The Aggregate Effects of Global and Local Supply Chain Bottlenecks: 2020–2022[*]

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Abstract

We study the aggregate effects of domestic and international supply chain disruptions similar to those in the post-Pandemic period in a two-country heterogeneous firm model with a rich set of supply chain frictions: shipping delays, fixed order costs, storage costs, uncertain delivery and uncertain demand. These frictions lead firms to hold inventories that depend on the source of supply, domestic or imported, and these inventories influence price setting. We consider a range of aggregate shocks to capture the dynamics of the global economy in the crises and recovery. We show that transitory increases to aggregate shipping times similar to those in 2021 can be quite contractionary and raise prices, particularly for goods intensive in delayed inputs. These effects are larger when inventories are already at low levels, as in the U.S. and the World in 2021. The short-run effects on output are mitigated if they coincide with stimulus, but these lead to longer term contractions in consumption as more future production goes to rebuilding stocks. The aggregate effects on employment and production are much larger when there is an input-output structure as delays constrain production. The restocking cycle induced by these shocks is a source of endogenous persistence. The persistence of supply delays into 2022 are expected to be a drag on economic activity and source of elevated prices.

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1 Introduction

The post-COVID reopening of the global economy has been hampered by large and unprecedented supply-chain disruptions that have substantially increased both the costs and time involved in moving goods within and across borders. For example, from the start of the Pandemic through February of 2022, the costs of shipping goods from Asia to the United States by air has nearly doubled while the costs of long-distance trucking in the United States have risen almost 25 percent (Figure 1). Accompanying these cost increases has been a large increase in delivery delays. The ISM delivery times index shows that the average lead time for materials and inputs has risen by about 35 days in the United States. The IHS Markit survey of Global purchasing managers show a similar increase in delays for the Euro area (Figure 2) and a general increase in delays worldwide. While the focus has been largely on delays at ports, which are processing record trade volumes, these delays are also present in purely domestic transactions. The higher costs and longer lead times come at a time in which inventories relative to sales in certain sectors in the United States are at historically low levels, making it hard for firms to adjust.

In this paper, we quantify the aggregate effects of supply-chain delays experienced in the US and the Rest of the World in the post-COVID recovery period. A key challenge to our analysis is that the unique features of the current environment—increased delivery times and depleted inventories—are absent in the standard macroeconomic and trade models used in policy or business cycle analysis. For our purposes, we apply the heterogeneous firm model developed by Alessandria et al. (2021) to these current events. In this model firms use imported and domestically produced goods that take time to arrive after being ordered subject to a fixed cost. This delay is costly and also uncertain. Firms also face idiosyncratic demand shocks, so they optimally hold inventories to guard against stocking out and missing sales.

In this model, we consider an increase in international delivery times from 45 days to 90 days, mirroring the recent U.S. experience. The shock is transitory, but persistent. As firms run down inventories, they optimally raise prices and consumer prices rise by more than five percent from their steady-state value. The increase in shipping time is contractionary,

lowering output in the traded goods sector by as much as 8.5 percent on impact. The large impact of this shock arises because it is not spread equally across all firms and constrains the sales of the firms for whom restocking is most valuable.

The effects of the shipping delays are magnified if the shock arrives when inventories are low or demand is high. Inventories in the United States were historically low in early 2021, reflecting the manufacturing shutdowns and closure of borders that were meant to mitigate the impact of COVID. The easing of COVID restrictions and significant government stimulus drove demand up right as shipping delays increased. With low inventories and high demand, prices increase more and inventories are driven to lower levels, suggesting that continued stimulus in the face of supply constraints will likely push prices higher.

In section 8, we use the model to recover a set of domestic and foreign shocks that can match the salient features of the global economy in the COVID collapse and recovery period in terms of the usual macroeconomic time series - productions, sales, inventories, trade and the trade balance - plus our delivery time oriented series. By shutting down the delivery delay shocks we can estimate the aggregate impact of these supply frictions. Generally, we find that the delays were a substantial drag on economic activity in the US and the ROW, particularly in 2021. Owing to the delays remaining into 2022 they are a larger drag on economic activity through 2022 and into 2023 and a key sources of elevated prices.

We undertake an analysis of the increase in global and local supply chain frictions on the global economy in the two-country heterogeneous firm model of Alessandria et al. (2021). That paper extends the two-country sS inventory model of Alessandria et al. (2010b) to include an input-output structure and sectoral heterogeneity in the use and consumption of domestic intermediates. That model has been shown to capture the cyclical behavior of trade, inventories, prices, and aggregate economic activity in the Great Recession and, more generally, over the business cycle. A key feature of the approach is that it explicitly models the differential costs in time, resources, and risk for domestic and international transactions. These risks are reflected in the different inventory management approaches used for imported and domestic transactions. For example, goods involved in international trade are held in inventory about twice as long as goods in domestic transactions (Alessandria et al., 2010a; Nadais, 2017; Khan and Khederlarian, 2020), and inventory accumulation and depletion

in international transactions are particularly sensitive to business cycles and policy shocks (Khan and Khederlarian, 2021; Alessandria et al., 2019). These kinds of differences between international and domestic transactions allow us to discipline the parameters of our model with firm-level data on inventories and ordering behavior.

Our paper builds on a recent, largely micro-oriented literature that studies the effects of supply disruptions on firms, to consider the aggregate implications. Barrot and Sauvagnat (2016) show that natural disasters that constrain production of upstream suppliers can have large and persistent effects on downstream firms' values and production. They find these effects are partly mitigated for firms with a relatively large stock of inventories. Several papers use the Tohoku earthquake and tsunami to identify and quantify firm-level disruptions. Boehm et al. (2019) show that firms that use inputs from Japan reduce output one-for-one with imports. Carvalho et al. (2020) study the firm-level impact of the Tohoku shock and quantify its aggregate effects in a closed economy general equilibrium model with production linkages. Our own earlier paper, studies the aggregate effects of these types of shocks on the US economy since 1950. Several recent papers have studied the effect of COVID in the presence of global production networks (see Cakmakli et al. (2021) and Bonadio et al. (2021)) but do not consider the types of supply constraints related to time. Recently, Cavallo and Kryvtsov (2021) has shown that COVID has substantially and persistently increased the retail stock out rate in the US and global economy. Motivated by our research, and consistent with our model, they also show that goods with a larger import content are taking longer to restock and that prices have risen by more for these goods. Our paper is also related to general equilibrium models of inventory management and business cycles (see Khan and Thomas (2007), Iacoviello et al. (2011), and Ortiz (2021)).

Our paper is also related to work that estimates the effects of timeliness on trade flows. Djankov et al. (2010) introduce a measure of "time to trade" into a gravity analysis and find that an extra shipping day lowers trade by more than one percent—more so for time-sensitive products. Hummels and Schaur (2013) use variation in shipping times to different ports and transport modes in the United States and estimate a tariff-equivalent time cost of 0.6–2.1 percent per day in transit. Clark et al. (2014) uses variation in arrival rates to the same port to estimate that 10-percent more delivery uncertainty (about 0.5 a day) lowers trade by 1–2

percent. Related, Feyrer (2019) use the change in geography from the introduction of faster air transport to estimate relatively large effects of trade on income.

The paper is organized as follows. In Section 2, we summarize the evidence on input lead times, shipping costs, and inventory levels. We also summarize the dynamics of the aggregate economy. Section 3 lays out the model. In Section 4, we use data, such as inventory holding and order frequency, to parameterize our model. In section 6 we introduce two alternative models that are useful to highlight the role of our production and trade cost structure. In Section 7, we study the contractionary and inflationary effects of a persistent increase in shipping times in our baseline model and some variants. We also consider the effects of these shocks in conjunction with stimulus and out of steady state when inventories are low. In Section ?? we consider a combination of home and foreign shocks to shipping times, productivity, and stimulus that best account for the salient features of the U.S. and global economy in the COVID collapse and recovery. Section 9 concludes.

2 Data

We summarize some salient features of the current state of the U.S. and global economy (as of February 2022). These features are related to increases in shipping times and costs and substantially depleted inventories. For many of these series the changes are unprecedented. Of course the shock and policy actions were unprecedented as well.

It is taking much longer than usual to get inputs for production. These delays vary across industries and by direction of trade. We have already noted that global measures of delivery times, measured by the IHS diffusion indices, increased substantially withe COVID and have only gotten worse. Figure 3 plots various measures from the ISM delivery times index which is a survey of purchasing manager times from order to delivery for important inputs. A nice feature of this series compared to a diffusion index is that it yields a time series of the level of delays that we can use to discipline our model parameters. There are four panels of delivery times. The first three show average delivery lead times, in days, for production materials, capital expenditures, and maintenance, repair, and operating (MRO) supplies.[1] The last panel is a diffusion index that summarizes the direction of delivery times,

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[1]Firms are asked to describe delivery times by windows and then these times are converted to an average.

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with numbers above (below) 50 reflecting an increase (decrease) in delivery times. All four panels display levels in 2021 that have not been experienced in last 25 years. Production material delivery times were stable in the 2000s at about 45-50 days, drifted up to about 60 days following the Great Recession, and have risen to almost 100 days since the start of 2021. Looking forward, it is useful to note that the previous increase following the Great Recession was quite persistent. Carreras-Valle (2021) attributes this secular rise in delivery times to a shift to more distant trade partners, particularly China.

Delivery times on international transactions appear to have risen by more than domestic transactions. In Figure 4, we plot a measure of delivery challenges, by type of transaction, from a survey of U.S. firms conducted by the Census Bureau that began at the early onset of COVID. Firms are surveyed about delivery delays on supplies by source (domestic and foreign) as well as their own delays. Firms reporting delays by foreign suppliers have more than doubled from the beginning to end of 2021 while domestic and own delays have risen by about 50 percent. These delays are concentrated in the tradable sectors (measured by inputs): construction, manufacturing, retail and wholesale sectors. Finally, Figure 5 shows that these delays are especially large in international shipping, as the time to ship measured by ocean shipment transit time from China to the United States has risen by almost 40 days (from 41 to 80 days), from the end of 2019 to the end of 2021.

