

Although we see large increases in inventories that appear to lead the drop in trade, we cannot say precisely how inventory dynamics of either imported goods or goods destined for export vary because the inventory-to-sales ratio includes inventory holdings of domestic and imported goods (as well as goods destined for export). To understand the connection between inventory holdings and international trade, we focus on the auto industry. A key advantage of the auto industry is that there are direct measures of domestic sales of imported autos and imports of autos. Moreover, autos are an important traded good (accounting for 10.8 percent and 17.8 percent of US nonpetroleum exports and imports, respectively, from 1999 to 2008).

Another key reason to study the auto industry, beyond the availability of data, is that this industry had the largest, and most immediate decline in trade in this recession. From Figure 2, which plots monthly real export and imports by end-use category relative to their August 08 levels, we see that imports and exports of motor vehicles and parts from December 08 had fallen twice as much as total trade flows and no other end-use category had fallen close to as much. Given the strength and immediacy of the trade collapse in auto trade, we believe that any explanation of the trade collapse must be able to explain autos to have a chance of explain the aggregates more generally.

We can construct a measure of inventory holdings using the series on imports and sales:

$$(1) \quad INV_{t+1}^{M} = INV_{t}^{M} + M_t - S_t^M,$$

where INV_t^M denotes real inventory holdings of imported goods at the start of period t, M_t denotes real imports of motor vehicles, and S_t^M denotes real final sales of autos imported from outside of North America. We focus on imports from outside of North America since the BEA breaks down final sales of autos into these two regions (N. America and rest of the world).

Figure 3 plots monthly real inventory, real sales, and real imports of autos in the current recession through July 2009. Here we plot log changes from July 2008, since demand is relatively stable before that month. As with the aggregate trade data, imports fall substantially more than domestic absorption of imported autos. From peak (May 2008) to trough (May 2009), the decline in imports is almost 3 times the decline in final absorption (1.11/0.38). Moreover, the initial drop in imports through November 2008 was only slightly larger than that of final sales. Consequently inventories levels remained relatively stable, but the inventory-to-sales ratio increased roughly 40 log points. The massive collapse in imports of autos from December 2008 on was necessary to bring inventory holdings in line with lower sales levels. Indeed, inventory considerations must be at the heart of trade dynamics since there is actually a slight rebound in sales of imported autos starting in December 2008, just as the decline in imports collapsed. Relative to July 2008, in the period December 2008 to June 2009 sales of imported autos were on average 29 percent lower while imports were 71 percent. Thus, the automobile data provide very strong evidence for a high demand elasticity of imports, since these data are unlikely to suffer from a compositional mismatch between our measure of imports and absorption.

These inventory dynamics in the auto industry are not peculiar to the recent recession but have occurred in other periods with large trade swings. Figure 4 plots the dynamics of imports, sales, and inventory holdings of foreign autos in the US using quarterly data from 1972 to 1977 and provides clear evidence of a gap between imports and final sales of imported goods that is filled by inventory holdings. In particular, this period was marked by a collapse of imports of nearly 40 log points in two quarters (from third quarter of 1974 to the first quarter of 1975) that followed a substantial inventory accumulation of 35 log points (from the first to the third quarter of 1974). It also was marked by a robust rebound in imports and inventory holdings that preceded a boom in final sales of imported autos.

While autos provide a clean guide to the connection between inventory and trade flows, a similar connection may holds for consumer and capital goods. Figures 5 and 6 plot the dynamics of imports, final demand (trade weighted), and inventory levels for consumer and capital goods in the current recession. As we saw with autos, and the aggregates, within these narrow categories imports have fallen more than final demand (29 percent vs. 18 percent for capital goods at the trough in April 2009, and 13 vs. 5 percent for consumer goods through April 2009) and have been associated with an increase in inventory-sales ratios (peaking up 19 percent for capital goods and up 6 percent for consumer goods).

Finally, inventory and trade dynamics are not particular to the US but are also evident in the aggregate in Japan. Figure 7 plots the manufacturing inventory-sales ratio, industrial production, import, and export dynamics in the four downturns in Japan since 1990: the 2007 to 2009 downturn, the 2001 recession, the East Asian Crisis (1997 to 1999), and the 1991 downturn. For each period, we plot time zero as the peak in industrial production. Much as for the US, these four downturns are associated with substantial increases in inventory levels relative to sales and substantial declines in trade flows and production. Unlike the US, the declines in trade flows tend to be steeper for exports than imports (in 3 of the 4 periods) and exports tend to fall more than production while imports fall less.

3. Model

We extend the partial equilibrium sS model of international trade and inventories in Alessandria, Kaboski and Midrigan (2009a) to a two-country general equilibrium environment. The model is similar to Backus, Kehoe, and Kydland (1994), augmented to include a monopolistic retail sector that hold inventories of both domestic and imported intermediates. Specifically, in each country, a continuum of local retailers buy imported and domestically-sourced 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 to consumers. Consumers purchase these varieties and then use an aggregation technology to transform varieties of the home and foreign varieties into final consumption. Retail firms are subject to two frictions that lead them to hold inventories: (i) fixed costs of ordering goods from intermediate producers; and (ii) a lag between orders and deliveries of goods. These frictions are more severe for retailers that sell imported goods, thus leading them to hold higher inventories.

A. Environment

Formally, consider an economy consisting of two countries, Home and Foreign. In each period of time 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 has standard expected utility preferences over consumption and leisure:

$$\sum_{t=0} \sum_{\eta^t} \beta^t \pi\left(\eta^t\right) U\left[C\left(\eta^t\right), 1 - L\left(\eta^t\right)\right]. \tag{2}$$

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

$$
\begin{aligned}
(3) \qquad C\left(\eta^t\right) &= Y\left(\eta^t\right) \\
(4) \qquad Y\left(\eta^t\right) &= \left[\begin{array}{c} \left(\int_0^1 v_H\left(j,\eta^t\right)^{\frac{1}{\theta}} y_H(j,\eta^t)^{\frac{\theta-1}{\theta}} dj\right)^{\frac{\theta}{\theta-1}\frac{\gamma-1}{\gamma}} \\ +\tau^{\frac{1}{\gamma}} \left(\int_0^1 v_F\left(j,\eta^t\right)^{\frac{1}{\theta}} y_F(j,\eta^t)^{\frac{\theta-1}{\theta}} dj\right)^{\frac{\theta}{\theta-1}\frac{\gamma-1}{\gamma}} \end{array} \right]^{\frac{\gamma}{\gamma-1}}
\end{aligned}
$$

Here 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. The parameter $\tau \in [0,1]$ captures the lower weight on Foreign goods (i.e., a Home bias). The Foreign consumer uses an analogous technology except that the lower weight τ multiplies the Home goods. The idiosyncratic shocks to preferences are not necessary but provide a simple way to generate heterogeneity across retailers that help to smooth out the effect of the non-convexities in the retailers ordering decision. [8]

The household 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 $W\left(\eta^t\right)$, and earn 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 t as $Q\left(\eta^{t+1}|\eta^t\right)$. The consumer's period t budget constraint is therefore:[9]

$$
\int_0^1 p_H\left(j,\eta^t\right) y_H(j,\eta^t)dz + \int_0^1 p_F\left(j,\eta^t\right) y_F(j,\eta^t)dz \; + \sum_{\eta^{t+1}} Q(\eta^{t+1}|\eta^t) B\left(\eta^{t+1}\right) =
$$

$$
(5) \qquad W\left(\eta^t\right) L\left(\eta^t\right) + \Pi\left(\eta^t\right) + B\left(\eta^t\right)
$$

The budget constraint for the Foreign consumer is 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.

[8] Alternatively, we could have followed Alessandria and Choi (2007) and modelled firm productivity as being stochastic, or Khan and Thomas (2007) in modelling inventory order costs as being stochastic.

[9] 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., $\underline{B} << 0$.

The consumer takes prices and profits as given and maximizes (2) by choosing a series labor supply, retail purchases, investment, and Arrow securities subject to (3), (4) and (5).

The maximization can be solved step-wise, with the consumer choosing an allocation of retail purchases $y_H(j,\eta^t)$ and $y_F(j,\eta^t)$ to minimize the cost of producing a given level of final output, $Y(t)$. The cost minimizing first-order conditions define the demand for retail varieties:

$$
\begin{aligned}
y_H(z,\eta^t) &= v_H\left(z,\eta^t\right)\left(\frac{p_H(z,\eta^t)}{P_H(\eta^t)}\right)^{-\theta}\left(\frac{P_H\left(\eta^t\right)}{P\left(\eta^t\right)}\right)^{-\gamma} Y\left(\eta^t\right) \\
(6) \qquad y_F\left(z,\eta^t\right) &= v_F\left(z,\eta^t\right)\tau\left(\frac{p_F(z,\eta^t)}{P_F(\eta^t)}\right)^{-\theta}\left(\frac{P_F\left(\eta^t\right)}{P\left(\eta^t\right)}\right)^{-\gamma} Y\left(\eta^t\right)
\end{aligned}
$$

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

$$
\begin{aligned}
(7) \qquad P_H\left(\eta^t\right) &= \left(\int_0^1 v_H\left(z,\eta^t\right) p_H\left(z,\eta^t\right)^{1-\theta}\right)^{\frac{1}{1-\theta}} \\
(8) \qquad P_F\left(\eta^t\right) &= \left(\int_0^1 v_F\left(z,\eta^t\right) p_F\left(z,\eta^t\right)^{1-\theta}\right)^{\frac{1}{1-\theta}} \\
(9) \qquad P\left(\eta^t\right) &= \left[P_H\left(\eta^t\right)^{1-\gamma} + \tau P_F\left(\eta^t\right)^{1-\gamma}\right]^{\frac{1}{1-\gamma}}
\end{aligned}
$$

Producers

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

$$
(10) \quad m_H\left(j,\eta^t\right) = A\left(\eta^t\right) l\left(j,\eta^t\right)
$$

where $m_H\left(j,\eta^t\right)$ are the output of intermediate j, $l\left(j,\eta^t\right)$ is labor inputs into $j's$ production, and $A\left(\eta^t\right)$ is the aggregate productivity shock. The analogous production function with country-specific productivity $A^*(\eta^t)$ exists for Foreign-produced intermediates, $m_F(j,\eta^t)$. Productivity, $\mathbf{A}(\eta^t)$, defined as the vector of the country-specific productivities, evolves according to:

$$\log \mathbf{A}\left(\eta^t\right) = \boldsymbol{\rho}\mathbf{A}\left(\eta^{t-1}\right) + \boldsymbol{\varepsilon}_t$$

Producers are completely competitive in that they choose capital and labor in order to maximize their profits, given the intermediate price $\omega(\eta^t)$ and wage $W(\eta^t)$. Free entry ensures that the intermediate price equals the minimum unit cost of production:

$$(11) \quad \omega\left(\eta^t\right) = \frac{W(\eta^t)}{A(\eta^t)}$$

Retailers

In Home there is a measure one continuum of retailers selling goods that were produced in Home, and another measure one continuum of retailers selling goods that were produced in Foreign. Retailers purchase intermediates from producers and sell them as retail goods to consumers. For a Home retailer of good j produced in Home, retail sales are again denoted $y_H(j,\eta^t)$, while purchases are denoted $z_H(j,\eta^t)$. We focus on this case, but the analogs apply for retailers of the Foreign produced good, and for for Foreign retailers of Home and Foreign-produced goods. (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.)

Retailers can hold inventories $s_H(\eta^t)$, with the initial level of inventories $s_H(\eta^0) > 0$ for each retailer given. Retailers face several technological constraints, however:

1. Purchases must be non-negative, $z_H(j,\eta^t) \geq 0$,
2. Any positive purchase $(z_H(j,\eta^t) \geq 0)$ requires a fixed amount ϕ^d of local labor.

3. With probability μ^d, purchases made at date t arrive in $t+1$ (otherwise they arrive immediately), and
4. Retailers can only sell goods on hand.

The assumption of random arrivals is intended to capture some of the uncertainty in the lags between orders and delivery that retailers face, but more importantly, it will allow us to flexibly vary the average length of these lags by varying μ^d. Note the lag structure is meant to capture the time between production and final consumption that take place as goods move from manufacturer to wholesaler to retailer to end user. We define ξ_t to be the random variable that takes a value of 1 if orders arrive immediately. We define a partition of the state as $\eta^t = \left\{\tilde{\eta}^t, \xi^t\right\}$, since the realization of ξ_t is known before prices are set, but not until after inventories are ordered. Thus, orders $z_H\left(j, \tilde{\eta}^t, \xi^{t-1}\right)$ are independent of the current ξ_t, while the price that retailers charge $p_H\left(j, \eta^t\right)$ can depend on the current ξ_t. Retailers choose these prices given consumer demand in equation (6). They take the intermediate price $\omega\left(\eta^t\right)$ and wage $W(\eta^t)$ as given. The problem of a home retailer selling home produced goods is therefore:

$$\max_{z_H\left(j,\tilde{\eta}^t,\xi^{t-1}\right),p_H(\eta^t)} \sum_{t=0}^{\infty}\sum_{\eta^t} Q\left(\eta^t\right)\left[\mu^d p_H\left(j,\eta^t,0\right) y_H\left(j,\eta^t,0\right) + \left(1-\mu^d\right) p_H\left(j,\eta^t,1\right) y_H\left(j,\eta^t,1\right)\right.$$

$$\left. -\omega\left(\eta^t\right) z_H\left(j,\eta^t\right) - W\left(\eta^t\right)\phi^d \times 1_{z_H\left(j,\tilde{\eta}^t,\xi^{t-1}\right)>0}\right]$$

$$s.t.\;\; y_H\left(j,\eta^t\right) = \min\left[\begin{array}{c} v_H\left(j,\eta^t\right)\left(\frac{p_H(j,\eta^t,1)}{P^H(\eta^t)}\right)^{-\theta}\left(\frac{P^H\left(\eta^t\right)}{P(\eta^t)}\right)^{-\gamma} Y\left(\eta^t\right), \\ s_H\left(j,\eta^t\right) + \xi_t z_H\left(j,\tilde{\eta}^t,\xi^{t-1}\right)\end{array}\right]$$

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

$$z_H\left(j,\eta^t\right) \geq 0$$

Future profits are valued using $Q\left(\eta^t\right)$, the Arrow-Debreu price in period 0 of a security paying one unit in state η^t. (In equilibrium, $Q(\eta^t) = Q(\eta^t|\eta^{t-1}) Q(\eta^{t-1}|\eta^{t-2}) ... Q(\eta^1|\eta^0) = \beta^t \frac{U_c(\eta^t)/P(\eta^t)}{U_c(\eta^0)/P(\eta^0)}$.) Also, note that both beginning-of-period inventories and orders depreciate at a rate δ_s.

Retailers of imported materials (e.g., Home retailers of Foreign-produced goods) face the analogous constraints, except that the fixed cost and probability of receiving orders are specific for importing, ϕ^{imp} and μ^{imp}, respectively. The constraints on Foreign retailers are completely symmetric.

B. Equilibrium

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

- Given prices, the allocations satisfy the consumers' problems, the intermediate producers' problems, and retailers' problems in Home and Foreign; and
- The retail goods, labor, and capital markets clear in each country, and the intermediate goods markets and Arrow security markets clear for the world economy.