Shipping costs, domestic and international, rose spectacularly in 2021. We take a conservative approach to measuring shipping costs by focusing on U.S. price indices rather than route-specific measures. Figure 1 plots several measures of shipping costs, for international and domestic transactions since the start of COVID. Air freight prices have more than doubled for products inbound from Asia and risen by about 50 percent for products from Europe. Outbound prices have been somewhat more stable, although there were some substantial increases from when COVID first occurred to the second half of 2021. These costs spiked with the onset of COVID and have not moderated. Part of this increase certainly reflects the reduced capacity from reductions in air travel, but at least some of the increase also reflects increased demand for faster transport to compensate for the delays in other modes of transport. Deep sea freight charges fell sharply with COVID, but have risen nearly 30 percent since the end of 2021. Domestic transportation costs have also grown sharply as the economy

has reopened. Based on the producer price index for long-distance trucking, domestic trade costs have risen about 25 percent since the onset of COVID, after being largely stagnant in the lead up to COVID. Rail charges have also risen substantially and are up about 12 percent since the start of COVID.

The current distribution of inventories across sectors is quite unusual, with retail stocks at record lows. Figure 6 plots a time series of U.S. inventory-sales ratios for three major sectors: manufacturing, retail trade, and an aggregate that includes those two sectors plus the wholesale trade sector. Two things are apparent. First, inventory-sales ratios have fallen in all sectors since the start of the crisis, but the decline has been largest in the retail sector, as retailers have moved from about 1.5 months of inventory to about 1.1 months. Second, the traditional structure of inventory holdings across sectors has been upended, with retail—normally the most inventory-intensive industry—becoming the least inventory-intensive.[2]

Finally, we summarize the dynamics of the aggregate economy Figure 7 plots some key variables of interest. The first three panels are relative to their levels in the fourth quarter of 2019. From the first panel we see that industrial production in manufacturing fell sharply in the U.S. and the ROW by about 20 percent. The recovery from this decline was relatively fast though, especially in the ROW which was producing more than prior to the crisis by the fall of 2020. Turing to the second panel, sales of goods in the U.S. fell sharply also but considerably less than production. Sales rebounded faster than production and have been about 5 percent above pre-crisis levels for some time. International trade fell about as sharply as production but international trade rebounded faster than production but lagged overall sales. The U.S. filled the gap between production and sales by running down inventories and running larger trade deficits. The stock of inventories fell about 3 percent, recovered a little in the fall of 2020 and then fell sharply as delays built. The trade balance, measured as a share of sales, widened by a little over 1 percentage point on impact, recovered a little and then has continued to widen. These variables along with our measures of delays are the key moments we seek to interpret through the lens of the model.

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[2]The inventory-sales ratio for motor vehicles has reached a record low. There are important challenges to rebuilding the stock of autos as lead times for parts have risen sharply due to several factors.

3 Model

In this section, we describe a two-country dynamic general equilibrium model with heterogeneous firms facing domestic and international transaction frictions that lead them to hold inventories developed by Alessandria et al. (2021). The model is well-suited to study aggregate fluctuations around COVID. The model extends the sS inventory adjustment model of Alessandria et al. (2010b) to include multiple sectors, input-output linkages, and a richer set of shocks. There are two sectors: 1) a *manufacturing sector* that combines labor and intermediate goods to produce and 2) a wholesale/retail sector (for brevity, the *retail sector*) that purchases goods from manufacturers, differentiates them, and sells the differentiated goods to consumers and the manufacturing sector.

The final-good firms order domestic and imported inputs to sell at home subject to source-specific delays, fixed ordering costs, and variable costs. Unsold goods can be saved in inventory to be sold in future periods, but they incur a holding cost that depends on the interest rate and a product's depreciation rate. These holding costs keep firms from holding too many goods in inventory. The firm pays a fixed cost for each shipment of goods, which gives firms an incentive to order infrequently and hold more goods in inventory. Firms face idiosyncratic demand shocks for their varieties, so their sales in each period are uncertain and goods do not always arrive in the period they are ordered. These two sources of uncertainty, demand and supply, affect the timing of a firm's orders and the price they set on goods. In general, firms want to avoid stocking out of their products to maximize profits. The fixed ordering costs and delivery lags make the model particularly well suited to study the aggregate effects of global and domestic shipping disruptions.

3.1 Shipping delays

Retail firms place orders after observing their idiosyncratic demand shocks but before setting prices. Goods ordered at the beginning of the period arrive within the same period with probability $1 - \mu_i$, where $i \in \{D, I\}$ denotes an order from a domestic supplier or an international supplier. With probability μ_i the goods are delayed and arrive in the next period.

We assume that μ_{it} follows a stochastic process defined by

$$\mu_{it} = \rho_\mu \, \mu_{i,t-1} + (1 - \rho_\mu)\bar{\mu}_i + \varepsilon_{\mu_i t}, \tag{1}$$

where ρ_μ is the persistence of the shock and $\bar{\mu}_i$ is the steady-state probability that goods from source i are delayed and arrive in the next period. Thus, a positive $\varepsilon_{\mu i}$ increases the average shipping delay faced by firms.

3.2 Households

There are two symmetric countries, Home and Foreign, populated by a unit mass of identical agents that are modeled as representative households. Foreign-country variables are denoted with an asterisk. Households in Home and Foreign supply labor, consume, and trade state-contingent bonds. The aggregate state is η_t, a history is $\eta^t = (\eta_0, \eta_1, ..., \eta_t)$ and the probability of a history is $\pi(\eta^t)$. The representative household maximization problem is

$$\max_{C,L,B} \sum_t \sum_{\eta^t} \beta^t \pi\left(\eta^t\right) u\left(C, L\right) \tag{2}$$

$$\text{s.t. } P_c(\eta^t)C(\eta^t) + \sum_{\eta^{t+1}} Q(\eta^{t+1}|\eta^t)B(\eta^{t+1}) = B(\eta^t) + W(\eta^t)L(\eta^t) + \Pi(\eta^t), \tag{3}$$

where $B(\eta^{t+1})$ denotes the quantity of bonds that pay one unit of consumption in state η^{t+1} (and zero otherwise) and are priced at $Q(\eta^{t+1})$. The consumption price and wage level are denoted by $P_c(\eta^t)$ and $W(\eta^t)$, respectively. Retail firms are owned by the household and their aggregate profits are denoted by $\Pi(\eta^t)$.

3.3 Consumption producers

The aggregate consumption good is a constant elasticity of substitution (CES) bundle of domestic (D) and imported (I) varieties,

$$Y_C(\eta^t) = \left[\left(\int_0^1 \nu_D(j,\eta^t)^{\frac{1}{\theta}} c_D(j,\eta^t)^{\frac{\theta-1}{\theta}} dj \right)^{\frac{\theta}{\theta-1}\frac{\gamma-1}{\gamma}} \right. \tag{4}$$

$$\left. + \tau_c^{\frac{1}{\gamma}} \left(\int_0^1 \nu_I(j,\eta^t)^{\frac{1}{\theta}} c_I(j,\eta^t)^{\frac{\theta-1}{\theta}} dj \right)^{\frac{\theta}{\theta-1}\frac{\gamma-1}{\gamma}} \right]^{\frac{\gamma}{\gamma-1}},$$

where ν_i denotes the demand shock to variety j from source $i \in \{D, I\}$ and c_i denotes the corresponding quantity demanded by the firm. Home bias in the consumption bundle is governed by τ_c. The elasticity parameters θ and γ denote the degree of substitutability within and across domestic and foreign goods, respectively.

The firm chooses quantities of domestic and imported consumption goods (c_D, c_I) to maximize profits,

$$P_C Y_C(\eta^t) - \int_0^1 p_D(j,\eta^t) c_D(j,\eta^t)\, dj - \int_0^1 p_I(j,\eta^t) c_I(j,\eta^t)\, dj, \tag{5}$$

subject to (4). The associated demand functions are

$$c_D(j,\eta^t) = \left(\frac{p_D(j,\eta^t)}{P_D(\eta^t)} \right)^{-\theta} \left(\frac{P_D(\eta^t)}{P_C(\eta^t)} \right)^{-\gamma} \nu_D(j,\eta^t) Y_C(\eta^t) \tag{6}$$

$$c_I(j,\eta^t) = \tau_C \left(\frac{p_I(j,\eta^t)}{P_I(\eta^t)} \right)^{-\theta} \left(\frac{P_I(\eta^t)}{P_C(\eta^t)} \right)^{-\gamma} \nu_I(j,\eta^t) Y_C(\eta^t), \tag{7}$$

where $P_D(\eta^t)$ is the price of the bundle of domestic varieties and $P_I(\eta^t)$ is the price of the bundle of imported varieties, defined by

$$P_D(\eta^t)^{1-\theta} = \int_0^1 \nu_D(j,\eta^t) p_D(j,\eta^t)^{1-\theta} dj \tag{8}$$

$$P_I(\eta^t)^{1-\theta} = \int_0^1 \nu_I(j,\eta^t) p_I(j,\eta^t)^{1-\theta} dj. \tag{9}$$

The aggregate price $P_C(\eta^t)$ is a function of the prices of domestic and imported bundles,

$$P_C(\eta^t)^{1-\gamma} = P_D(\eta^t)^{1-\gamma} + \tau_C P_I(\eta^t)^{1-\gamma}. \tag{10}$$

3.4 Manufacturing Producers

In each country, there are a continuum of manufacturers that produce a homogeneous good and operate in a perfectly competitive market. These manufacturers are modeled as representative firms. They combine local labor and intermediate goods to produce,

$$M(\eta^t) = L_p(\eta^t)^{1-\alpha} Y_M(\eta^t)^\alpha, \tag{11}$$

where L_p denotes labor used production. The bundle of intermediate goods used in manufacturing production is Y_M and is a CES bundle of the varieties of intermediates,

$$Y_M(\eta^t) = \Bigg[\left(\int_0^1 \nu_D(j,\eta^t)^{\frac{1}{\theta}} m_D(j,\eta^t)^{\frac{\theta-1}{\theta}} dj \right)^{\frac{\theta}{\theta-1} \frac{\gamma-1}{\gamma}} \tag{12}$$

$$+ \tau_m^{\frac{1}{\gamma}} \left(\int_0^1 \nu_I(j,\eta^t)^{\frac{1}{\theta}} m_I(j,\eta^t)^{\frac{\theta-1}{\theta}} dj \right)^{\frac{\theta}{\theta-1} \frac{\gamma-1}{\gamma}} \Bigg]^{\frac{\gamma}{\gamma-1}},$$

where ν_i is the same firm-specific demand shock in (4). The quantity of variety j used to produce manufactured goods is denoted by m_i. The home bias in intermediate good use is captured by τ_m. The differential home bias in consumption and manufacturing allows us to make trade less intensive in consumption goods, as observed in the data (Boileau, 1999; Miroudot et al., 2009). Note that the home bias is the only difference in the consumption and manufacturing production technologies.

Manufacturers take the wage (W) and the price of intermediates (P_M) as given. The manufacturer's problem yield's demand functions for each intermediate variety,

$$m_D(j,\eta^t) = \left(\frac{p_D(j,\eta^t)}{P_D(\eta^t)} \right)^{-\theta} \left(\frac{P_D(\eta^t)}{P_M(\eta^t)} \right)^{-\gamma} \nu_D(j,\eta^t) Y_M \tag{13}$$

$$m_I(j,\eta^t) = \left(\frac{p_I(j,\eta^t)}{P_I(\eta^t)} \right)^{-\theta} \left(\frac{P_I(\eta^t)}{P_M(\eta^t)} \right)^{-\gamma} \nu_I(j,\eta^t) \tau_M Y_M. \tag{14}$$

The CES price index for the intermediate input is

$$P_M(\eta^t)^{1-\gamma} = P_D(\eta^t)^{1-\gamma} + \tau_M P_I(\eta^t)^{1-\gamma}. \tag{15}$$

3.5 Retailers

Each country has two retail sectors, one for domestic and one for imported goods. Each sector consists of a unit mass of firms that sell differentiated products. The firms face idiosyncratic demand $(\nu(j, \eta^t))$ and hold inventories (s). In each period, firms decide how much input, z, to order and what price, p, to charge for their differentiated variety.

Input orders are subject to delay, as defined in (1). The timing is as follows: firms observe their demand and place their input orders, they observe whether the inputs arrive in the current period, and finally, they set prices. Firms pay a fixed cost ϕ_D or ϕ_I if they order a positive quantity of inputs. Thus, firms have an incentive to order less frequently and save inputs in inventories to meet demand. Inventories of firms selling domestically-sourced goods $s_D(j, \eta^t)$ (and for imported-good firms, $s_I(j, \eta^t)$) depreciate at rate δ. Goods that were ordered but not delivered in the current period also depreciate at the same rate—they depreciate in transit.

A firm's sales are limited by the stock of goods on hand, so total sales are restricted to sales of inventories and any goods that arrive in the current period. If demand exceeds this value, the firm sells all of its goods on hand and carries zero inventories into the next period. Ending-period inventories are carried over to the next period net of depreciation.

In the following, we present the problem of the home country's domestic-good retailers. The problems for the home country's imported-good retailers and the foreign country's retailers are analogous. For simplicity, we suppress the notation for the aggregate state. Given the firm's beginning of period inventory and its demand (s, ν), the firm's value is

$$V(s, \nu; i) = \max \left\{ V^N(s, \nu), J(s, \nu) - W\phi_D \right\}, \tag{16}$$

where V^N is the value of the firm is does not place an order for inputs and $J(s, \nu)$ is the gross value of the firm if it places an order for inputs. If the firm places an order, it pays the fixed cost ϕ_D, which is denominated in units of labor.

If the firm does not place an order, it chooses its price and quantities to sell to the manufacturing and consumption-good firms. These quantities are constrained by the inventories

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on hand,

$$V^N(s,\nu) = \max_{p,c,m} p\left[c\left(p,\nu\right) + m\left(p,\nu\right)\right] + \mathop{\mathbb{E}}_{\nu'} QV(s',\nu') \tag{17}$$

$$\text{s.t.} \quad s \geq c\left(p,\nu\right) + m\left(p,\nu\right) \tag{18}$$

$$s' = (1-\delta)\left[s - c\left(p,\nu\right) - m\left(p,\nu\right)\right]. \tag{19}$$

If the firm places an order, either the inputs arrive in the current period or the next. If the inputs did not arrive in the current period, the value of the firm is

$$V^O(s,\nu,z) = \max_{p,c,m} p\left[c\left(p,\nu\right), m\left(p,\nu\right)\right] + \mathop{\mathbb{E}}_{\nu'} QV(s',\nu') \tag{20}$$

$$\text{s.t.} \quad s \geq c\left(p,\nu\right) + m\left(p,\nu\right) \tag{21}$$

$$s' = (1-\delta)\left[s + z - c\left(p,\nu\right) - m\left(p,\nu\right)\right]. \tag{22}$$

Notice that the inputs (z) do not appear in the stockout constraint (21) and deterministically arrive in the next period. If the inputs arrive in the current period, the firm's value is the same as that defined in (17) except its inventories are $s + z$. The value of the firm when it places an order is

$$J(s,\nu) = \max_{z} \; -p^m z + (1-\mu)V^N(s+z,\nu) + \mu V^O(s,\nu,z). \tag{23}$$

The solution to these problems takes the form of an "sS rule," where firms place orders when inventories have fallen to low enough levels. Conditional on reordering, the firm sets the expected marginal value of a unit of inventory in the next period to the marginal price of the input

$$\mathop{\mathbb{E}}_{\nu',\eta'} Q(\eta'|\eta)V_1\left(s',\nu';\eta'\right) = p^m(\eta), \tag{24}$$

where V_1 is the derivative of the value function with respect to the inventory level. Firms are monopolistic competitors, so the pricing function has the usual constant markup specification,

$$p(s,\nu) = \frac{\theta}{\theta-1} \mathop{\mathbb{E}}_{\nu'} Q(\eta'|\eta)V_1\left(s',\nu';\eta'\right). \tag{25}$$

Notice that the markup is over the opportunity cost of a unit of inventories. If the firm makes a sale today, it begins the next period with fewer inventories. Only when the firm orders and it arrives in current period is the price a markup over p^m.

3.6   Equilibrium

An equilibrium is sequences of quantities for Home and Foreign: $C(\eta^t)$, $B(\eta^t)$, $L(\eta^t)$, $M(\eta^t)$, $\Pi(\eta^t)$, $L_p(\eta^t)$, $m_D(j,\eta^t)$, $m_I(j,\eta^t)$, $c_D(j,\eta^t)$, $c_I(j,\eta^t)$, $s_I(j,\eta^t)$, $s_D(j,\eta^t)$, $z_I(j,\eta^t)$, $z_D(j,\eta^t)$ and prices: $p^m(\eta^t)$, $W(\eta^t)$, $Q(\eta^{t+1}|\eta^t)$, $p_I(j,\eta^t)$, $p_D(j,\eta^t)$, for $t = 0, \ldots, \infty$ and $j \in [0,1]$ such that

1. Given prices, allocations are the solutions to the households', consumption-good firm, manufacturing-good firm, and the retail firms' optimization problems in each country.

2. The consumption-, and retail-good markets clear in each country.

3. The manufacturing-good markets clear in each country. The supply of the manufactured good produced in each country is sold both domestically and exported,

$$M(\eta^t) = \int_0^1 z_D(j,\eta^t)dj + \int_0^1 z_I^*(j,\eta^t)dj \tag{26}$$

$$M^*(\eta^t) = \int_0^1 z_D^*(j,\eta^t)dj + \int_0^1 z_I(j,\eta^t)dj. \tag{27}$$

   where $z_i(j,\eta^t)$ denotes the intermediate good orders by retailer j of type $i \in \{D, I\}$.

4. Inventories are equal to

$$S(\eta^t) = \int_0^1 s_D(j,\eta^t)dj + \int_0^1 s_I(j,\eta^t)dj$$

$$S^*(\eta^t) = \int_0^1 s_D^*(j,\eta^t)dj + \int_0^1 s_I^*(j,\eta^t)dj$$

   where $s_i(j,\eta^t)$ is the end-of-period stock for retailer j of type i, which evolves according to,

$$s_i(j,\eta^t) = (1-\delta)(s_i(j,\eta^{t-1}) + z_i(j,\eta^t) - c_i(j,\eta^t) - m_i(j,\eta^t))$$

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5. Labor markets clear in each country. Labor-market clearing in the home country equates labor supply with labor demand from production labor and labor used for order costs,

$$L(\eta^t) = L_p(\eta^t) + \int_j \phi_D \mathbf{1}_{z_D(j,\eta^t)} dj + \int_j \phi_I \mathbf{1}_{z_I(j,\eta^t)} dj, \tag{28}$$

where $\mathbf{1}_{z_D(j,\eta^t)}$ is equal to one when firm j places an order and zero otherwise.

6. Bonds are in zero net supply, i.e. $B(\eta^t) + B^*(\eta^t) = 0$ for all η^t.

4 Quantification

In this section, we describe how we choose parameters for our quantitative analysis. The parameter values are summarized in Table 1.

4.1 Baseline Model

Assigned Parameters. The model is quarterly. Utility is

$$u(C, L) = \frac{C^{1-\sigma}}{1-\sigma} - \chi \frac{L^{1+\frac{1}{\psi}}}{1+\frac{1}{\psi}}. \tag{29}$$

The intertemporal elasticity of substitution $(1/\sigma)$ is set to one, but we present sensitivity to a range of values of σ. The weight on leisure, ψ, is set so that households work one-third of their available time. We set the Frisch elasticity to two but provide sensitivity. The discount factor, β, is $0.96^{1/4}$.

In the manufacturing (equations 11 and 12) and consumption-good technologies (4) we set the elasticity of substitution across varieties (θ) to four to generate a 33 percent gross markup. After accounting for the fixed order costs and inventory holding costs, the net markups are 12 percent. We set the intermediate-good share (α) of manufacturers to 50 percent, to match the U.S. ratio of gross output to value added of 2.8 in manufacturing. The home biases in consumption (τ_c) and manufacturing production (τ_m) are set to match a trade-to-GDP ratio of 33 percent, where trade is the sum of exports and imports, and the share of intermediate goods in total imports of 80 percent.

The Armington elasticity, γ, is a key parameter. Estimates of this parameter vary widely

between work in international macro and international trade (Ruhl, 2008) and our model includes elements from both of these literatures. These difference stem in large part from the identification scheme and horizon considered. Alessandria and Choi (2021) estimates both short-run and long-run Armington elasticities for the United States, accounting for inventory adjustments, and find a quarterly elasticity of 0.2 and a long-run elasticity of 1.1, with about 7 percent of the gap closed per quarter. Heathcote and Perri (2014) show that international business cycles are best explained with an Armington elasticity of about 0.6. Given our focus on the aggregate economy, we set the Armington elasticity to equal one, although it is also consistent with less substitution at the firm level given each wholesale/retail firm is specialized in the distribution of a single input distinguished by source.[3] We provide sensitivity to the Armington elasticity.

Jointly determined parameters. The remaining parameters are jointly determined so that our model matches key empirical moments. The ordering fixed costs (ϕ_D, ϕ_I), average order delays (μ_D, μ_I), inventory depreciation rate (δ) and the variance of the idiosyncratic shock process (σ_ν) shape the ordering and inventory behavior in the model. We set these parameters to match the average restocking times, inventory-purchase ratios and ordering frequencies in the data.