Two market clearing conditions deserve comment; First, Arrow securities are in zero net supply, so the market clearing constraint is $B(\eta^t) + B^*(\eta^t) = 0$. Second, labor demand includes both labor used in the production of intermediates as well as that used by retailers in purchasing, i.e., $\int \left[l(j,\eta^t) + \phi^d \times 1_{z_H\left(j,\tilde{\eta}^t,\xi^{t-1}\right)>0} + \phi^i \times 1_{z_F\left(j,\tilde{\eta}^t,\xi^{t-1}\right)>0}\right] dj = L(\eta^t)$.

4. Parameterization

We now describe the functional forms and parameter values considered for our benchmark economy. The parameter values are used in the simulation exercises are reported in

Table 3. The instantaneous utility function is given as $U(C, 1-L) = \log(C) + \psi \log(1-L)$. Our calibration involves several parameters that are relatively standard in the international real business cycle literature, and so we can assign typical values. These parameters include the preference parameters $\{\psi, \gamma, \tau, \beta\}$ and technology parameters $\{\delta_s, \alpha\}$. We choose ψ, the relative weight on leisure in the utility function in order to match a labor supply of 1/3. We assign the elasticity of substitution between domestic and imported goods $\gamma = 1.5$, a standard value. We choose the relative utility of imported varieties $\tau = 0.19$ in order to match a share of imports in GDP of 15 percent.[10] In order to facilitate comparison with available data, we model a period to be a quarter. We therefore assign a discount factor of $\beta = 0.99$. We assign the depreciation rate on inventories using various estimates of annual non-interest inventory carrying costs range[11]. These range from 19 to 43 percent of a firm's inventories, which implies quarterly carrying costs ranging from 4.5 to 11 percent.[12] Our assigned value of $\delta_s = 0.075$ is in the mid-range of these estimates.

We have several other parameters, $\left\{\theta, \sigma_v, \mu^d, \mu^{imp}, \phi^d, \phi^{imp}\right\}$ that are particular to our inventory/retailing set-up. We start by assigning $\theta = 3$, which yields a typical markup of 50 percent over replacement cost of a unit over inventory, though a smaller markup over total retailing costs. The standard deviation of demand shocks σ_v is set at 0.8. [13]

What is key for our study of the dynamics of trade is the different characteristics of imported and domestic inputs, particularly the lags and fixed costs. Given our focus on these differences, we let $\mu^{imp} = 1$, so that imported goods arrive with a one-quarter lag. It is common to have a such a lag on inventories in the closed economy inventory literature (see Christiano, 1988). We then calibrate the delay on domestic goods μ^d, the fixed cost of

[10] This parameter must be jointly chosen with the inventory and retailing parameters, since these parameters affect the relative retail costs (and prices) of imported and domestic goods.

[11] These include taxes, warehousing, physical handling, obsolescence, pilfering, insurance, and clerical controls.

[12] See, e.g., Richardson (1995).

[13] The shocks generate heterogeneity across firms which helps to smooth out the aggregate response in a model with non-convexities. With the lag structure, they also generate a precautionary motive for inventories.

ordering domestic intermediates ϕ^d, and the fixed cost of ordering imports ϕ^{imp} so that the steady state in the model jointly matches three key moments in the data.

The first target is the aggregate inventory to (quarterly) sales ratio (for all firms in the U.S.) of 1.3. This matches both the average inventory-to-sales ratio[14] from the first quarter of 2002 (after the 2001 recession was completed) through third quarter of 2007 and the inventory-to-sales ratio in the third quarter of 2007. Thus, if we choose the level of productivity to match pre-crisis output, we also broadly match the pre-crisis level of inventories.

The second target is that importing firms hold twice the inventory (relative to sales) as firms that source domestically. This ratio is consistent with the best available evidence presented in AKM. Specifically, using a balanced panel of 1798 manufacturing plants over 12 years (1990 to 2001), regressions of inventory holdings on import content implied that a plant that sourced only internationally would hold twice the inventories of a plant that only sourced domestically.[15]

The resulting value for μ^d is 0.5. This implies an average delay of 1.5 months on domestic transactions and an additional 1.5 month delay on imported transactions. The six week additional delay for international trade compares well with the evidence presented on shipping by Hummels (2001) and customs/processing times in Djankov, Evans and Pham (2006). Consequently, the base 1.5 month delay on domestic purchases is somewhat lower than the one quarter delay often assumed in the inventory literature (see Christiano, 1988). The values for ϕ^d and ϕ^{imp} imply that fixed costs account for roughly 4.5 percent and 28.7 percent of mean revenues, respectively (of course since these costs are not incurred each

[14] **To be precise, we measure the inventory-sales ratio as the ratio of business inventories to manufacturing sales. This is roughly twice as large as the quarterly private inventory-sales level in the US. The difference in measures is due to our narrow focus on inventories of tradeable goods rather than the entire economy including education, healthcare, etc.**

[15] While these data are for Chile and not the U.S., AKM also confirmed a related pattern using a ten year time series (1997-2006) with over 16,000 intermediate purchase transaction for a U.S. steel producer. Regressions using these data implied that imported shipments were only half as common as domestic shipments but were 50 percent larger.

period they are a lower fraction of total revenues). Our calibration targets and additional implications of the model are summarized in Table 4.

A. Policy Rules

Given our parameterization, we can now discuss the policy rules of our retailers (focusing on the stationary distribution with no aggregate uncertainty[16]). We start by noting that the retailers' problem can be written recursively. We therefore drop the time and state notation from variables and note that in a steady state, the ordering decision is only a function of the current values of inventory s_H and the taste/demand shock ν_H, while the pricing decision is a function of (s_H, ν_H), and the delivery shock, ξ_H.

Figure 8 plots the ordering policy of retailers selling domestic and foreign goods for a given demand shock. Clearly, the presence of fixed costs creates a region of inaction and adjustment region that depends on (s, v). An importer only orders when its inventory level is below some given level, and below this threshold the amount ordered does not depend on the current inventory level because the firm sells all of its current inventory to its customers..Compared to an importer, a retailer selling domestically-produced goods has a higher threshold to reorder, but the amount ordered is much smaller. Moreover, because goods may arrive in the current period, the amount ordered now is decreasing in the current inventory level. The relatively large frictions of ordering internationally create a wider band of inaction leading to larger inventory holdings on average and less frequent transactions.

Figure 9 plots the pricing policy as a function of inventory holdings for the same idiosyncratic demand shock. Focusing first on the pricing policy of an importer, there are two regions divided by the order threshold. For inventory holdings below the order threshold, the importer stocks out and so the price is set to absorb its total inventory. Above the order

[16] Given that idiosyncratic uncertainty is an order of magnitude greater than aggregate uncertainty, we expect these steady state decision rules to be a good approximation of those with aggregate uncertainty. Of course, our solution method allows for these rules to be state-dependent.

threshold, the firm charges a price equal to a markup of $\frac{\theta}{\theta-1}$ over the marginal value of an additional inventory. Thus in this region the price charged is falling in inventory holdings. The pricing policy of a domestic firm depends on whether or not its ordered inputs have arrived. If the products have not arrived, the rationale for two pricing regions will be similar to that described for the importer. On the other hand, if the products have arrived then the firm will not stockout and will be charging a price equal to a markup over the marginal value of an additional inventory. Its price will be very much like the price of a firm that has substantial inventory and has not decided to order this period.

5. Experiments

In this section, we quantitatively evaluate the role of inventory holdings on aggregate trade dynamics. To isolate the role of inventory holdings we compare the impulse response dynamics for our benchmark inventory economy to an alternative economy without inventories. The no inventory economy uses the identical model and parameter values, except that we eliminate the fixed cost and delivery delay frictions. That is, we assign $\phi^d = \phi^i = 0$ and $\mu^d = \mu^i = 0$, so that retailers do not hold inventories in equilibrium. Comparing these models provides an estimate of the role of inventory holdings in the propagation of aggregate shocks.

We consider three experiments designed to give insight into key aspects of the economic crisis: (i) a persistent negative productivity shock to the Home country, which illuminates the international propagation of country-specific shocks; (ii) a persistent negative productivity shock to both countries, designed to capture the global decline in economic activity; and (ii) a positive shock to the depreciation rate δ_s, designed to capture the increase in carrying costs due to an increase in interest rates.

Modeling the global crisis as a productivity shock is intended simply as a shortcut designed to capture the aggregate effect of the financial crisis in the US and the rest of the world. For our purposes, since we are mainly concerned with the effect of a downturn on trade flows, we expect alternative shocks that reduce economic activity to have similar effects on trade flows. Nonetheless, in the most microfounded models of disaggregated plants/firms and borrowing constraints (e.g., Buera and Moll, 2009, Buera and Shin, 2008, Buera, Kaboski, and Shin, 2009, Khan and Thomas, 2009, Midrigan and Xu, 2009, and Moll, 2009), financial frictions show up primarily as aggregate productivity shock by distorting the allocation of resources across firms with different productivities/marginal products. Hence, in terms of considering a simple aggregate shock, a productivity shock may well be the most appropriate.

In any case, the results for all three shocks show large decreases in trade and short run adjustments in inventory-to-sales ratios, and indeed the common technology shocks yields impulses of similar magnitude to those observed empirically in Section 2 for the recent recession.

A. Home productivity shock

The technology shock we consider is a persistent decline of A of 0.05 percent, with an AR coefficient of 0.75. Considering the no-inventory model, the top panels of Figure 10 shows that the impact of this shock on Home's consumption is somewhat less than five percent, since there is perfect risk sharing and the shock is specific to Home. Foreign consumption also falls by less than 1 percent. The dynamics of the economy then fade out with the shock.

The impulse response of the model with inventories differs substantially from the model without inventories. With inventories, the largest decline in consumption at occurs in the second period. With inventories, the available stock of inventories for consumption dampens the effect of the shock on impact. Two quarters out, however, the impact is substantially larger in the model with inventories, and this continues for several years. By four years out, the effect of the shocks are essentially gone, however. Comparing the upper left and right panels in Figure 10, we see that the shapes of the responses are similar in Home and Foreign. However, on impact Foreign actually experiences an *increase* in consumption before dropping in the later quarters. In these later quarters, the inventory model generates substantially larger drops in foreign consumption.

The lower panels of Figure 10 show the response of the price level in each country. On impact, the negative shock to Home's productivity increases prices in both countries. Given the bias toward domestic goods, this increase is substantially larger in Home. Thus, the real exchange rate of Home increases. The presence of inventories has little impact on prices in Home, but inventories greatly increase the volatility of the price level in Foreign, leading to a much smaller terms of trade effect than without inventories.

Figure 11 shows the impulse responses for intermediate production (top panels) and imports (lower panels). In Home, the negative productivity shock yields a drop in output, and the drop is more than twice as large in the model with inventories. In contrast, the shock leads to a (very small) production boom in Foreign, and this is because the risk-sharing arrangement leads to a drop in lifetime income in Foreign, which induces an increase in labor. Given the presence of inventories in Home, the effect on Home's production upon impact is about half as large in the model with inventories, however, and the peak lies two quarters out.

The bottom panels show the response of trade. Imports increase on impact in the Home country (given the risk-sharing arrangement). In Foreign, the shock has a negative effect on imports, and it is substantially larger since both the risk-sharing arrangement and the increase in Home's terms of trade reinforce each other. In both countries, volatility is increased by the presence of inventories, however. This is particularly true in Foreign, where the drop in imports is three times as large with inventories than without. In sum, the relatively small increase in imports in Home (2.5 percent percentage points) and the much larger decrease in imports in Foreign (20 percentage points) lead to a drop in total trade that is fifty percent larger than the total drop in production in the upper panels. Again, these differences are short-lived, lasting between four and six quarters.

We analyze inventory dynamics in Figure 12 by presenting the impulse responses of retail sales and the inventory-to-sales ratios in the calibration with inventories. The solid and dashed lines in Figure 12 now distinguish between retailers of imported and domestic goods, respectively. Focusing on the upper panels, it is clear that the shock has big effects on the consumption bundle in both countries, inducing fewer sales of Home goods. The drop in sales of Home goods is substantially larger in Foreign, however, since the Foreign retailers of Home produced goods have a larger stock of inventory than Home retailers of Home goods. The lower panels show the response of the inventory-to-sales ratios, which look similar in both countries. Namely, given the drop in sales, the inventory-to-sales ratio of Home's goods increases substantially on impact. Then in their adjustment downward they overshoot in the second quarter before returning to their steady state values within about 15 quarters.

B. Global productivity shock

The boom in Foreign that occurs from a technology shock in Home appears counterfactual in reference to the global economic crisis, where the drop in output has been synchronized across many countries. To capture this global drop in output, we therefore shock both Home and Foreign with the same negative technology shock with which we shocked Home in the previous subsection. Clearly, the common shock yields perfect comovement in all variables across Home and Foreign, since the countries are symmetric.

Figure 13 shows that the shock now induces a drop in consumption and an increase in the price level of five percent. The drop in consumption now occurs in both countries. Again, the presence of inventories yields a delayed response in consumption.

Figure 14 shows that in our benchmark model the drop in production is more than twice as large as the drop in consumption. The drop in production is also more than twice as large in the model with inventories than in the model without. (In the model without inventories, given the absence of capital, the drop in consumption exactly equals the drop in production.) Thus, inventories greatly increase the volatility of production in response to a shock.

Can this model with inventory models produce movements in output, trade and inventories that are quantitatively similar to those observed in the recent crisis? The magnitudes of the drop in production and imports (12 and 16 percent, respectively) are of comparable magnitude to those in the data of Figure 2 (almost 15 percent and 20-25 percent). Moreover, the model generates 2 to 3 percent increase in the inventory-to-sales ratio compared to about 5 percent in the data. The model also generates a 3 to 4 percent drop in sales, compared to about a 5 to 6 percent decline in the data.

Again, focusing on the model with inventories, the upper panel Figure 15 shows a deeper and more prolonged drop in sales for imported retail goods relative to domestic goods. Nonetheless, the lower panel shows *less* volatility in the inventory-to-sales ratio for imported goods.

C. Shock to Inventory Carrying Costs

A key feature of the current downturn has been substantial stress at financial firms. Some have argued that this has reduced the financing that is available for firms involved in trade. Here we explore this avenue by considering a persistent increase in the carrying costs of inventories. Such a shock will affect importers and domestic firms, but have a larger effect on importers, since they hold more inventory on average. We models this as a persistent (again, AR coefficient of 0.75) increase in δ_s from 7.5 percent to 10 percent, which we can interpret as a 2.5 percentage point increase in the 3-month interest rate (or 10 percentage point increase at an annual level). This shock is effectively a negative productivity shock for retailers.

Figure 16 shows that consumption actually increases on impact, since pass-through of the higher inventory carrying costs is slow, as firms keep prices lower in the short-term to rid themselves of excess inventory that have become more costly to hold. Later these higher costs lead to a decline in consumption. The eventual drop in consumption is only about one-fifth of that observed in response to the common technology shock of the previous section, however. Although it is larger than the model without inventories, where there is obviously no effect.

The effect on domestic production and imports is shown in Figure 17. Production of intermediates drops by just less than 2.5 percent on impact before later overshooting above the steady state after a few quarters. Production essentially returns to the steady state within fifteen quarters. In the lower panel, imports show a similar qualitative pattern. The change in imports is somewhat larger, however, and yet imports have effectively returned to their steady state after only nine quarters. Again, these effects are less than a fifth of those in response to the common technology shocks.