Measuring delays is difficult because the ISM data not allow us to measure the differences between domestic and international transactions. Thus, we cannot determine both μ_D and μ_I from the data. As a starting point, we assume the delay in international shipments is 45 days in order to match the ISM data on production materials. We provide sensitivity analysis to these values.

We target the steady-state aggregate inventory-purchases ratio of 1.4 quarters, as it is in the U.S. data.[4] The inventory-purchases ratio of imported goods is 2.5 times that of domestic goods, as documented in (Alessandria et al., 2010b; Nadais, 2017; Khan and Khederlarian, 2020). From the ordering frequency data, we target that 30 percent of importers order per quarter and domestic buyers order twice as often, in line with the evidence in Alessandria

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[3]Boehm et al. (2019) estimate a firm level substitution following the Tokhu earthquake and find foreign inputs are Leontief with domestic inputs.

[4]In our model, all inventories are held by the retail/wholesale sector, while in reality, inventories are distributed across manufacturers, wholesalers, and retailers. Thus, we use the aggregate inventory-purchases ratio in the data.

et al. (2010b) and Alessandria and Ruhl (2021).

To match these moments, we set the variance of the demand shocks to be 1.5 and the annual depreciation rate to 20 percent, similar to the value in (Richardson, 1995). The fixed cost of ordering the domestic good relative to the imported good is critical in determining the ordering frequencies. These parameters are set to be 1.2 percent and 12.9 percent of average quarterly revenues for domestic and imported goods buyers, respectively. Given our targets, the probability of receiving the domestic good in the current quarter is calibrated to get an average domestic delay of 23 days. In total, the expenditure-weighted delay is 27 days so that slightly more than two-thirds of inputs are received in the period they are ordered.

5   Baseline model

Before studying the model with transitory shocks, we study the firm-level and aggregate responses to a permanent change in shipping times. We add 30 days to international shipping (in both countries) and leave domestic shipping times unchanged. From the perspective of the importer, this increases inventory holding costs by one-third of the quarterly interest and depreciation rates: $(r + \delta)/3 \approx 2\%$. We report our results in Table 2.

The longer shipping time is contractionary. Importing firms adjust to the increase in shipping times by holding more inventories to guard against stockouts and ordering more often. The aggregate inventory-purchase ratio rises by 10.1 percent. Importing firms pass through the higher inventory holding costs to their prices, and the aggregate consumption price rises by 1.3 percent; real consumption falls by 1.4 percent. The decrease in manufacturing production decreases the labor used in production by 0.15 percent, but more frequent ordering by importers increases the labor used in paying order costs. The second force dominates, and total labor supplied in the economy increases by 0.12 percent. Imports are relatively more expensive, so the manufactured- and consumption-good firms substitute towards domestic varieties. The import share falls by 0.8 percent.

The parameter γ governs the substitution between domestic and imported goods in response to the change in relative prices induced by the increased import shipping times. In Table 2 we report sensitivity to this parameter.[5] When the elasticity is increased from one to

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[5]When we change γ we recalibrate the fixed order costs so that the XXX what do we do? only two

two, the import share falls more, but the other aggregate effects are largely unchanged. If the elasticity is 0.5, the import share rises, but the other aggregate are also largely unchanged.

We can compare the effects of shipping times on trade and income in the model to some results in the literature. Djankov et al. (2010) study a group of low-income countries and find that an extra day of shipping lowers trade across sources by 1.3 percent, more so for less-storable goods. We find that an extra 30 days in transit will lower international trade relative to domestic purchases by 0.82 percent—about one-fiftieth of their estimate.

The effect of delivery times on international trade in the model depends on the elasticity of substitution between domestic and imported goods. Given our focus on the short-run responses to transitory delays, we chose an elasticity from the business cycle literature, which is significantly lower than those used in the trade literature.[6]

The effects on international trade of changes in the relative delivery time between suppliers in the model depends on the elasticity of substitution, which given our focus on the dynamic response to transitory delays we have targeted to be low relative to the trade literature.[7] With an elasticity of substitution of **10** we can recover a similar effect of time on trade as in Djankov et al. (2010). The negative effects of time on trade in our model also depend on holding costs, specifically the interest and depreciation rate. Thus the model is consistent with the larger effects on trade for less storable goods found in the data. With a higher holding costs, as one might expect for the sample of countries used in Djankov et al. (2010), the model can be made more consistent with the data with a lower elasticity of substitution. [8]

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parameters need to be changed?

[6]The results on delays are based on the amount of substitution between different sources of imports, which are generally much more substitutable than domestic and imported goods. More generally, if we had products within the imported nest with different time to trade we could also recover these results.

[7]The results on delays are based on the amount of substitution between different sources of imports, which are generally much more substitutable than domestic and imported goods. More generally, if we had products within the imported nest with different time to trade we could also recover these results.

[8]Feyrer (2019) also estimates the elasticity of trade to shipping using a change in the log of shipping times from the Suez canal closing and opening and finds an elasticity of about -0.15 to -0.45, with the bigger responses accumulating over time. This elasticity estimate is of similar magnitude to those in Djankov et al. (2010).

6 Alternative Models

We introduce two alternative models to help isolate the key determinants of the aggregate effects of the delays. In the first variation we eliminate the reliance of production on inputs held by our retail wholesale sector. This is the model developed in Alessandria et al. (2010b). In the second model, we eliminate all the supply frictions related to inventory management and replace them with an iceberg cost that yields the same trade flows. This is a variation of the Armington trade model common to most studies of international business cycles.

6.1 No roundabout production

Our model features supply chain frictions for production and consumption. To highlight the role of these supply chain frictions we remove them from production. That is, we assume that all trade is in final goods and that final goods are not used in the production of intermediates but rather just labor. To match the level of trade to value added we increase the taste parameter in consumption, τ_c, accordingly. There is still a vertical structure to production with goods moving from producers to retailers and then consumers.

6.2 Armington model

Our model nests standard models used for analysis of aggregate shocks to technology, government spending, and trade barriers. The traditional Armington model is recovered when we set the fixed order costs to zero (ϕ_i), remove delivery delays ($\mu_i = 0$), eliminate the demand shocks ($\sigma_v = 0$) and assume goods depreciate completely within the same period $\delta = 1$. The Armington model summarizes the wide range of static and dynamic trade costs in the baseline model with the two taste parameters, (τ_c, τ_m) and an iceberg shipping cost, ξ.[9]

The Armington model is calibrated to match the same trade and macroeconomic targets. To match the same level of trade we increase the home bias in the Armington model by reducing the Armington weights ($\tau_c = 0.03$ and $\tau_m = 0.28$). The lower weights capture the

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[9]The Melitz-Chaney model is recovered when we eliminate delivery delays ($\mu_j = 0$), and assume goods depreciate completely within the same period $\delta = 1$. This is a variation of those models with a constant set of firms and the fixed costs yields active and inactive producers. The idiosyncratic demand shock is chosen to capture the mass of export participants and their size.

importance of the inventory frictions as emphasized by Alessandria et al. (2010a). To align economic activity across models, we also adjust the overall productivity of the intermediate goods sector up by 95 percent to match the same level of consumption as our baseline model holding hours worked constant. This increase captures the productivity equivalent of the inventories as a type of capital in the stationary equilibrium.

7 Aggregate Effects of Transitory Delays

In this section, we illustrate how the aggregate economy responds to an exogenous increase in shipping times for international and domestic goods. We consider the transition from a temporary change. We show that these effects can be larger if the economy has lower inventories. We also show how the effects of stimulus, modelled as a consumption subsidy, would be offset partly by supply chain delays. Finally, we also study the effects in alternative models without an input-output structure or without the frictions that give rise to inventories. In these alternative models the effect of delays or the trade cost equivalent of delays are minor.

7.1 A Transitory Shock to International Shipping Times

Our baseline analysis considers a shock, ε_{μ_I}, that temporarily increases international shipping times from 45 days to 90 days. Given the share of trade in total expenditures, this is equivalent to increasing the average shipping delay by about seven days. This requires lowering the probability of within-period delivery of imported goods, $1 - \mu_I$, to zero from its calibrated value of 0.5 for both countries We assume the shock is unanticipated and decays at a rate of 50 percent per quarter. Figure 8 plots the aggregate implications of this shock relative to the steady state.

The direct effect of the international delay is to reduce international trade, although the effects are non-monotonic and extremely large on impact owing to the nature of the shock. Recall that prior to the shock, half of imports ordered were delivered with a lag of one period. With the shock, all firms' import orders are delayed, so all imports in the initial period are from the prior period's orders. The large decline on impact is partially reversed in the second period as more goods arrive, the shock begins to abate, and firms begin to restock.

The delays in importing foreign goods lead to a substantial contraction in economic activity, with production, employment, and consumption falling sharply on impact. The largest effect is on production, which drops by 8.5 percent on impact. Production rebounds sharply in the second quarter, but still remains two percent below the initial steady state. The economy gradually converges to the steady state, although one year after the shock, with international delays only six days above steady state, production remains one percent below its steady-state value. The movements in production are larger than in employment or consumption. The smaller effects on employment are caused by the substitution between inputs and labor as well as an increase in logistic costs related to restocking inventories. The weaker effects on consumption are related to imports being less important for consumption than for production. The sustained effects of the shock are related to low inventories constraining production.

Given the difficulty in restocking within the period, more firms now face the possibility of a stock out in the period and they raise the price of the imported goods sold to consumers and intermediate-good producers. In Figure 8d, we see that the foreign-good price index increases by almost four percent on impact. The price increase in foreign goods feeds through to inflation in consumer and material prices. Consumer prices grow by more than five percent, and the material price, because it is more intensive in imported goods, increases by nearly seven percent.

7.2 Low Inventories

A key feature of the aggregate economy since COVID is the very low inventory levels. When inventories are low, the increase in shipping delays can lead to much larger aggregate effects. Specifically, we examine the aggregate effects of the import delay when the economy starts with aggregate inventories that are about half of their steady-state levels. To control for the natural recovery such inventories would entail we plot the path of the economy with the delay shock relative to the path without the delay shock. Figure 10 shows that the effects are magnified when the economy starts out with lower inventories. This result is intuitive, as lower inventories bring firms closer to stocking out, even without any delay in deliveries. Adding the delay results in firms charging higher prices to avoid stocking out.