Clearly the effect of carrying costs has important effects on sales and inventory-to-sales ratios. We examine this in Figure 18. Again, as mentioned earlier, sales of both imported and domestic goods increase on impact, as firms shed excess inventories. After two quarters, however, sales drop below steady state, particularly for imported goods. These sales reach their nadir at one year before returning to their steady state about five years out. Given the increase in sales on impact, inventory-to-sales ratios in the lower panel fall and continue to fall over the first year. Quantitatively, the impacts on sales and inventory-to-sales ratios are relatively large with the shock to carrying costs, and the relative impact on imports is also larger. For example, for imported goods these impacts are roughly half as large as the impacts in response to the common technology shock, while the impacts on consumption, prices, production and imports were only about one-fifth as large in response to the shock to carrying costs.

In summary, quantitatively, we find the impacts of this shock to be substantially smaller than the technology shocks overall, but qualitatively many of the effects of technology shocks are reinforced, though not all. Shocks to carrying costs cause immediate increases in sales and slower growth in prices as desired inventory levels decline immediately.

6. Conclusion

This paper examines the role of inventory dynamics and international trade empirically and theoretically, especially with regards to the dramatic drop in trade of the most recent recession. Empirically, we show that trade is more volatile than either measures of trade-weighted production or demand, and that inventory dynamics play an important role in this volatility. However, we also find that trade dynamics in this current recession are not unusual. What is unusual is the magnitude and synchronization of the downturn.

The role of inventories are most clearly evident for trade in autos, a good for which we can separately measure retail sales of imported autos and imports. Indeed, for autos we see that imports of autos fell off a cliff in December 2008 even as final sales of autos recovered somewhat. The gap between sales and imports can be explained in part because inventory levels had become quite large relative to the rate of sales. Given that auto trade fell the soonest and the most in this recession, we believe any explanation of the decline in aggregate trade must be able to explain these dynamics.

To study these issues for the aggregate economy, we embed an sS model of inventory adjustment and trade in a two country general equilibrium model, where inventory holdings differ for domestic and imported products because of larger frictions to international trade. We then use the quantitative theory to show that the relatively high elasticity of trade over the business cycle may arise from inventory considerations.

To explain the current synchronized global decline in trade, our model requires a global negative shock. With such a shock, the model can generate drops in production and international trade and movements in inventory-to-sales ratios that are of comparable magnitude to those in the U.S. economy. We also explore the role of changes in financing costs on trade flows and find a relatively small impact of a rise in these costs on trade flows.

Indeed, it takes quite a large increase in financing costs, nearly 250 basis points on a three month loan, to generate one fifth of the drop in trade observed in the current downturn. From this we conclude that financing frictions have played a secondary role in the reduction in trade. Of course, if the availability of finance has fallen more for international trade, then the effects on trade will be larger. Also, financing frictions may still matter for consumption decisions.

In summary, we find that inventory concerns may play an important role in the propagation of shocks across countries. It appears that the role of trade in the most recent recession has not been exceptional. Trade has been particularly important in past recessions. What has been exceptional is the size of the shock itself. Future research should consider the role of inventories in the propagation of international business cycles more generally.

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Table 1: Summary Statistics on US Business Cycles

	SD (relative to IP)	Corr with IP	Corr with Demand	Autocorrelation
Industrial Production (IP)	1.00	1.00	0.87	0.89
Exports	1.49	0.52	0.35	0.73
Imports	1.64	0.81	0.82	0.75
Demand	0.88	0.87	1.00	0.87
GDP	0.43	0.90	0.92	0.87
Inventory	0.50	0.67	0.60	0.90
IS Ratio	0.64	-0.70	-0.69	0.82

Notes: Based on quarterly data from 67:1 to 09:02. Data is HP filtered with a smoothing paramter of 1600.

Table 2: Peak drop in Trade relative to absorption

				IMPORTS				
	Median	1971Q1	1975Q2	1980Q3	1982Q4	1991Q1	2001Q4	2009Q2
Y	**4.66**	4.67	4.63	5.21	2.38	2.59	6.01	4.66
IP	**1.63**	1.15	1.64	2.41	1.18	1.54	1.97	1.63
Demand	**2.48**	2.61	2.48	2.89	2.47	1.59	5.74	1.72
				EXPORTS				
	Median	1971Q2	1975Q2	1980Q4	1982Q4	1990Q4	2002Q1	2009Q2
Y	**2.54**	2.54	1.51	0.22	3.52	1.80	7.07	3.93
IP	**1.38**	0.69	0.54	0.15	1.74	1.53	2.26	1.38
Demand	**1.45**	1.64	0.81	0.09	3.65	1.41	3.45	1.45
				EXPORTS (peak to trough)				
	Median	1971Q2	1975Q2	1980Q4	1982Q4	1990Q4	2002Q1	2009Q2
Y	**3.33**	3.33	2.43	1.61	3.52	1.80	7.07	4.69
IP	**1.53**	0.90	0.86	1.05	1.74	1.53	2.26	1.64
Demand	**1.74**	2.15	1.31	0.66	3.65	1.41	3.45	1.74
				INVENTORY-SALES Ratio				
IP	**-0.56**	-0.40	-0.77	-1.15	-0.56	-0.77	-0.13	-0.41

Notes: Measured from start of recession based on the NBER dates. The third panel measures the difference in exports between the peak and trough, where the peak is either the start of the recession if exports fall immediately. All data was HP filtered with a smoothing paramter or 1600, and so the drop is measured relative to the trend.

Table 3: Parameter Values

	Assigned Parameters	
γ	Armington elasticity of H vs. F	1.5
θ	elasticity across varieties in H & F	3
β	discount factor	0.99
δs	inventory depreciation	0.075
σ	std. dev. taste shocks	0.8
μ^f	probability orders arrive immediately foreign purchases	1
	Calibrated Parameters	
τ	Home bias	0.19
μ^d	probability orders arrive immediately domestic purchases	0.5
ϕ^d	fixed cost domestic orders (fraction mean revenue, %)	4.57
ϕ^i	fixed cost imports (fraction mean revenue, %)	28.71

Table 4: Moments

Used for Calibration:

	Data	Model
Aggregate Inventory-to-Sales ratio (all firms)	1.3	1.3
Ratio I/S imports to I/S domestic	2	2.07
Share imports in GDP	0.15	0.15
Ratio of frequency of domestic vs. imported orders	2	2

Other implications

I/S domestic retailers		1.13
I/S imported retailers		2.34
Frequency of orders, domestic		0.56
Frequency of orders, imports		0.28

Figure 1: Log Deviations from Trend in the Recent Recession

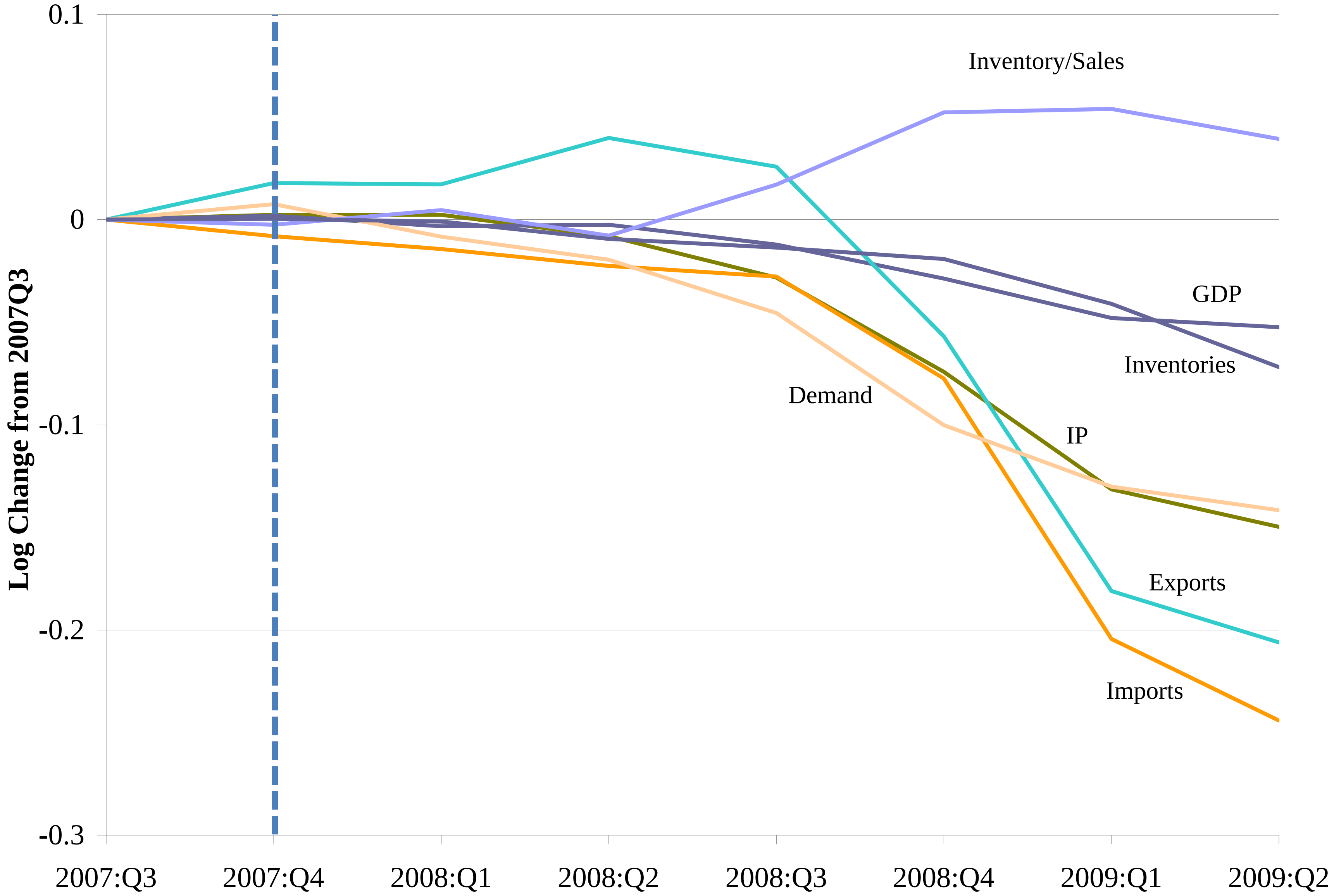


Figure 2A: US Real Imports (SA, $2005)

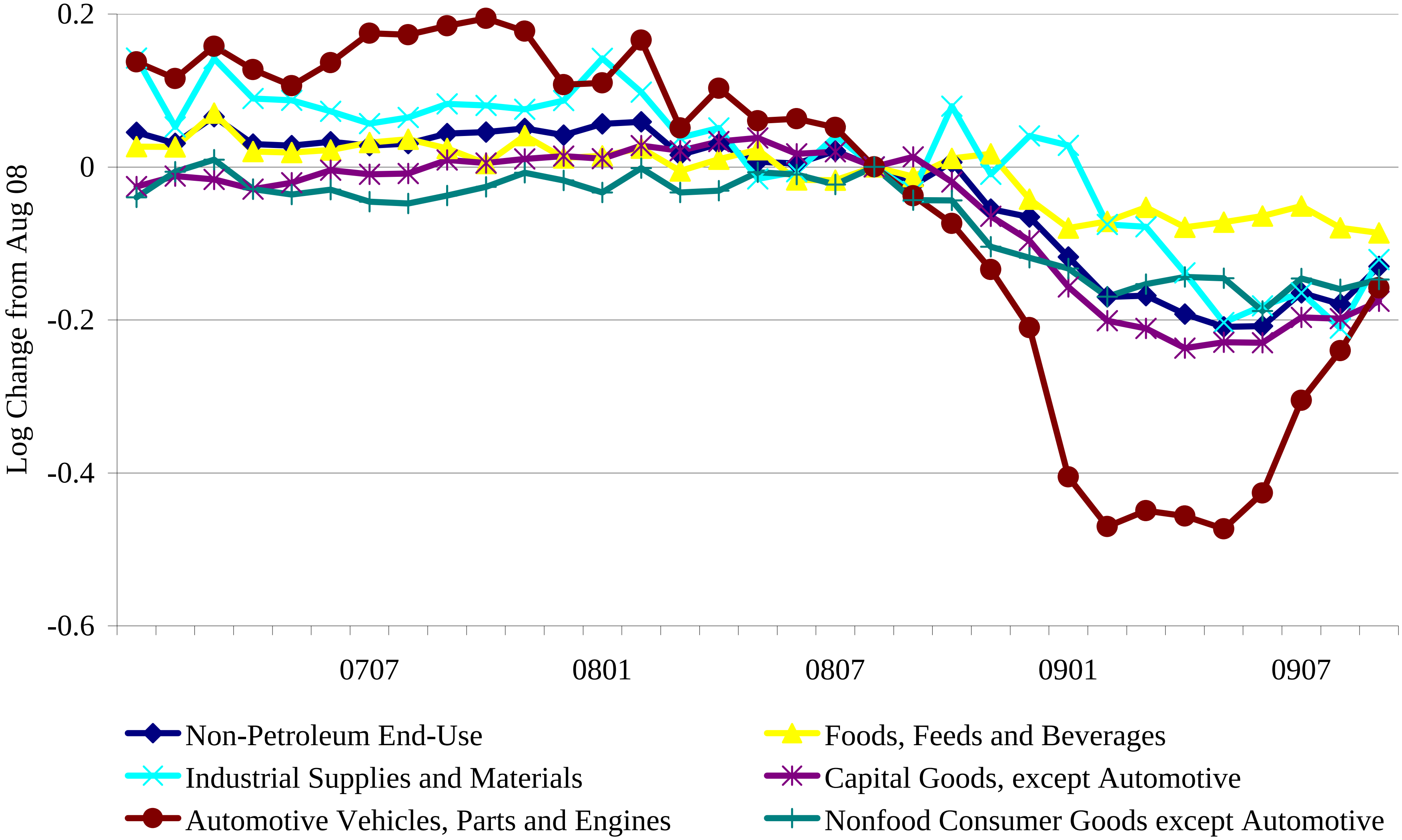


Figure 2B: US Real Exports (SA, $2005)