7.3 Demand induced delays

Our analysis focuses on the aggregate effect of delivery delays. We attribute these to exogenous factors. Some aspect of these shocks–the closure of the Suez canal and the Covid-induced port closures in the world–are exogenous, but some aspect is related to reopening post-Covid and substantial stimulus. We now show that including these delays as part of another shock largely weakens the effects of that shock. For simplicity, we consider demand shocks that increase consumption and trade that hit the economy concurrently with our delay shocks. This reduced form way of correlating delays to demand is a useful stand-in for a richer endogenous mechanism.

To capture stimulus we modify the consumer's budget constraint to include a proportional consumption tax, τ_c that is rebated lump-sum. We assume that in steady state there is no consumption tax.

$$\tau_c(\eta^t)\mathrm{P}_c(\eta^t)C(\eta^t) + \sum_{\eta^{t+1}} Q(\eta^{t+1}|\eta^t)B(\eta^{t+1}) = B(\eta^t) + W(\eta^t)L(\eta^t) + \Pi(\eta^t) + T(\eta^t), \quad (30)$$

To capture the high demand for imported goods we also include a shock to the taste for imported consumption goods in the aggregator. These two shocks are unanticipated and also decay with an autocorrelation of 0.5. The effect of the international delays with and without the demand shocks are plotted in Figure 11.

The demand shock scenario largely increases consumption temporarily. After the surge in consumption, which is about 7.5 percent above our baseline experiment, consumption falls below steady state and stays much lower than our baseline scenario. The consumption boom is primarily accomplished through a much larger draw down of inventories. The effects on production are only slightly weakened. The prices increase is substantially larger as more firms' sales are constrained by their current stock on inventory. Owing to the larger draw on inventories and longer restocking period, prices are persistently elevated. Even two years after the shock prices are 1 percent higher than the steady state.

7.4 A Model without Input-output Linkages

Our model features an input-output structure with inventories and uncertain shipping times. A key feature of this structure is that the available inputs for consumption and production are partly constrained by the stock of inventory. We show that these supply constraints substantially magnify the effects of the delivery delay shock.

To evaluate the effect of shipping delays on production we make two changes. First, we eliminate the roundabout structure so that only labor is used to produce intermediate goods. Second, we assume all trade is in final goods. An implication is that all inventories are held as a buffer for consumption sales. If we eliminate the input-output structure and hold the other trade costs constant, we reduce the level of trade as a share of value added. To compensate, we increase the importance of foreign goods in consumption to maintain the same level of trade as a share of GDP.

Figure 12 compares the paths of the baseline economy with those from the model without roundabout production. The path of trade is quite similar in both models, but the aggregate effects are quite different. Without roundabout production, the shock has a muted effect on production, both on impact and over the following year. Indeed, production and employment fall only gradually with the peak effects occurring three quarters after the shock to shipping delays. In terms of consumption dynamics, the model without input-output linkages has a sharper drop on impact since consumption is more trade intensive, but it recovers much faster than in our baseline as inventories can be rebuilt faster without the constraint of using inventories in production.

7.5 Trade Cost Shock in Armington Model

We now compare the aggregate dynamics in our model to the extension of the Armington model described in subsection 6.2. The baseline model introduced two novel frictions, fixed ordering costs and time to ship, to capture important aspects of trade. How important are these features for accounting for the data? We show that matching the increase in trade cost of the benchmark model with iceberg costs in the Armington model is not sufficient to match the dynamics of output or consumption. Precisely, we introduce a shock to the iceberg costs that is equivalent to the increase in holding costs in transit. This shock allows

us to understand how the lack of availability of inputs operates separately from the cost of inputs. Figure 9 shows that the decline in trade, consumption, production, and employment are much smaller now. The key difference between the cost shock and a delay shock is that with a cost shock a firm with low inventories and high demand can still get their products quickly while the delay shock means the firms whose products are most valuable will be constrained in their sales.

8   A fitting exercise (in progress)

In this section we introduce several contemporaneous shocks to account for key features of the U.S. and global economy from the end of 2019 to early 2022. We then shut these shocks off one at a time to decompose the relative importance of each shock for the aggregate economy both in and out of sample. We find that shipping delays caused a substantial reduction in economic activity in 2021 and owing to their elevated levels will continue to be a drag on economic activity and source of elevated prices through 2023.

We focus on three types of shocks. First, to capture the decline in economic activity from COVID and the government lock downs, we introduce a productivity shock. This shock is larger and less persistent than in previous recessions. Second, we introduce a shock to capture the stimulus. This shock comes in two steps to capture the first and subsequent rounds of stimulus in the U.S. These stimulus shocks are large but also transitory. Finally we introduce our delivery delay shocks for domestic and international shipments. Save for the import delay shock, we allow all of these shocks to be asymmetric to capture differences in economic activity across country. We have 7 possible shocks. Key to identifying the differential shocks are the cross country differences in production as well trade, net and gross.

We assume the economy is in steady state in 2019Q4 and 2020q1. In 2020q2 it is hit by a shock that affects each of our main exogenous variables at different times over the next two years. Thus there is a single shock that affects the exogenous states to different extents. Agents have perfect foresight over this new path. We choose these shocks to match the 6 aggregate series in Figure 7 and the evidence on delays at home and abroad. To capture the dynamic path of the shocks we allow each series to follow an AR2 process. We then choose

the size of the initial shock along with the coefficients of the AR2 process to minimize the root mean squared error between the model and the data in the eight quarters of 2020 and 2021.

In figure 13 we plot our target series along with the paths predicted by the model. The model captures the salient features of the data quite well, particularly the collapse and recovery in 2020 and into 2021. The model misses out on the expansion in row production, U.S. sales and trade in 2021.

In figure 13 we also plot counterfactual paths for our macroeconomic time series eliminating the delivery delays. Without delays we find a much more modest decline in economic activity and trade. Sales actually rise owing to the stimulus

9 Final Thoughts

Lead times to acquire inputs depend on where the inputs are being sourced. Firms consider these lead times, and the uncertainty around them, when finding suppliers, placing orders, and producing. These lead times, along with other supply chain frictions, are reflected in a firm's inventory holdings and pricing decisions. Firm's can use their inventories to a certain extent as a buffer to unexpected and expected delays or demand uncertainty, but they do impose a constraint on current sales and production, especially when shocks are very large or restocking is hard.

Lead times can vary over the cycle for endogenous and exogenous reasons. In 2021, these lead times in the U.S. rose to extreme levels unseen for 50 years owing to a confluence of factors. We show how changes in these lead times, both domestic and international, can influence the aggregate economy. In particular, we show that an increase in lead times similar to those in 2021 can be quite contractionary, more so when inventories are already low, and lead to a substantial, but transitory increase in prices. The restocking cycle increases the persistence of these shocks on prices and production.

Our model allows us to decompose the source of aggregate economy in the U.S. and the world economy. Delays in moving goods appear to have been a substantial drag on economic activity and a source of rising prices. Given the challenges in bringing these delays down, our model suggests these will continue to be an important factor in aggregate economic activity.

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10   Figures and Tables

Table 1: Parameter Values and Moments

Common parameters:		$\beta = 0.96^{1/4}$, $\theta = 4$, $\psi = 1.2$				
Moments		Parameters		Baseline	High EoS	Low EoS
		Armington Elasticity	γ	1.1	2	0.5
Value added to gross output	36%	Input cost share	α	0.5	0.6	0.5
Trade share of value added	33%	Home bias manufactures	τ_m	0.4	0.45	0.4
Manufactures' share of imp	80%	Home bias consumption	τ_c	0.045	0.05	0.045
Inventory-Sales ratio (dom)	0.39	Depreciation	δ	5.5%	5.5%	5.5%
Inventory-Sales ratio (imp)	0.98	Domestic delay	$\bar{\mu}_D$	23 days	23 days	23 days
Inventory-Sales ratio (agg)	0.45	Demand variance	σ_x^2	1.5	1.1	1.1
Authors' choice		Import delay	$\bar{\mu}_I$	45 days	45 days	45 days
Order freq (dom)	60%	Fixed order cost† (dom)	ϕ_D	0.85%	2.03%	1.93%
Order freq (imp)	30%	Fixed order cost† (imp)	ϕ_I	15.62%	15.54%	13.84%

†Expressed as share of average revenue.

Table 2: Steady-State Results – Increase import delay by 30 days

Model	Percent change in					
	Import share	Inv/Purch (Agg)	Total labor	Prod labor	Consumption	P_c
Baseline	–0.78	10.12	0.12	–0.15	–1.36	1.33
High γ	–3.11	8.50	0.12	–0.12	–1.09	1.07
Low γ	0.95	8.60	0.15	–0.12	–0.94	1.06
Armington	–0.78	—	0	0	–0.53	0.53

Figure 1: Domestic and International Shipping Costs
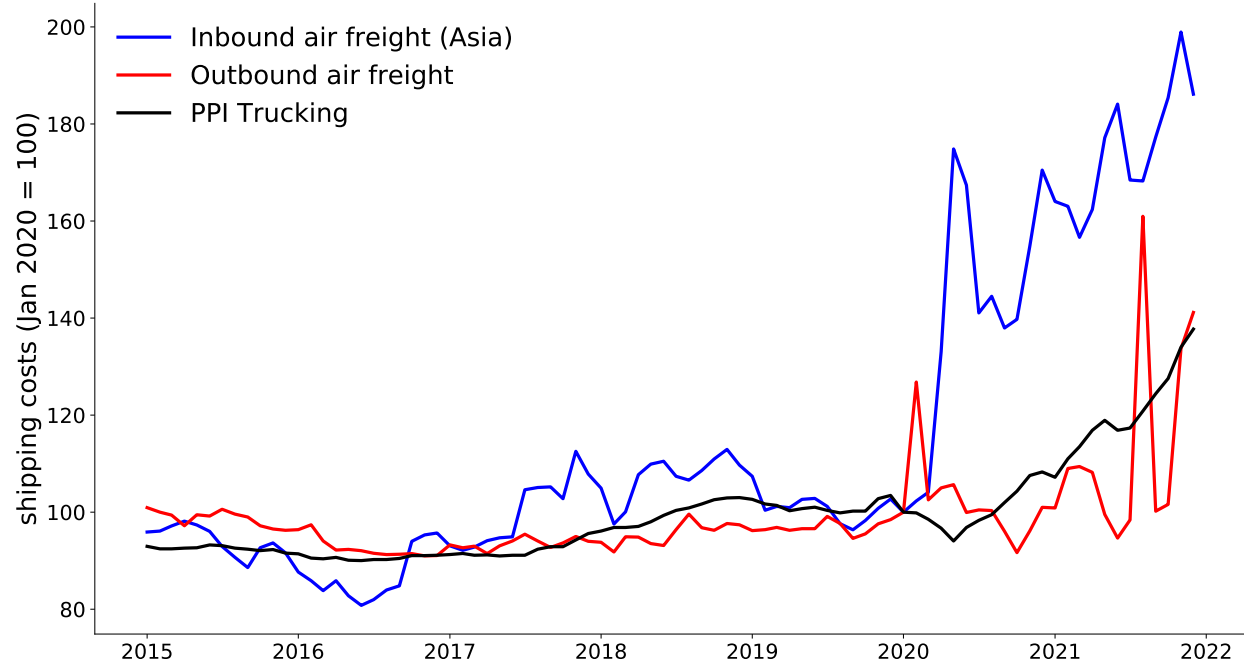
Figure 2: Delivery Delays