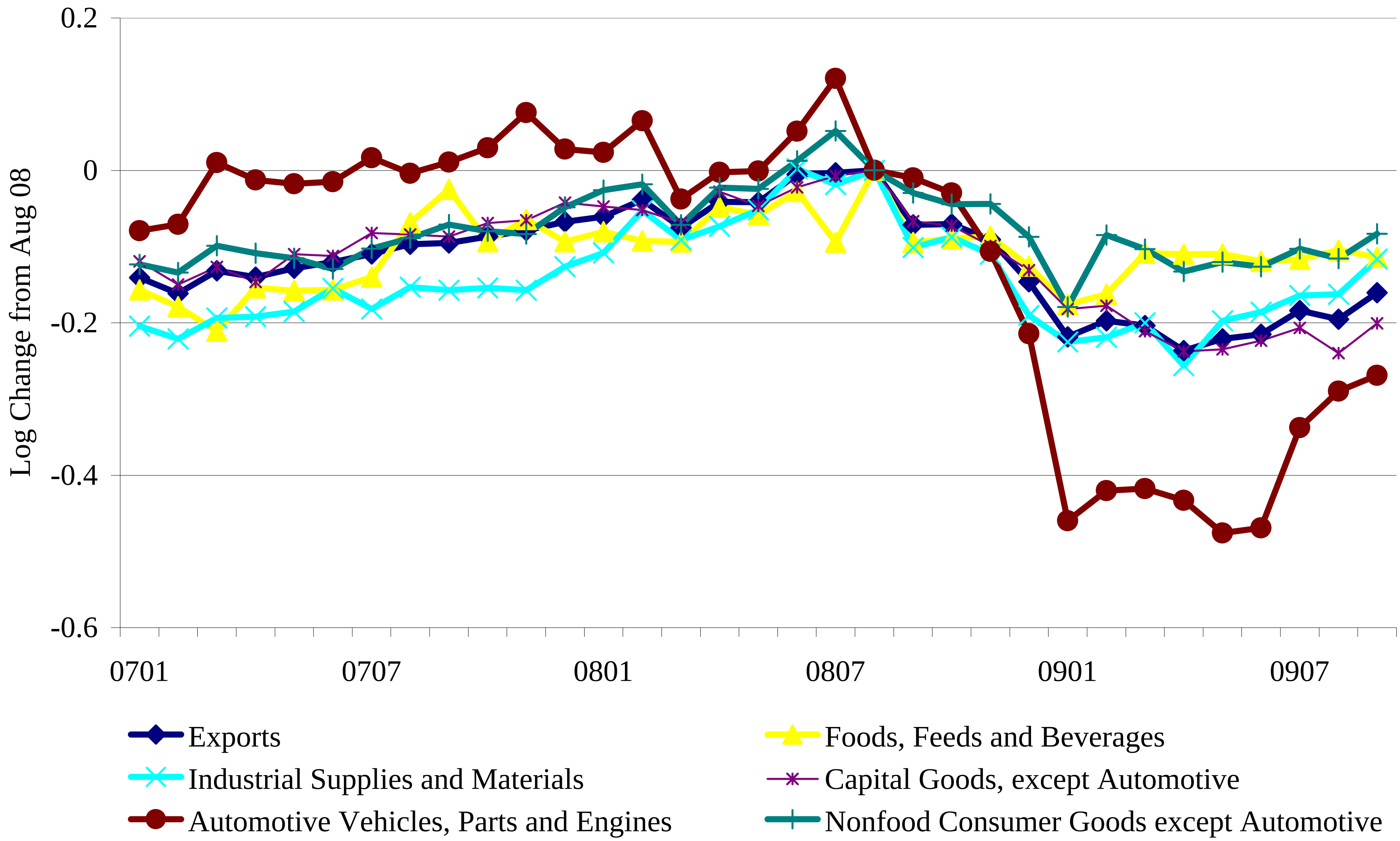


Figure 3: Dynamics of Imported Autos
Real Imports, Inventory, and Retail Sales

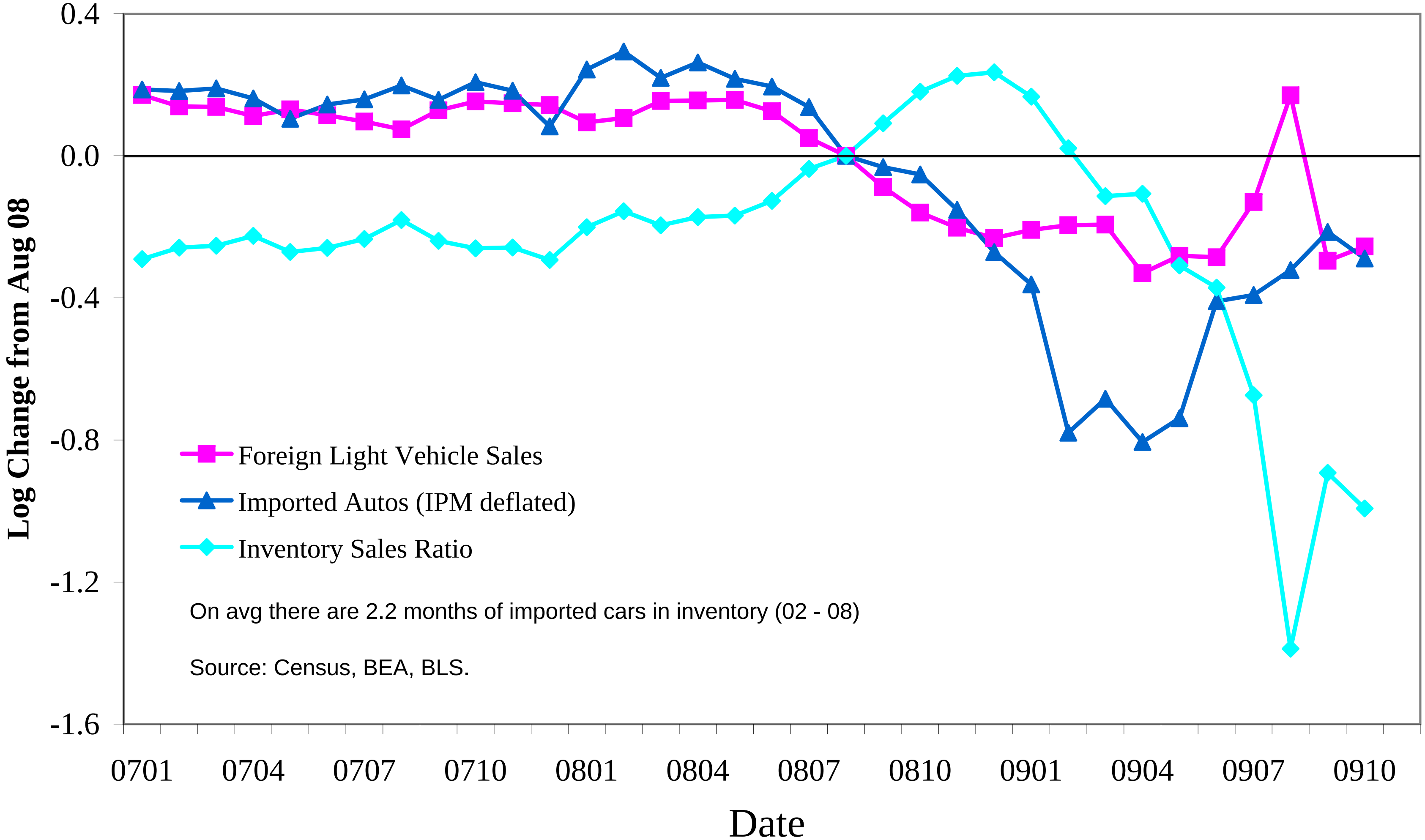


Figure 4: Imported Autos lagged sales collapse, lead recovery in 70s

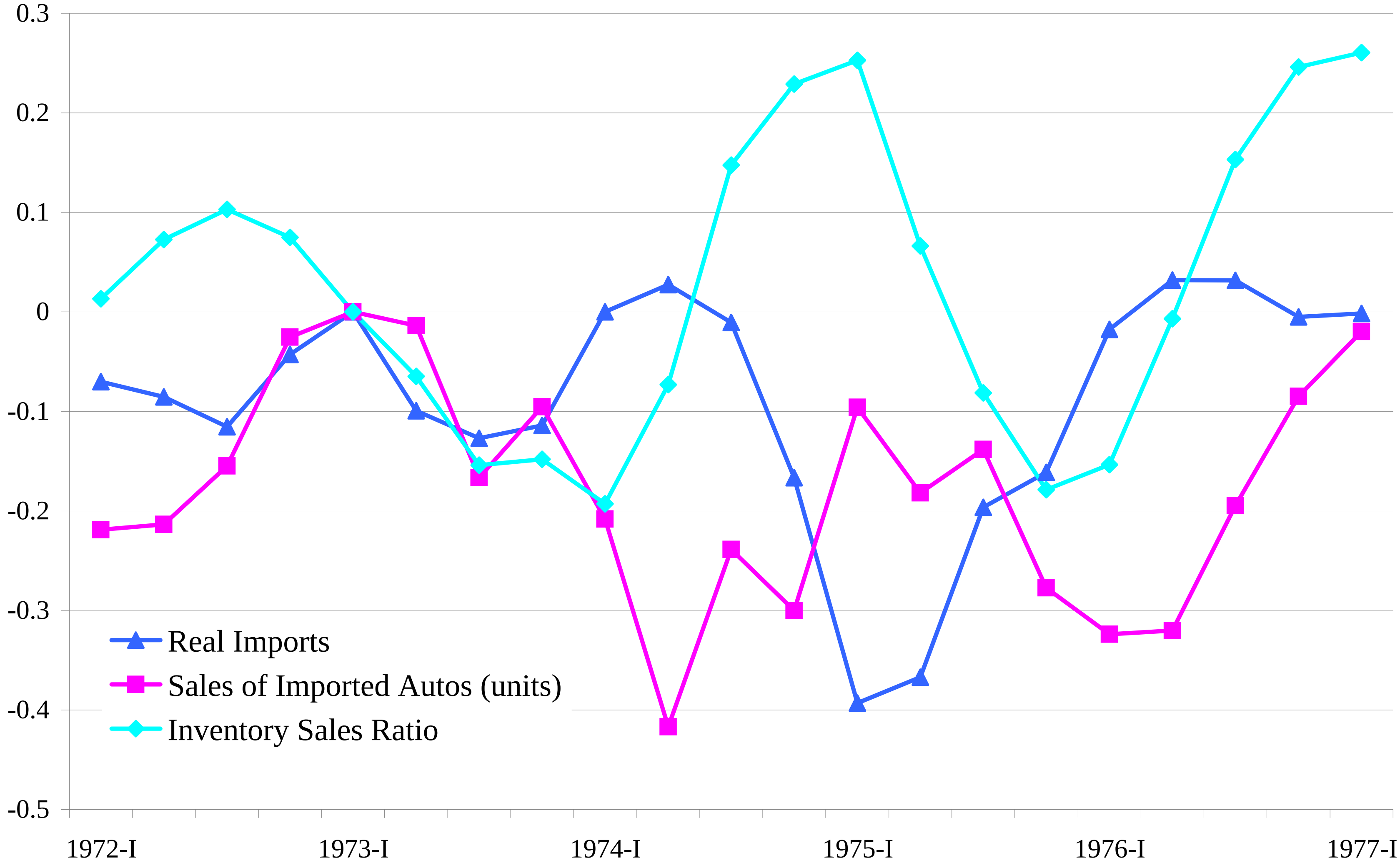


Figure 5: Capital Goods

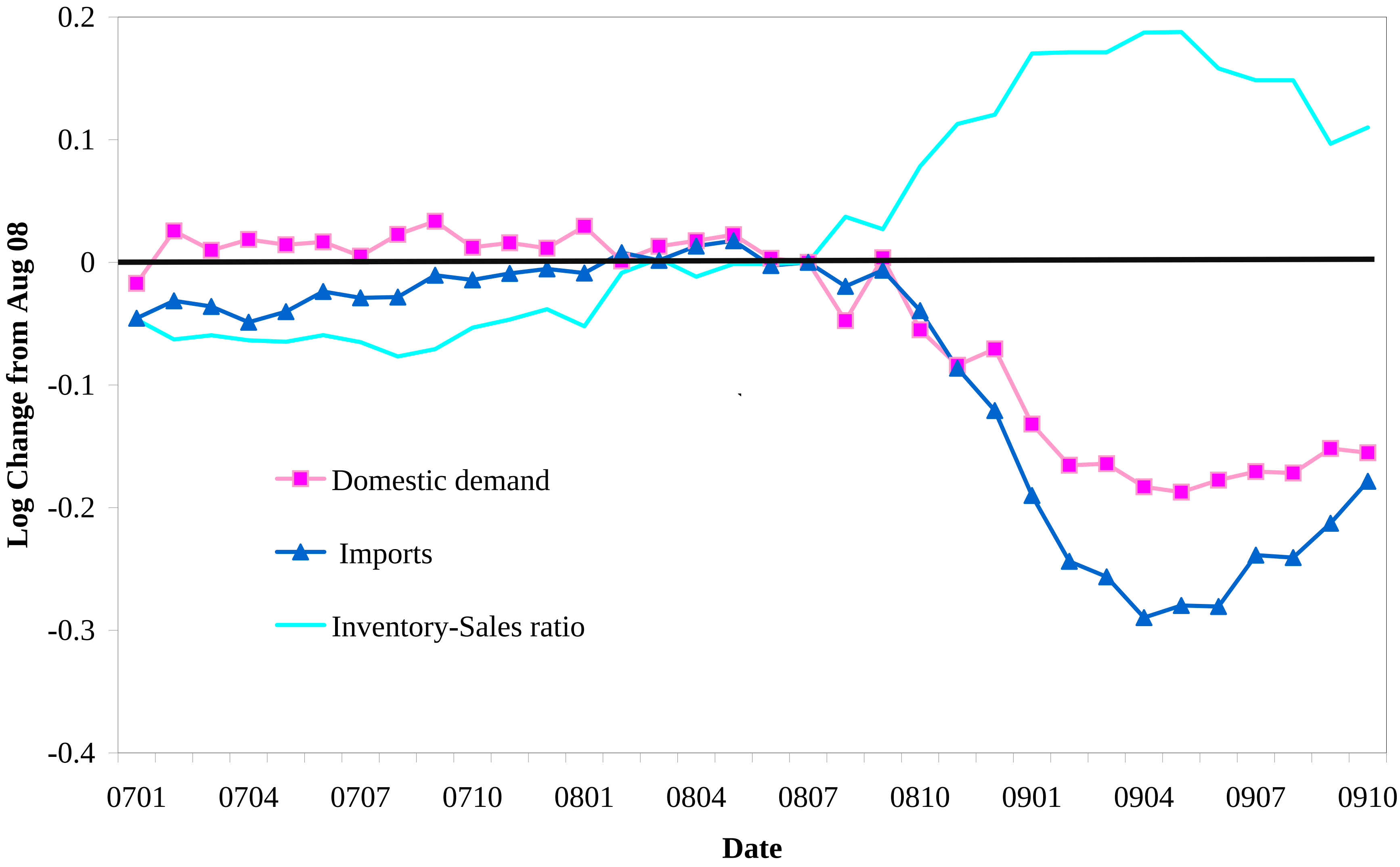


Figure 6: Consumer goods (non autos)

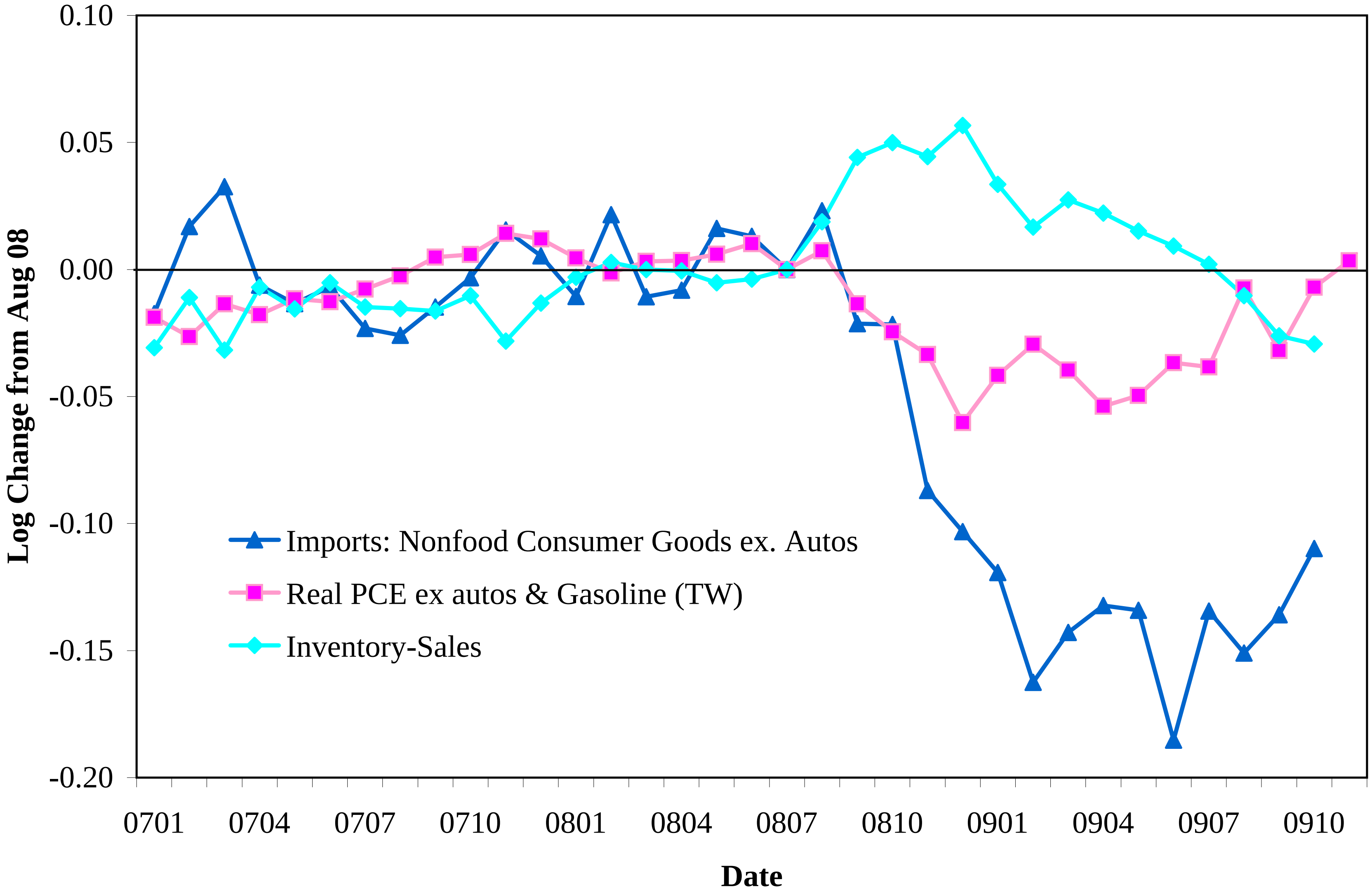


Figure 7: Aggregate Dynamics in Japanese downturns

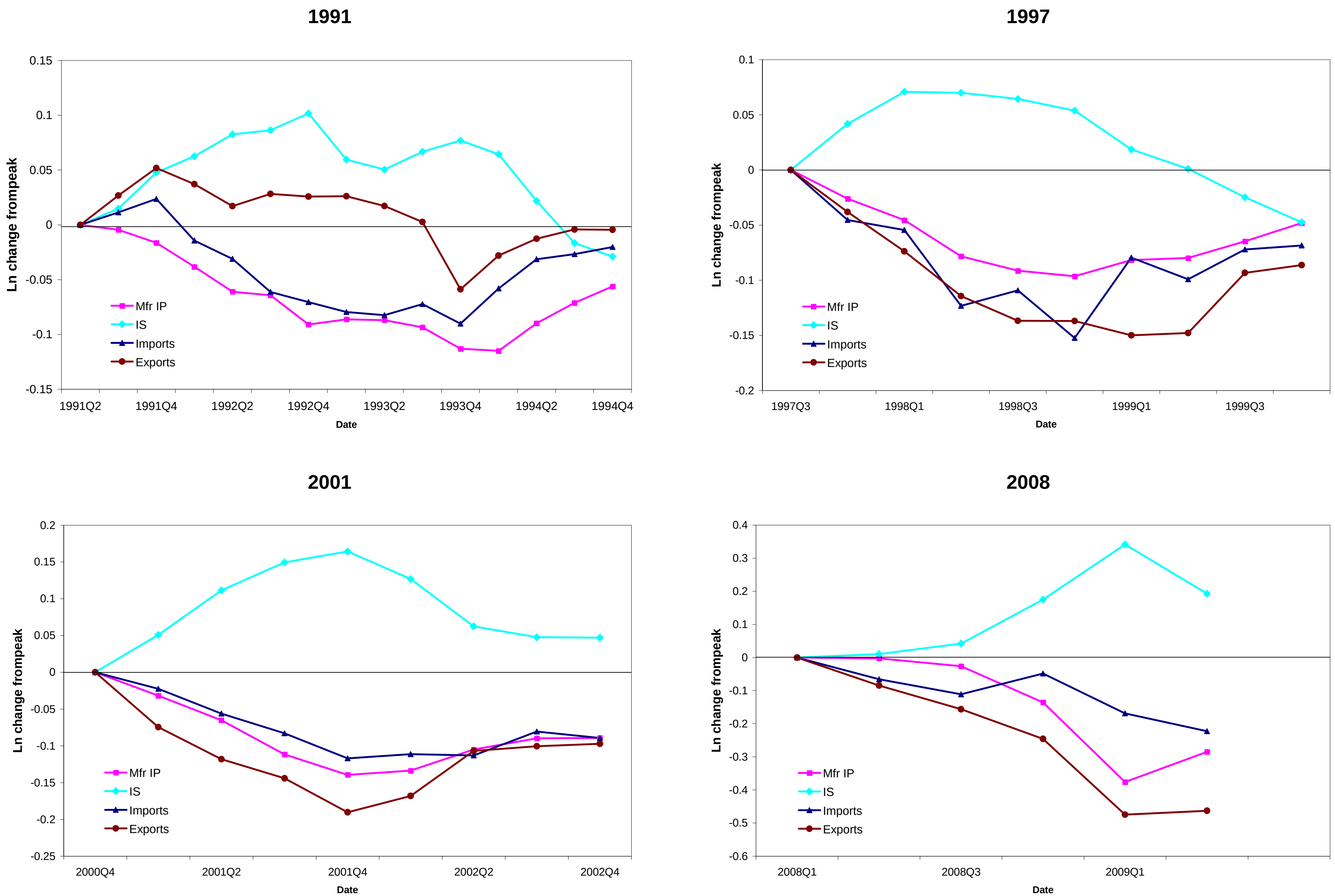


Figure 8: Policy Rules: Orders

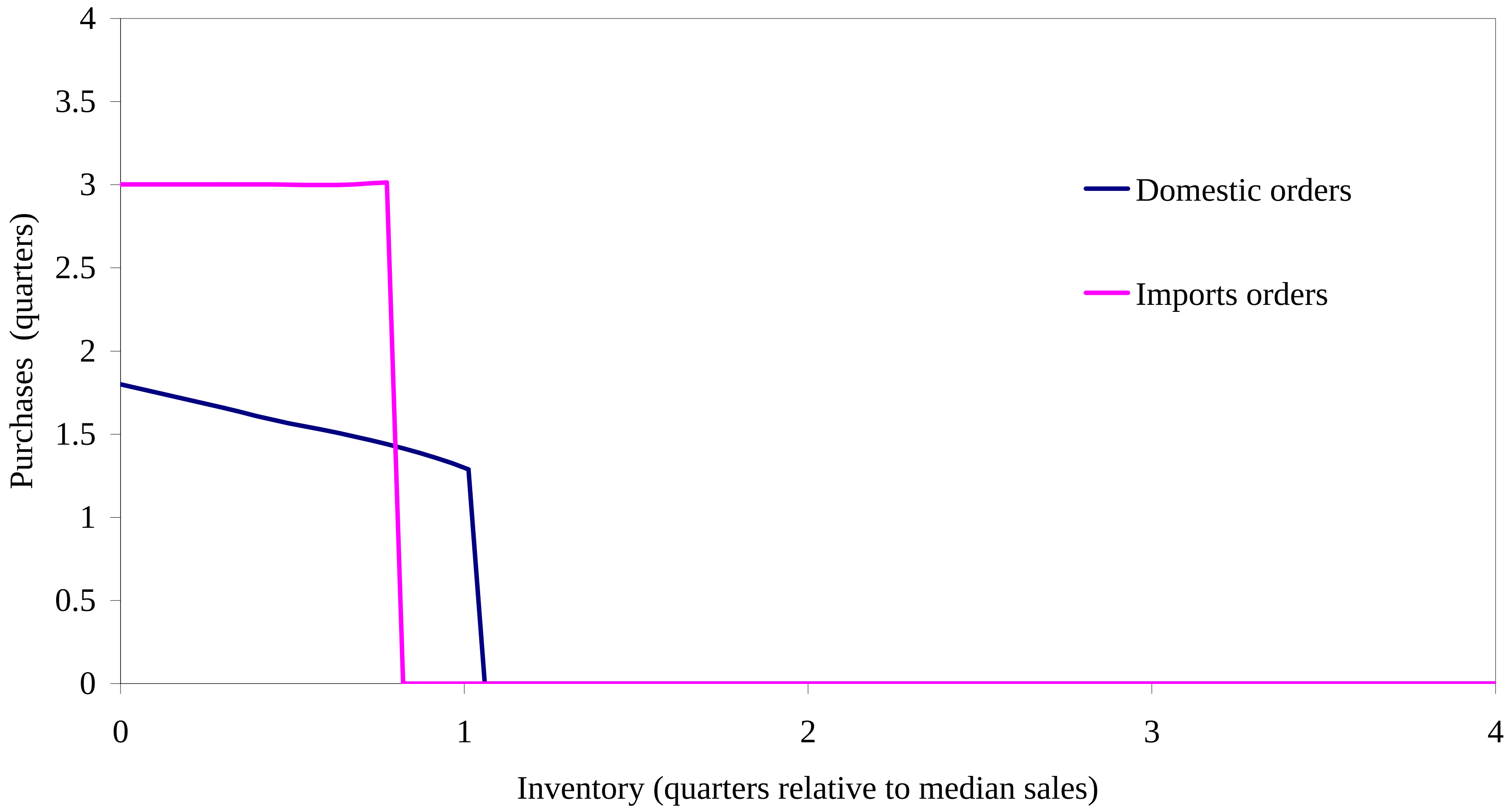


Figure 9: Policy Rules: Prices

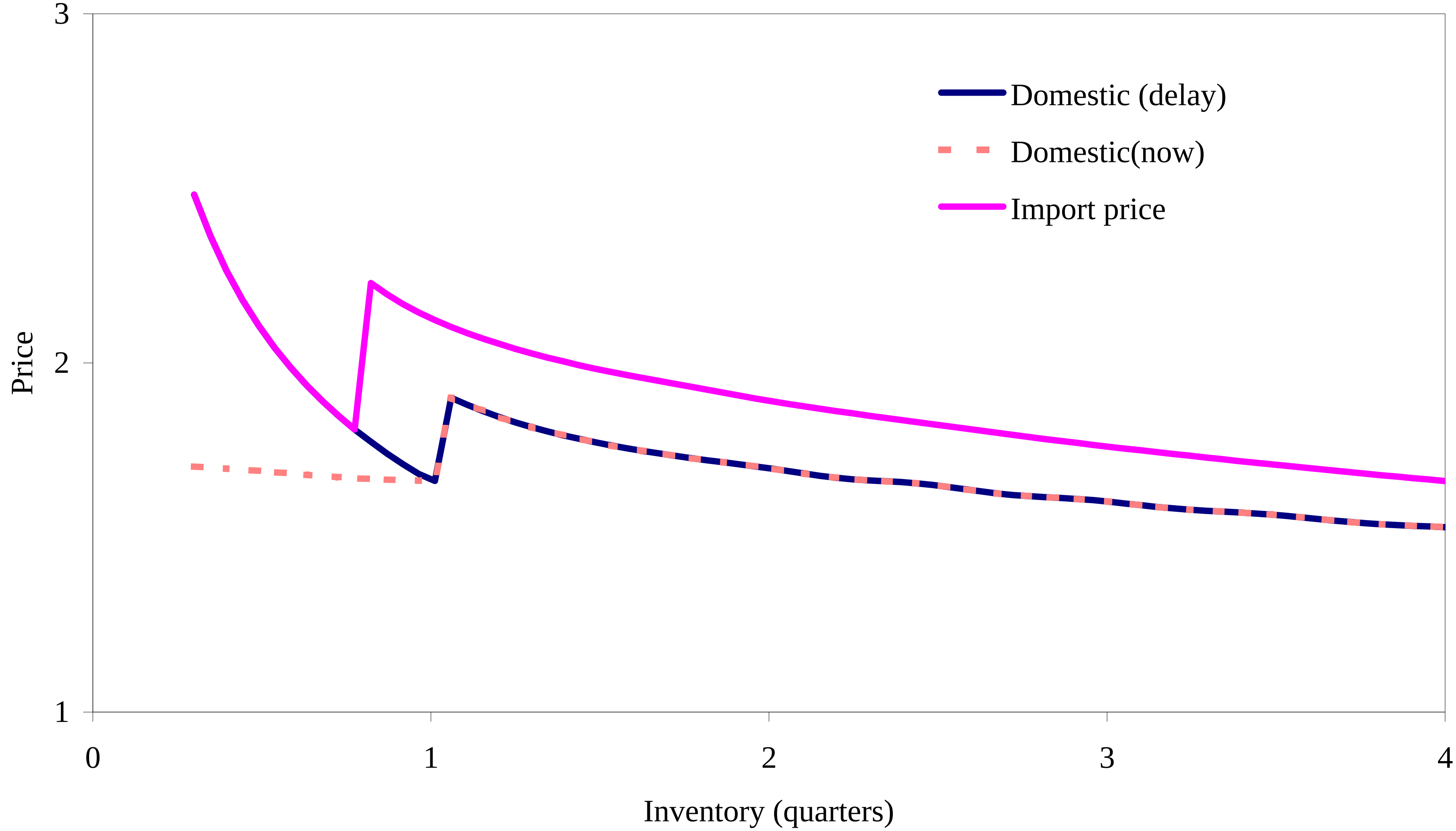


Figure 10: Impulse response to -0.05 Home Productivity Shock

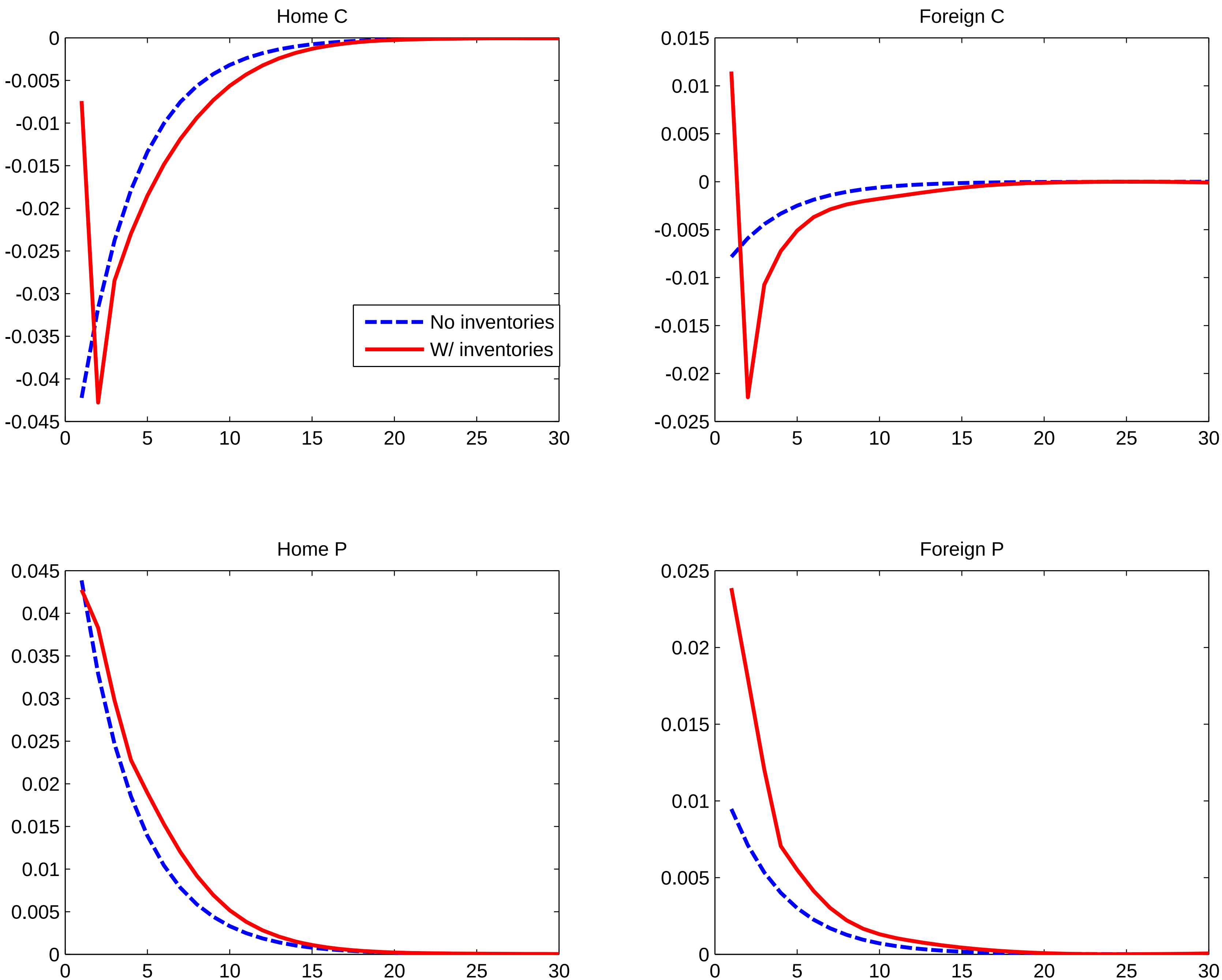