Source: IHS Markit; Last Obs:March 2022
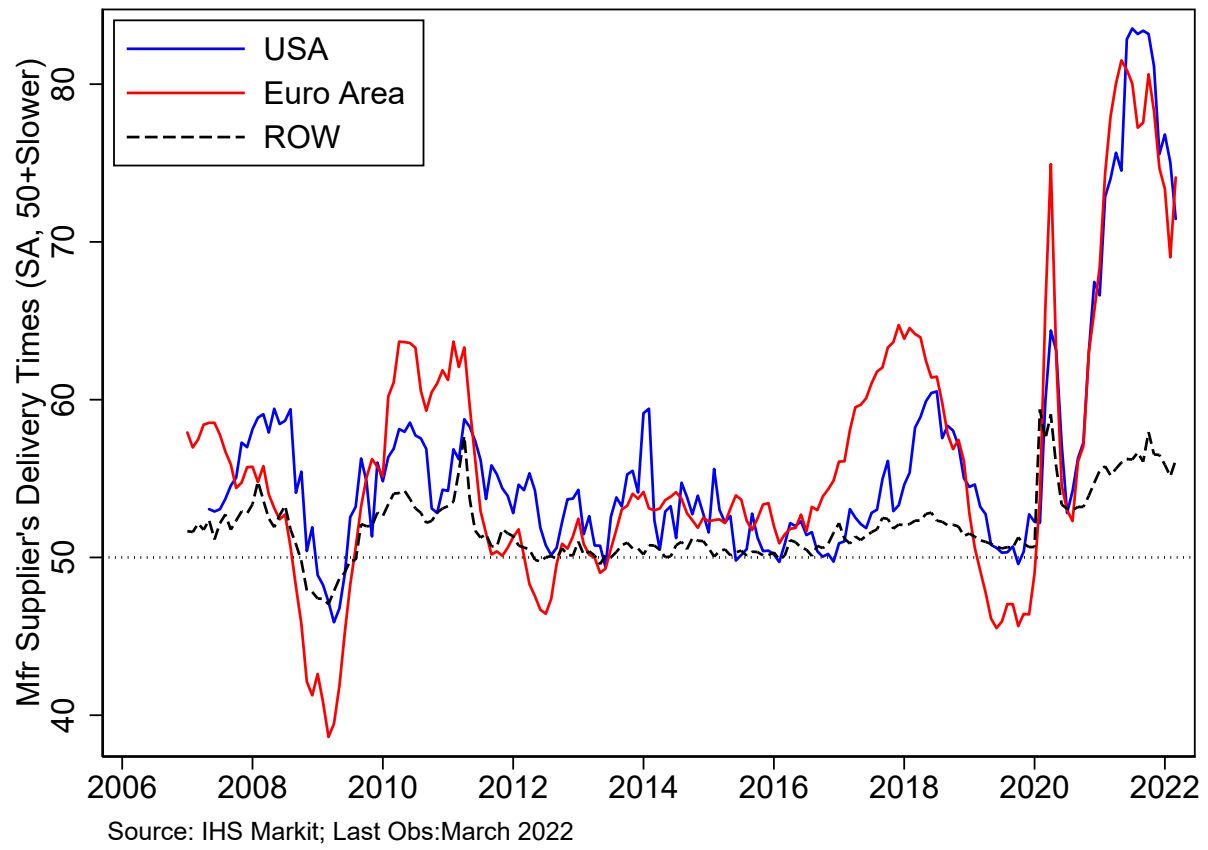
Figure 3: Delivery delays
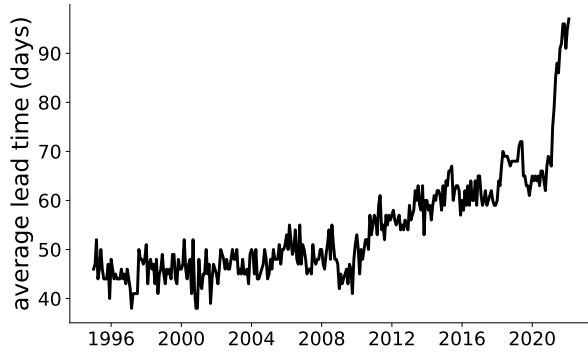
(a) Production materials
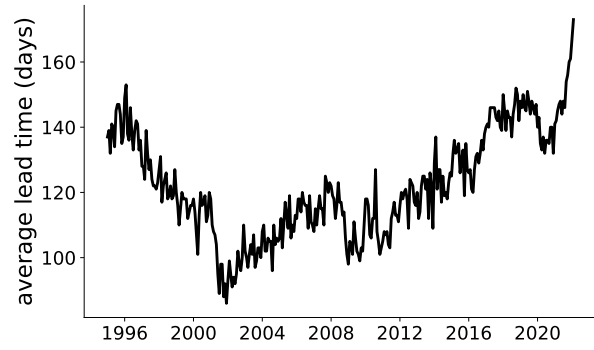
(b) Capex
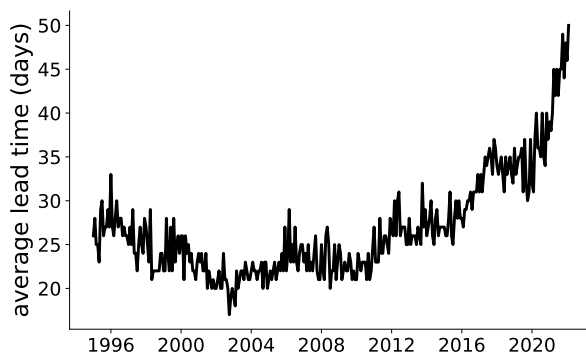
(c) MRO
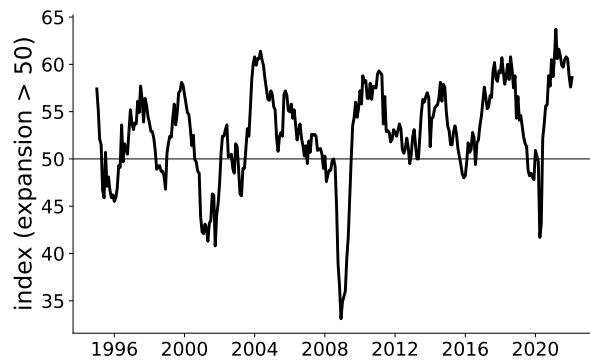
(d) Composite index

Figure 4: In the last week, did this business have any of the following?
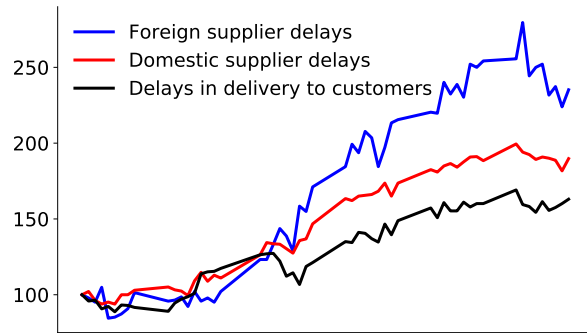
(a) Manufacturing
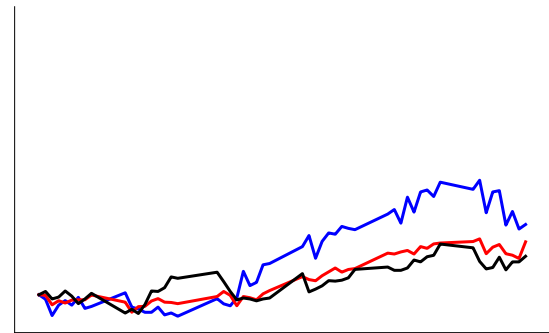
(b) Retail
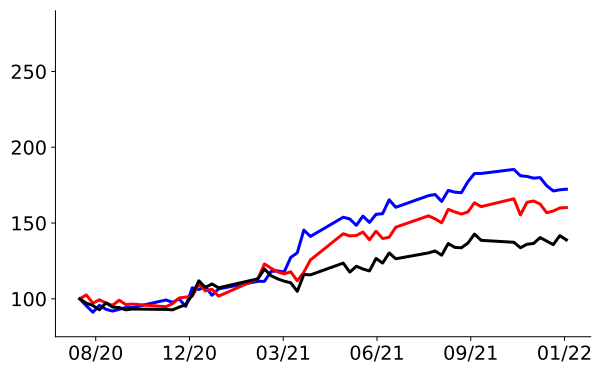
(c) Wholesale
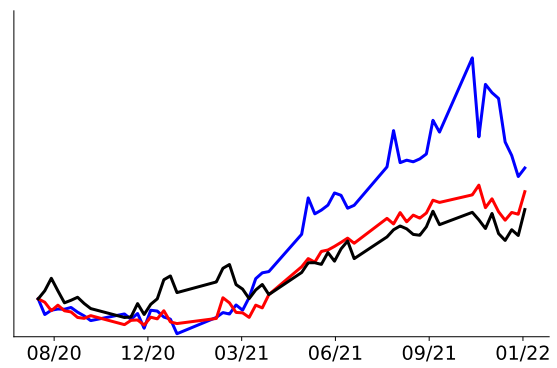
(d) Other

Figure 5: Shipping Time to US from China

China - US Ocean Shipment Transit Time - Freightos Marketplace Shipments
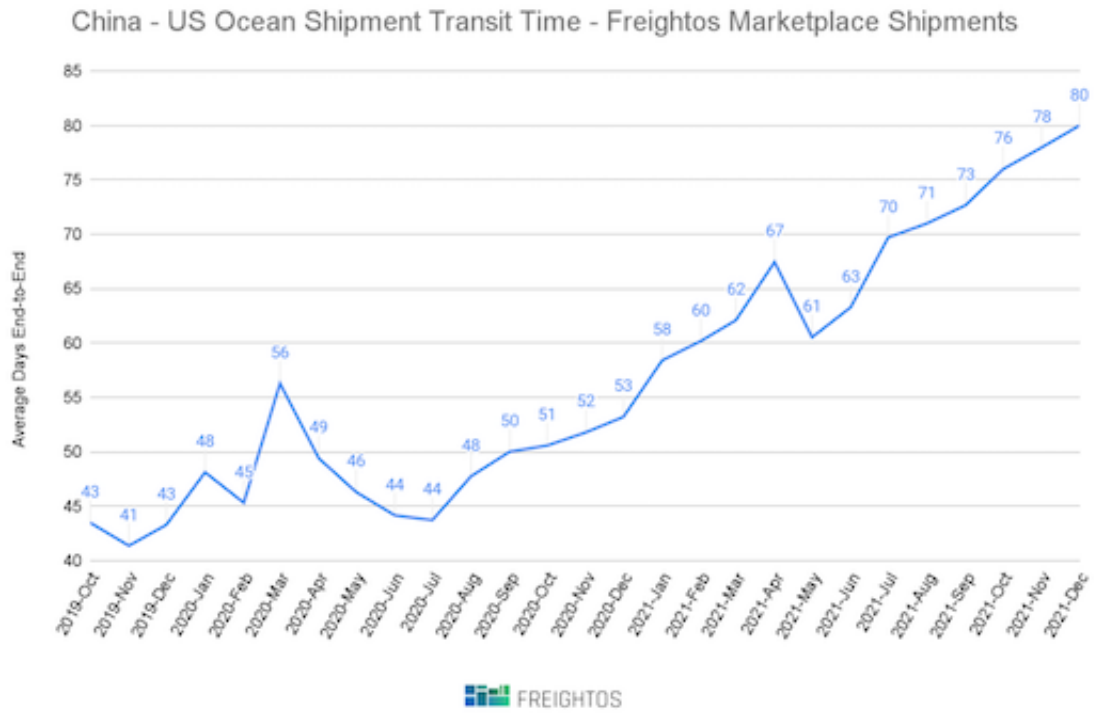
Figure 6: U.S. Inventory-sales ratio
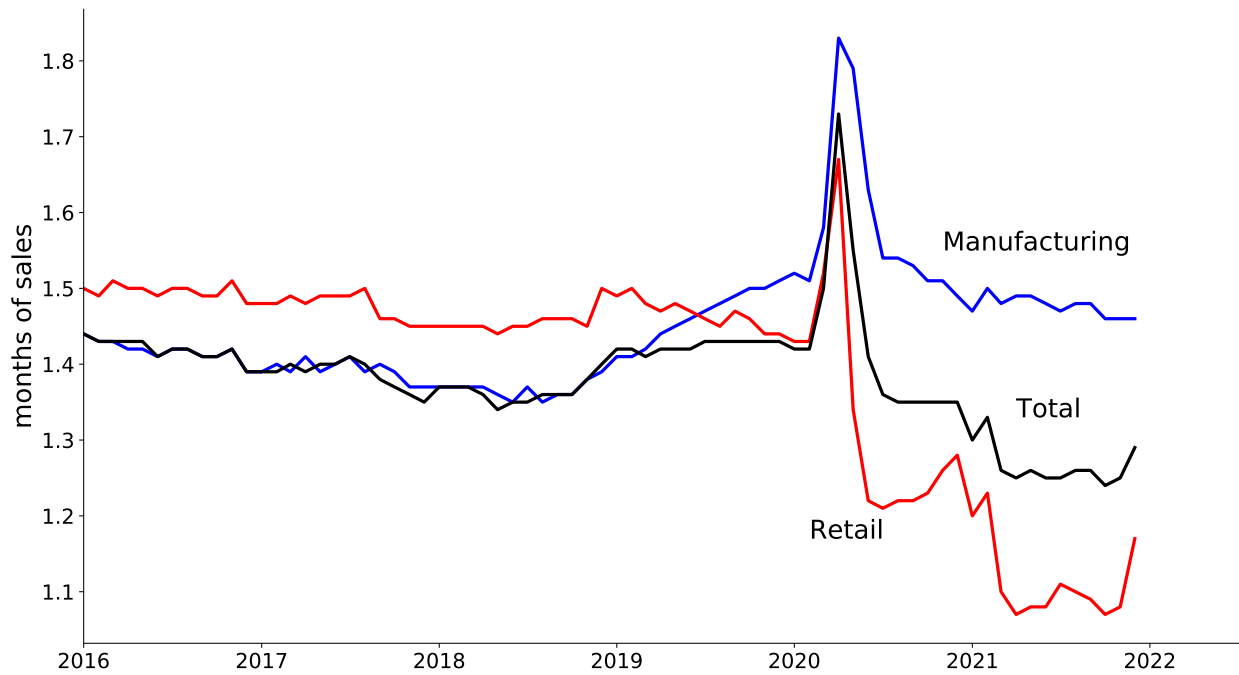
Figure 7: Salient Features
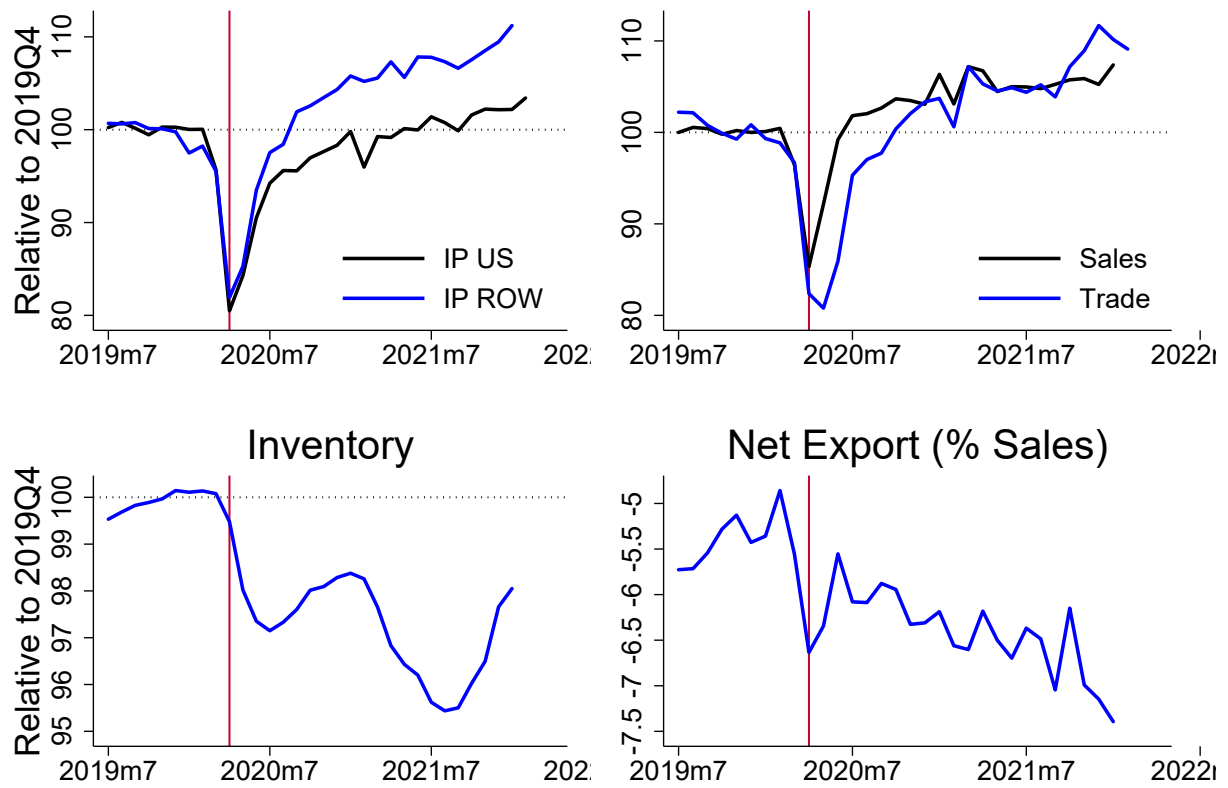
Last date: February, 2022, Source: Census, Dallas Fed

Figure 8: International delay shock
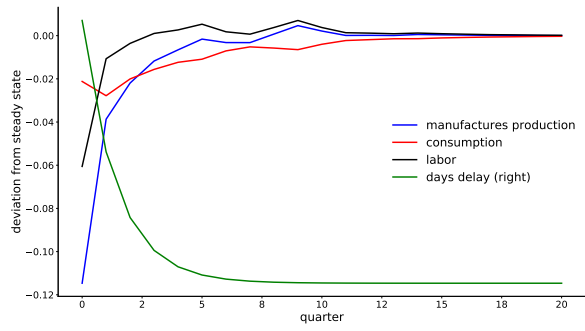
(a) Aggregates
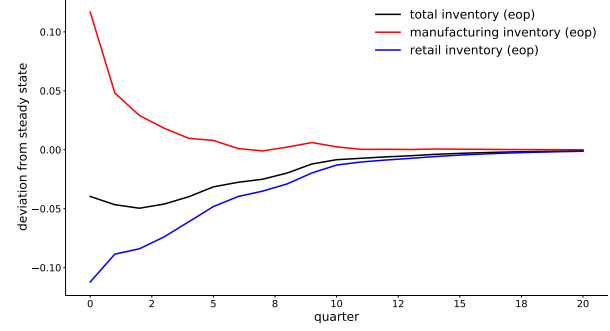
(b) Inventory
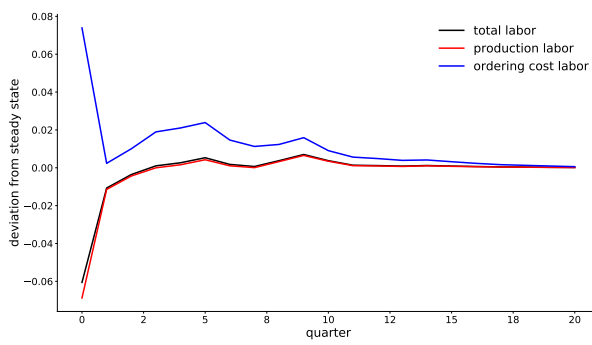
(c) Labor
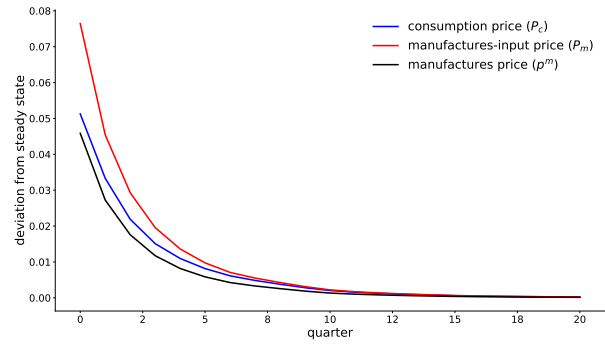
(d) Prices