Figure 11: Impulse response to -0.05 Home Productivity Shock

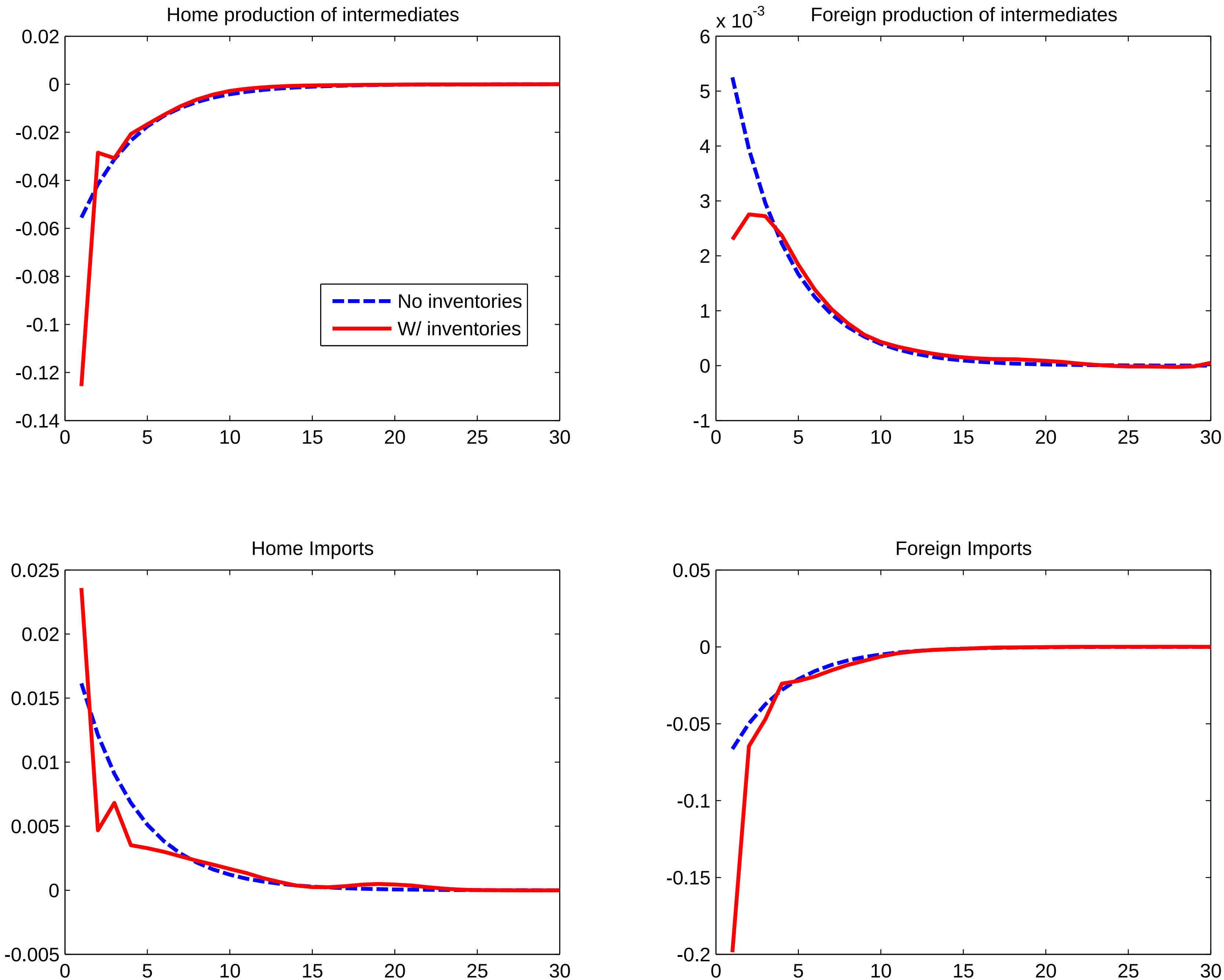


Figure 12: Impulse response to - 0.05 Home Productivity Shock

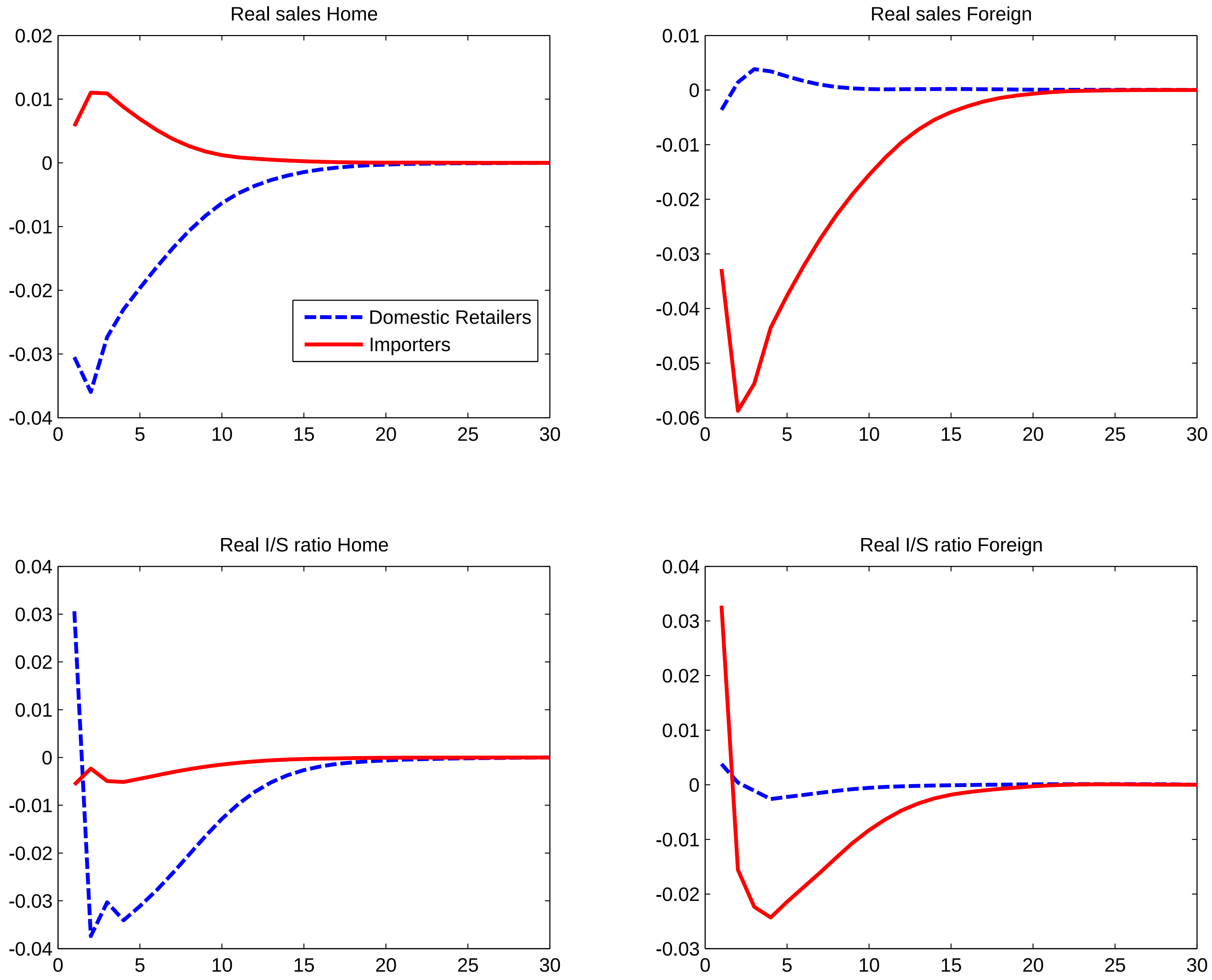


Figure 13: Impulse Response to -0.05 Productivity Shock in Home and Foreign

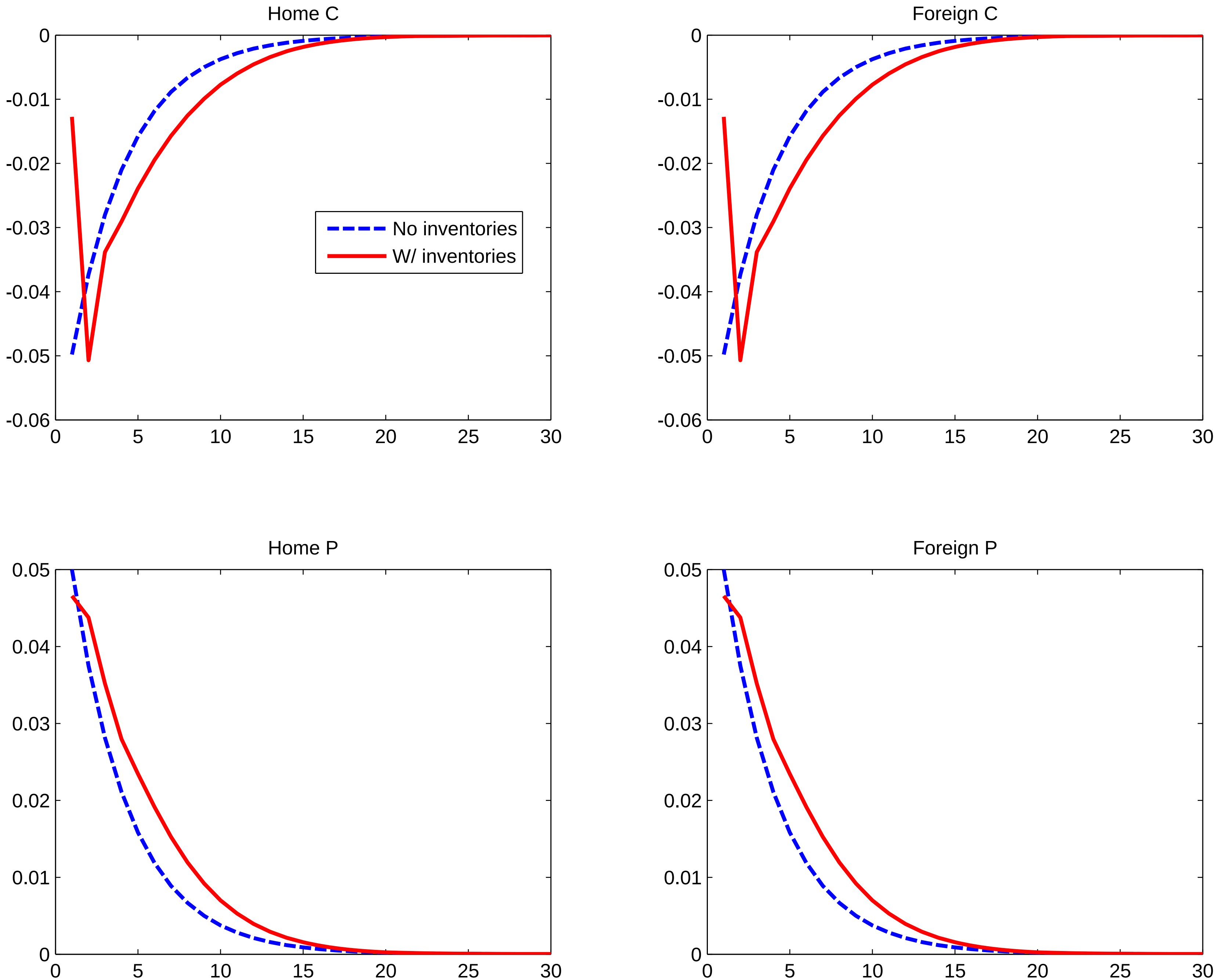


Figure 14: Impulse Response to -0.05 shock in Home and Foreign

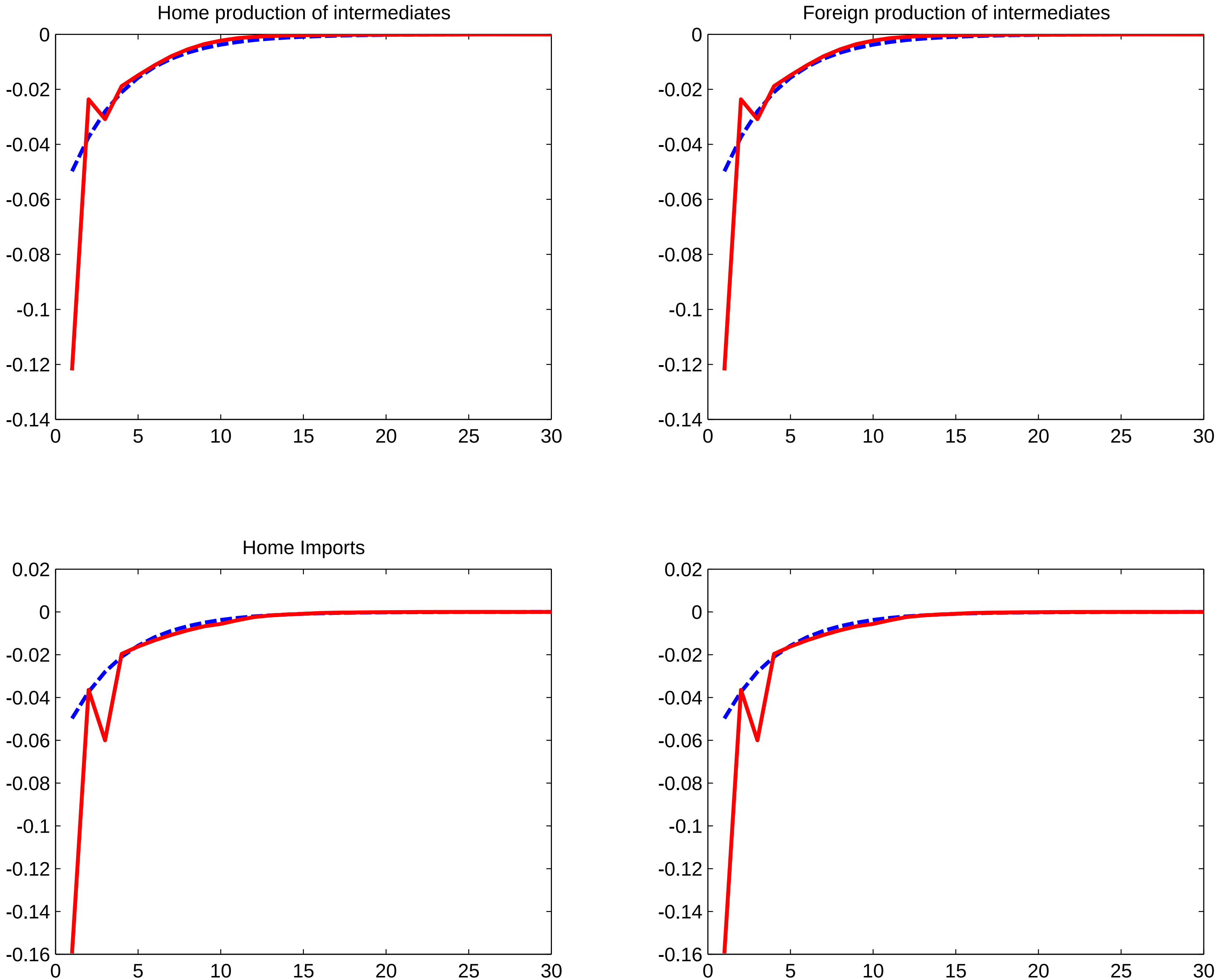


Figure 15: Impulse Response to - 0.05 Productivity Shock in Home and Foreign

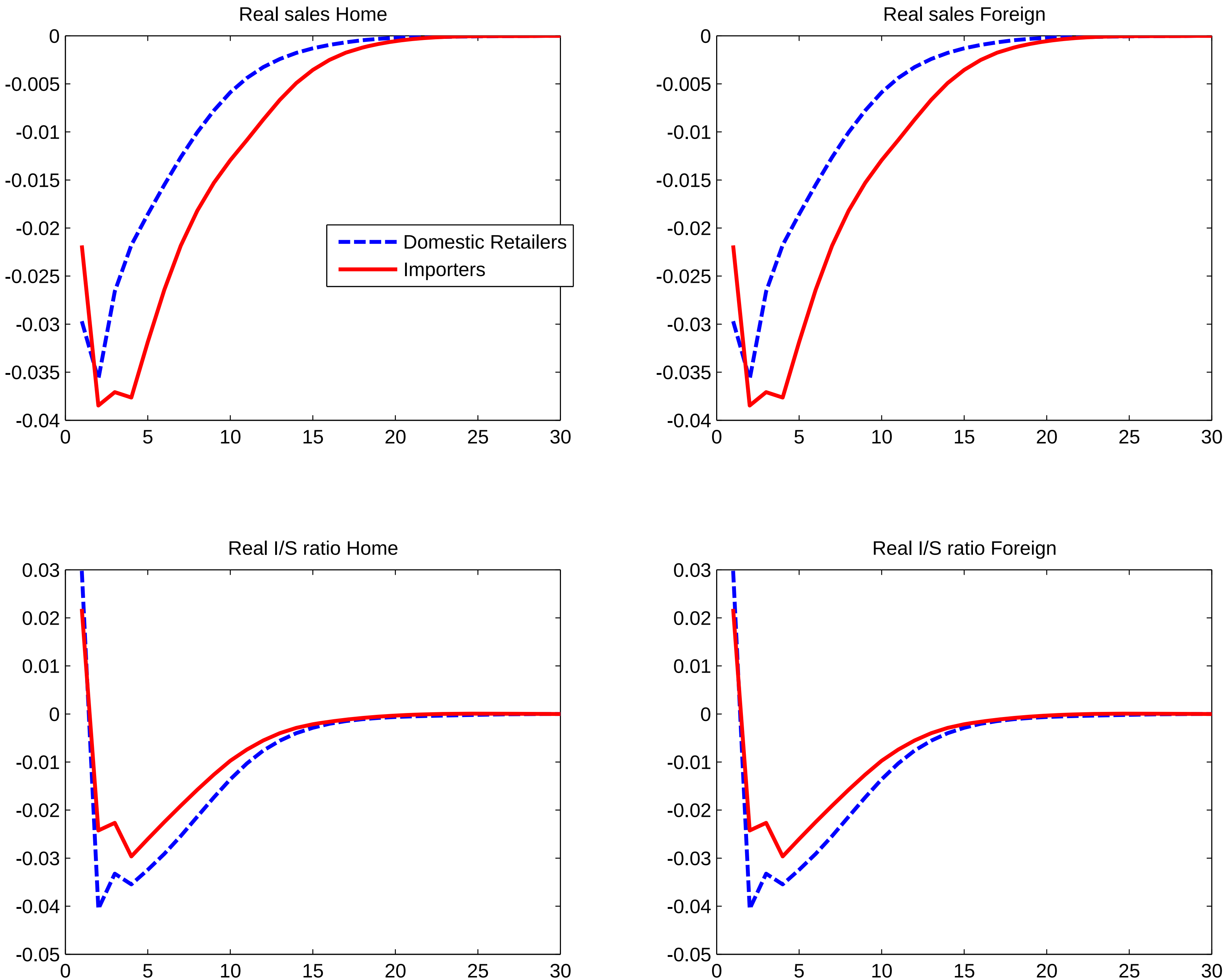


Figure 16: Response to interest rate shock in Home and Foreign

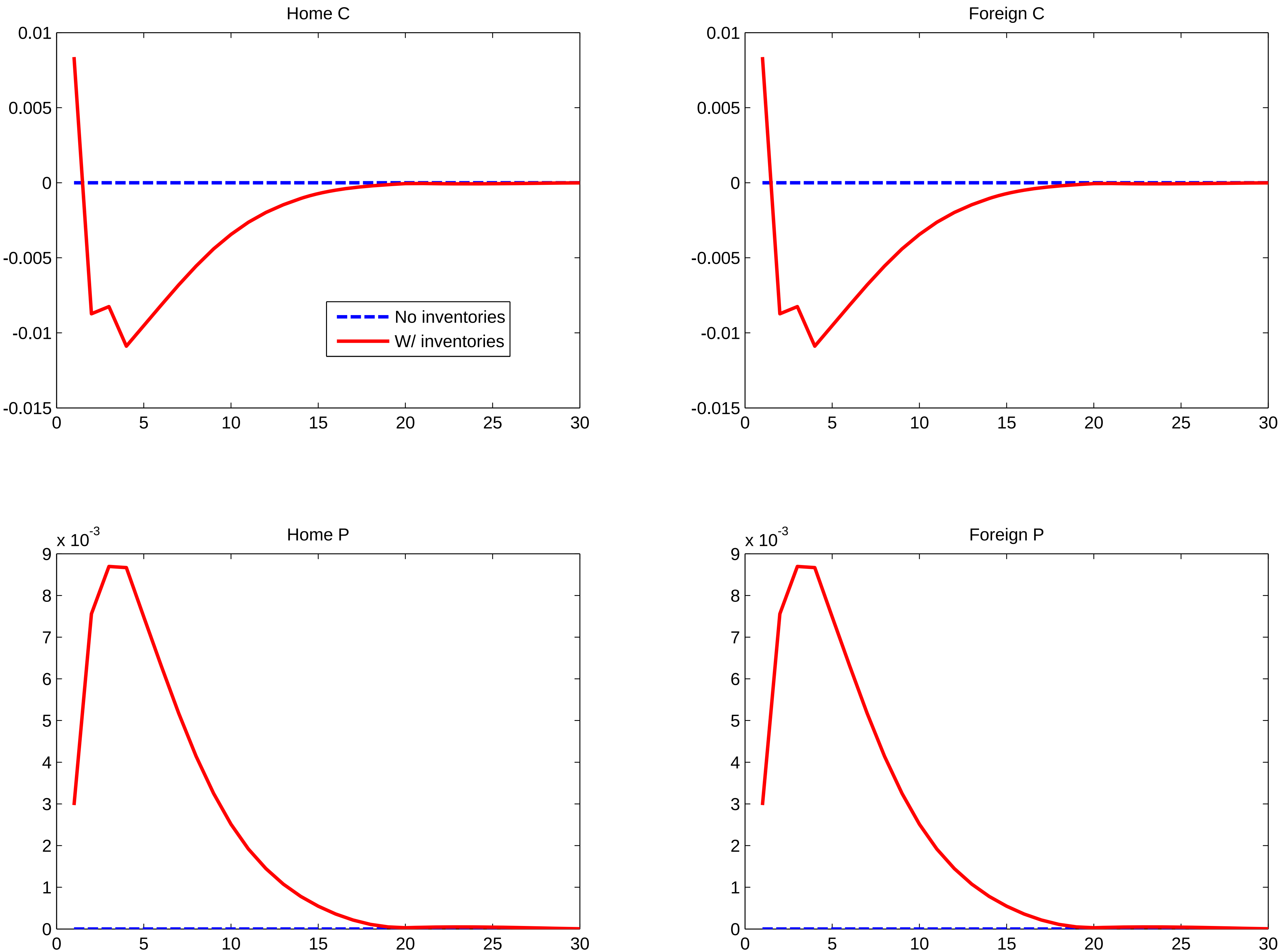


Figure 17: Response to interest rate shock in Home and Foreign

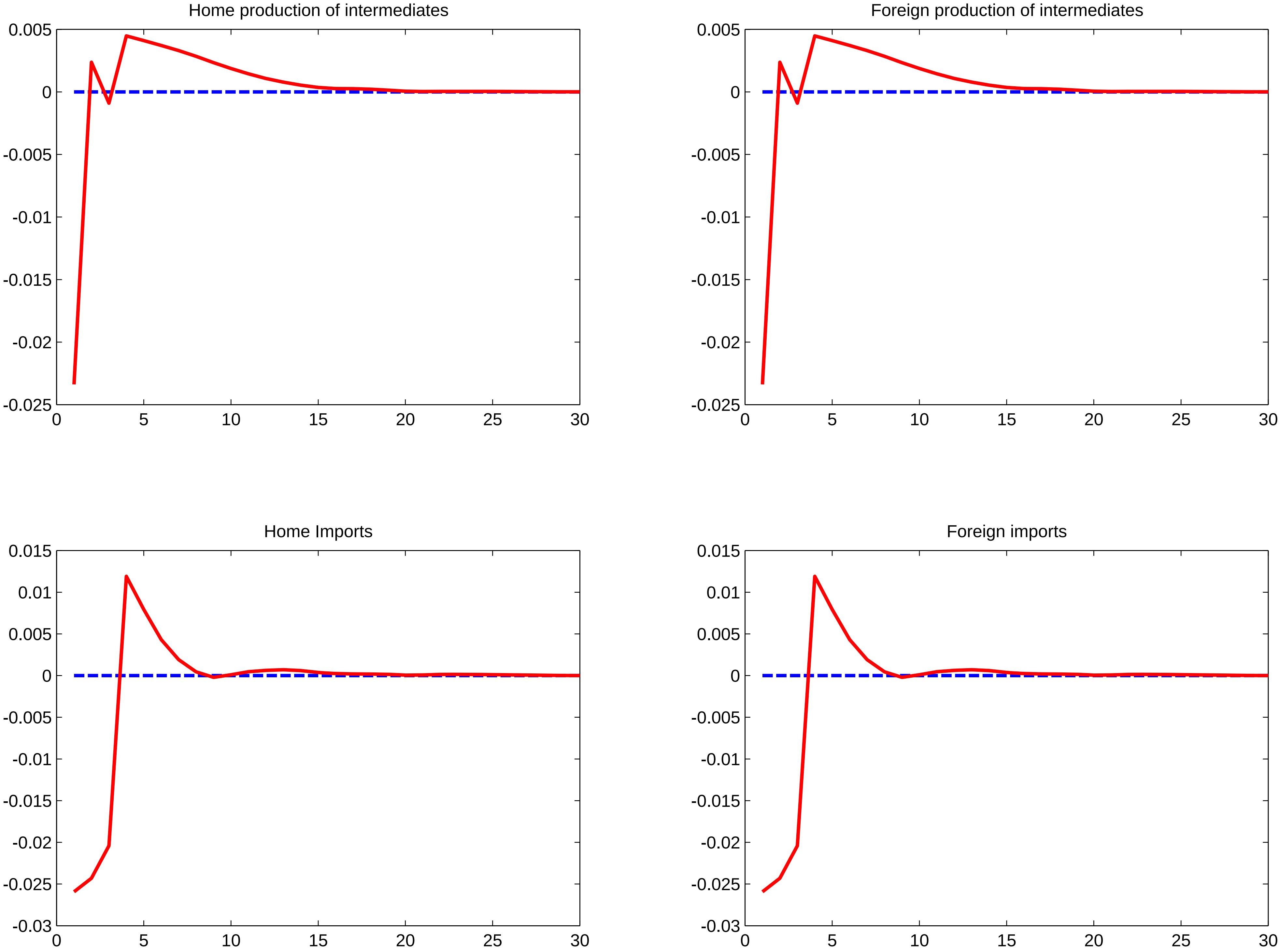
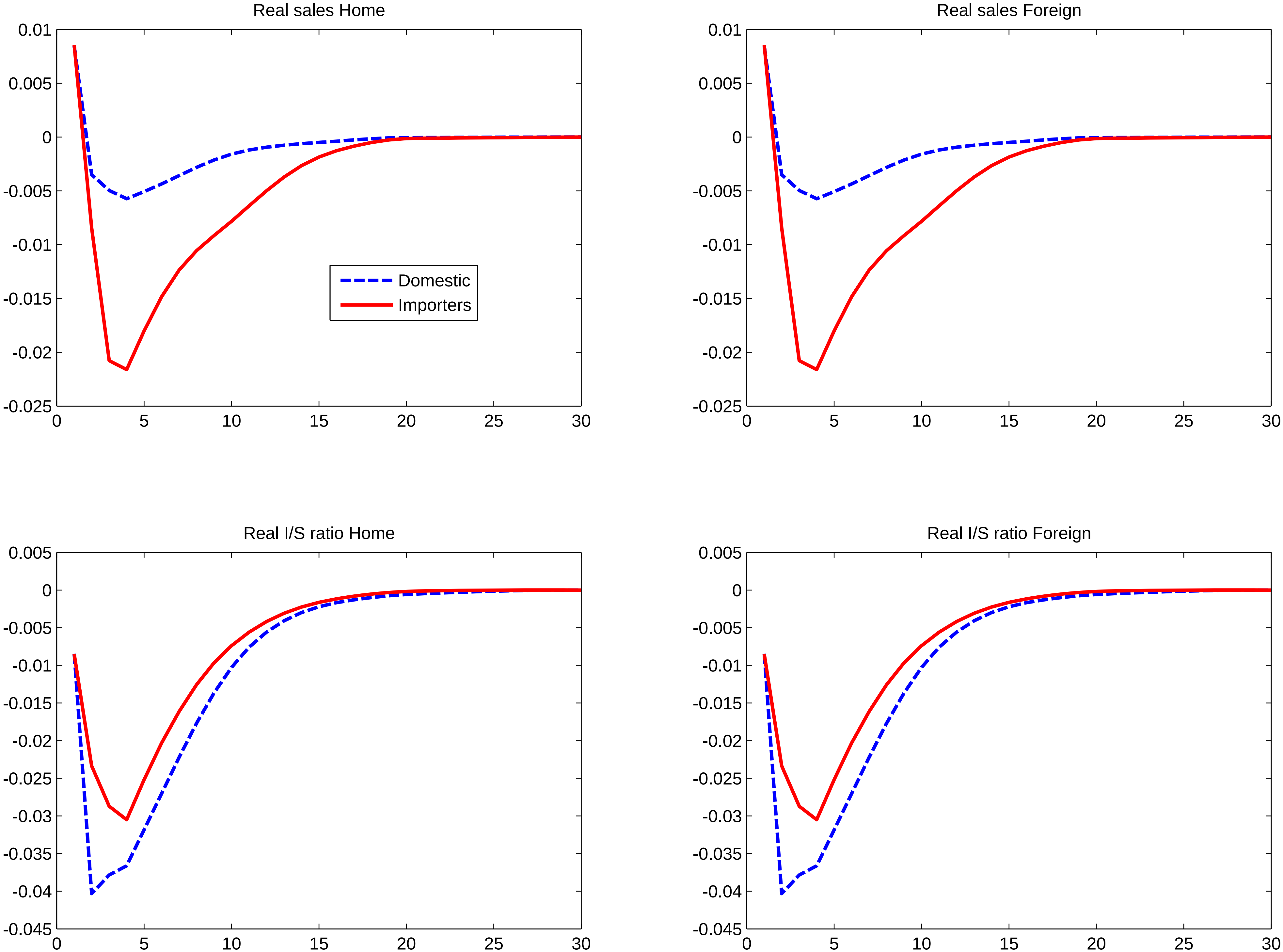


Figure 18: Response to interest rate shock in Home and Foreign



7. Appendix 1: Data summary

Here we describe the data series used in constructing our figures and tables. [To be completed]

Data for Table 1 All data is collected from Haver: The IPMFG@USECON Industrial Production: Manufacturing [SIC] (SA, 2002=100); GDPH@USECON Real Gross Domestic Product (SAAR, Bil.Chn.2005$); CTGH@USECON Real Personal Consumption Expenditures: Goods (SA, Bil.Chn.2005.$); CDH@USECON Real Personal Consumption Expenditures: Durable Goods (SAAR, Bil.Chn.2005$); CNH@USECON Real Personal Consumption Expenditures: Nondurable Goods (SAAR, Bil.Chn.2005$); FNEH@USECON Real Private Nonresidential Investment: Equipment & Software(SAAR,Bil.Chn.2005$); FNENSH@USECON Real Private Investment: Software (SAAR,Bil.Chn.2005$); VFH@USECON Real Change in Private Farm Inventories (SAAR, Bil.Chn.2005$); XMH@USECON Real Exports of Goods (SAAR, Bil.Chn.2005$); MMH@USECON Real Imports of Goods (SAAR, Bil.Chn.2005$); TITH@USECON Real Manufacturing & Trade Inventories: All Industries (EOP, SA, Mil.Chn.2005$); TSTH@USECON Real Manufacturing & Trade Sales: All Industries (SA, Mil.Chn.2005$); Final demand, $Y_t^T = \alpha\left(I_{EQ,t} + C_{D,t}\right) + (1-\alpha)\, C_{ND,t}$ where $I_{EQ,t} = I_{EQS,t} - I_S$ and I_{EQ} =Investment in Equipment, I_{EQS} =Investment in Equipment and Software, I_{EQ} =Investment in Software, C_D =Consumption of Durables, C_{ND} =Consumption of Non-durables and $\alpha = \left({}_tI^M_{EQ,t} + C^M_{D,t}\right) / {}_tI^M_{EQ,t} + C^M_{D,t} + C^M_{ND,t}$, where each of these variables is measured as real imports.

Data for Figure 6 (Japanese data); Japan: Producers Shipments: Manufacturing (SA, 2005=100) S158TSM@G10; Japan: Producers Inventories: Mining & Manufacturing (SA, 2005=100) S158TI@G10; Japan: Export Price Index: All Commodities (SA, 2005=100) F158PFXI@G10; Japan: Import Price Index: All Commodities (SA, 2005=100) F158PFMI@G10; Japan: Imports of Goods (SA, Bil.Yen) S158IM@G10; Japan: Exports of Goods (SA, Bil.Yen) S158IX@G10; Japan: Industrial Production: Mining and Manufacturing (SA, 2005=100) S158DMN@G10; Japan: Industrial Production: Manufacturing (SA, 2005=100) S158DM@G10;

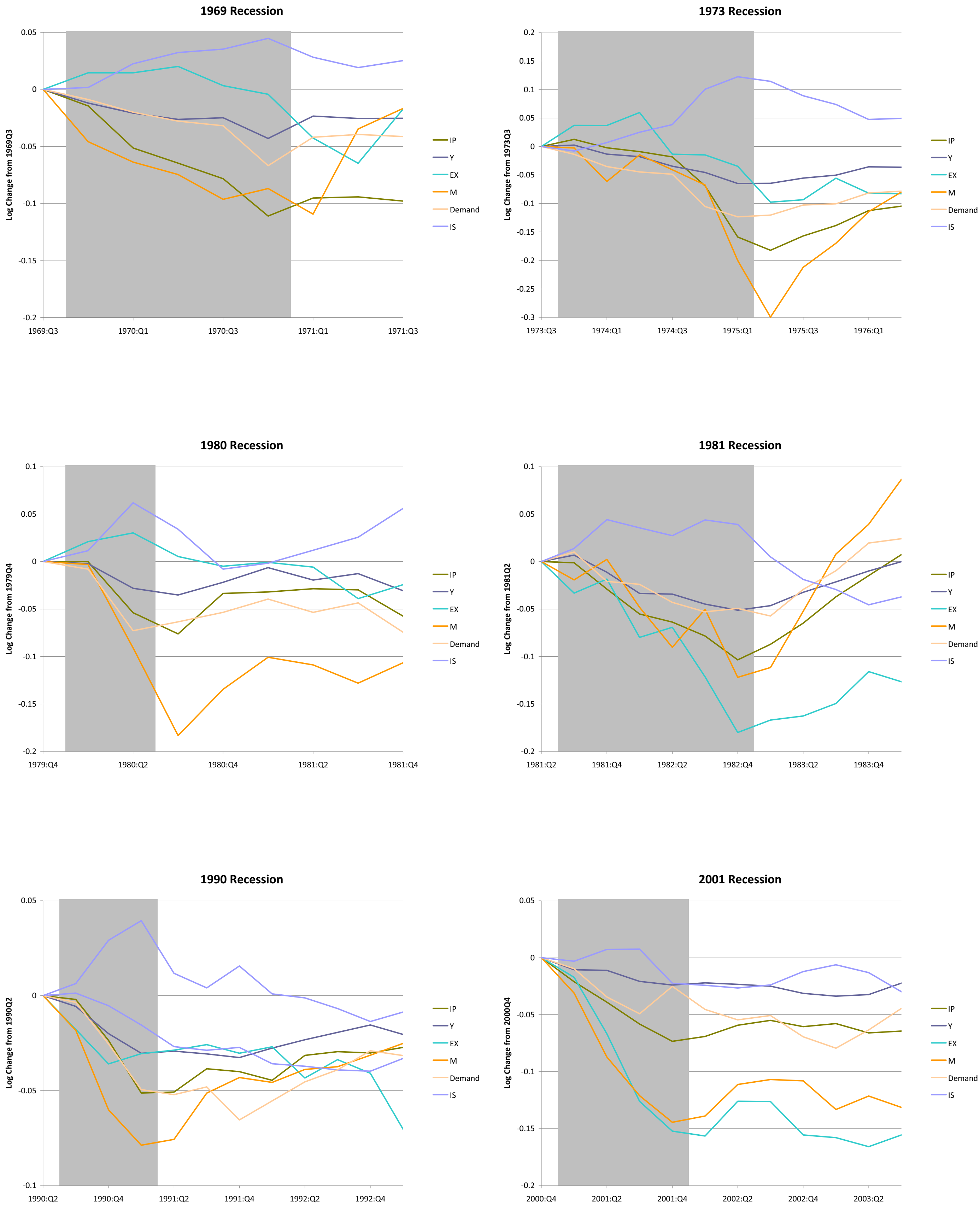


Figure A2: Previous US Recessions

9. Appendix 3: solving SS

We normalize W to ensure $P = 1$ in the frictionless steady state. Given a guess for equilibrium, we compute $p^H(s,v)$ and $p^F(s,v)$, $z^H(s,v)$ and $z^F(s,v)$. We can then compute

$$\begin{aligned} P^H &= \left(\int_0^1 v p^H(s,v)^{1-\theta} d\lambda^H(v,s)\right)^{\frac{1}{1-\theta}} \\ P^F &= \left(\int_0^1 v p^F(s,v)^{1-\theta} d\lambda^F(v,s)\right)^{\frac{1}{1-\theta}} \end{aligned}$$

$$P = [P^{H,1-\gamma} + \tau P^{F,1-\gamma}]^{\frac{1}{1-\gamma}}$$

$$R = P\left(\frac{1}{\beta} - 1 + \delta\right)$$
$$\omega = \alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)} R^\alpha W^{1-\alpha}$$
$$M(\eta) = \int z^H(s,v;\eta) d\lambda^H(s,v;\eta) + \int z^{*H}(s,v;\eta) d\lambda^{*H}(s,v;\eta)$$

K, L, C, Y follow from a) firm's focs of how much to hire, b) labor-lesiure choice, c) aggregate resource constraint. Given these new quantities, solve for an equilibrium again. Converge in a few rounds.

10. Appendix 4: solving transition

Shock to home technology: $\log(A_0) = -0.05$ and $A_t = A_0 \rho^t$ thereafter with $\rho = 0.95$. Solve first firm decision rules using response of prices/quantities in the frictionless economy. That is, use guess for $P_t, R_w, W_t, P_t^h, P_t^f$ and foreign counterparts to compute prices, sales etc.

This would yield $P_t, P_t^h, P_t^f, P_t^*, P_t^{*h}, P_t^{*f}$ and M_t, M_t^* along the transition. Then compute the rest of the quantities according to:

$$
\begin{aligned}
1 &= \beta \frac{C_t}{C_{t+1}} \left[\frac{R_{t+1}}{P_{t+1}} + (1-\delta) \right] \\
1 &= \beta \frac{C_t^*}{C_{t+1}^*} \left[\frac{R_{t+1}^*}{P_{t+1}^*} + (1-\delta) \right] \\
Y_t &= C_t + K_{t+1} - (1-\delta) K_t \\
Y_t^* &= C_t^* + K_{t+1}^* - (1-\delta) K_t^* \\
P_t C_t &= P_t^* C_t^* \\
\omega_t &= (1-\alpha)^{-(1-\alpha)} \alpha^{-\alpha} \frac{R_t^\alpha W_t^{1-\alpha}}{A_t} \\
\omega_t^* &= (1-\alpha)^{-(1-\alpha)} \alpha^{-\alpha} \frac{R_t^{*\alpha} W_t^{*1-\alpha}}{A_t^*} \\
R_t &= \alpha \omega_t \frac{M_t}{K_t} \\
R_t^* &= \alpha \omega_t^* \frac{M_t^*}{K_t^*} \\
L_t &= (1-\alpha) \omega_t \frac{M_t}{W_t} \\
L_t^* &= (1-\alpha) \omega_t^* \frac{M_t^*}{W_t^*} \\
C_t &= \frac{1}{\psi} (1-L_t) \frac{W_t}{P_t} \\
C_t^* &= \frac{1}{\psi} (1-L_t^*) \frac{W_t^*}{P_t^*}
\end{aligned}
$$

Notice that this problem simplifies considerably for the home country because M_t is implied by firm decision rules $\left(z_t^h (v,s), z_t^{*h} (v,s) \text{ etc.}\right)$ while K_t is predetermined at the time of the shock and W_t is normalized. So we can compute, starting from date $t=0$, and then updating:

$$
\begin{aligned}
\omega_t &= (1-\alpha)^{-1} \frac{1}{A_t} \left(\frac{M_t}{K_t} \right)^{\frac{\alpha}{1-\alpha}} W_t \\
R_t &= \alpha \omega_t \frac{M_t}{K_t} \\
\\
L_t &= (1-\alpha) \omega_t \frac{M_t}{W_t} \\
C_t &= \frac{1}{\psi} (1-L_t) \frac{W_t}{P_t}
\end{aligned}
$$

We cannot do this for the foreign country because W_t^* will vary. But we can use the risk-sharing condition:

$$C_t^* = \frac{P_t}{P_t^*} C_t$$

and then

$$\begin{aligned} L_t^* &= \frac{1}{A_t^*} \left(\frac{M_t^*}{K_t^*} \right)^{\frac{\alpha}{1-\alpha}} M_t^* \\ W_t^* &= \psi P_t^* \frac{C_t^*}{1 - L_t^*} \end{aligned}$$

$$\begin{aligned} \omega_t^* &= (1-\alpha)^{-1} \frac{1}{A_t^*} \left(\frac{M_t^*}{K_t^*} \right)^{\frac{\alpha}{1-\alpha}} W_t^* \\ R_t^* &= \alpha \omega_t^* \frac{M_t^*}{K_t^*} \end{aligned}$$

Finally, to pin down K_{t+1} and K_{t+1}^*, make use of the Euler equations. Notice that K_{t+1} pins down C_{t+1} given the decision rules. Hence, choose K_{t+1} using a golden search method to solve

$$\begin{aligned} 1 &= \beta \frac{C_t}{C_{t+1}} \left[\frac{R_{t+1}}{P_{t+1}} + (1-\delta) \right] \\ 1 &= \beta \frac{C_t^*}{C_{t+1}^*} \left[\frac{R_{t+1}^*}{P_{t+1}^*} + (1-\delta) \right] \end{aligned}$$