Figure 9: International delay shock and trade costs

Trade Costs vs International delivery delays
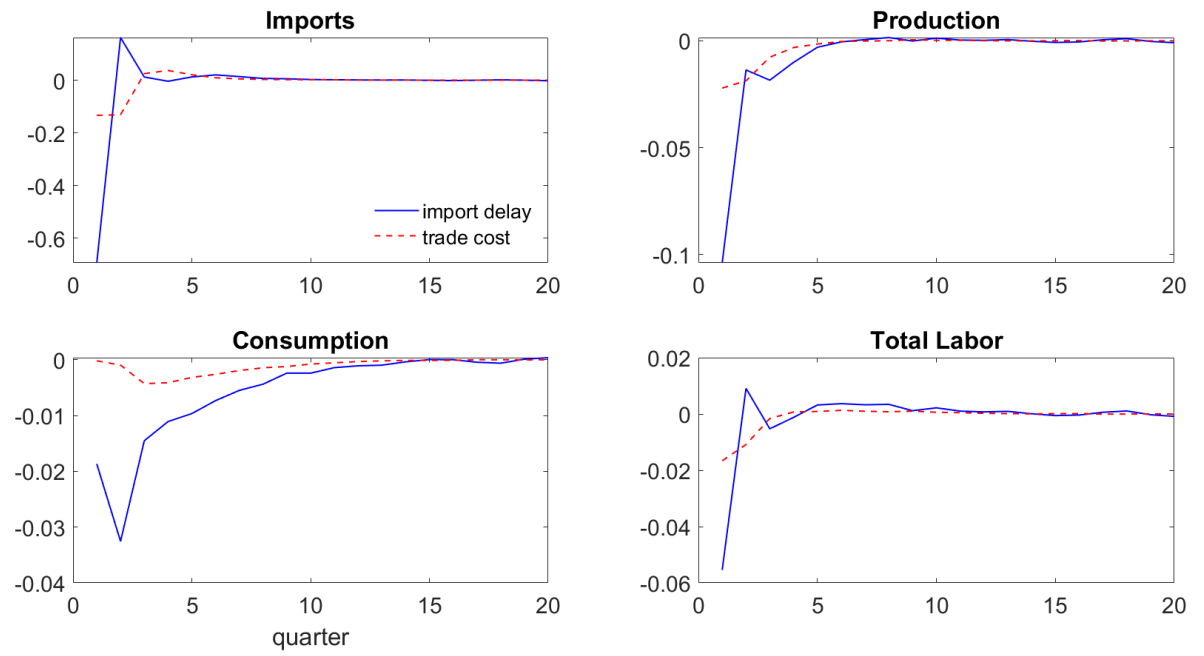
Figure 10: International delays and low inventories
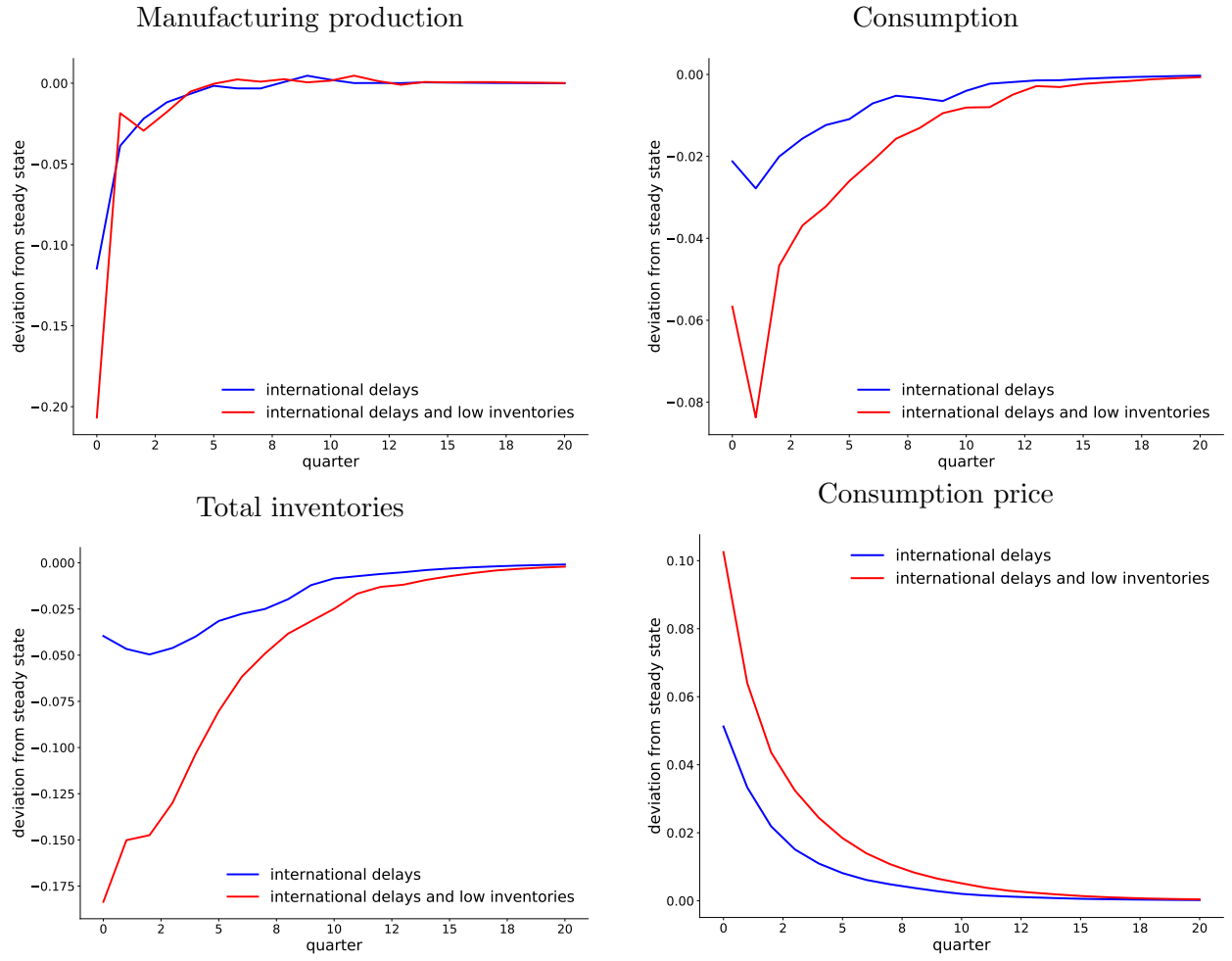
Figure 11: International delay shock and Stimulus
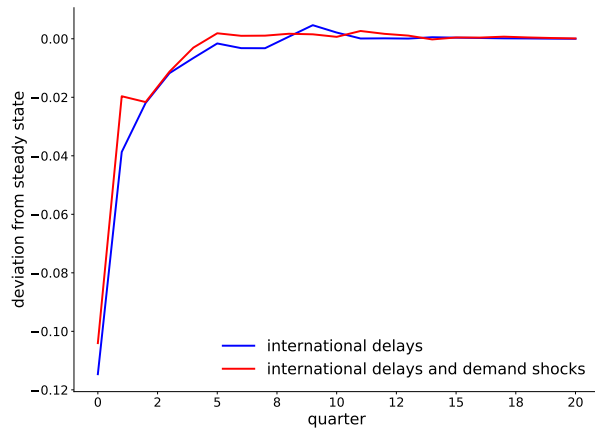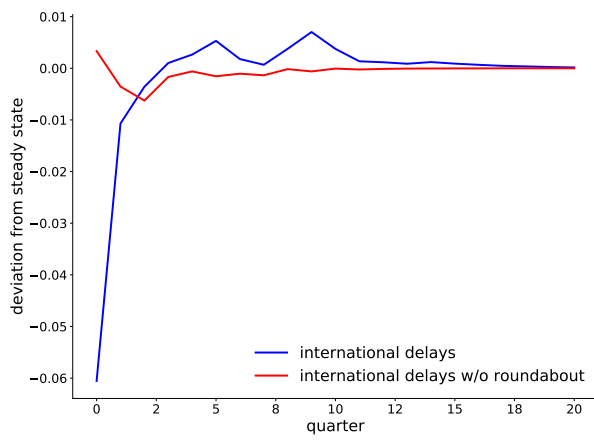
(a) Production
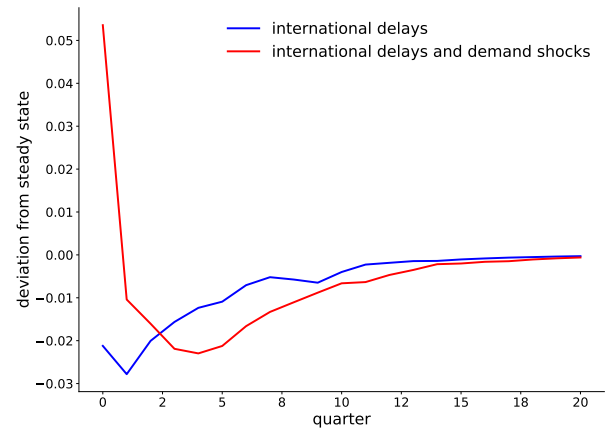
(b) Consumption
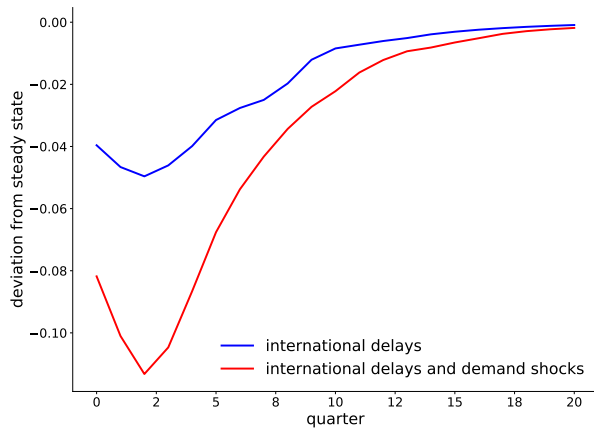
(c) Inventory
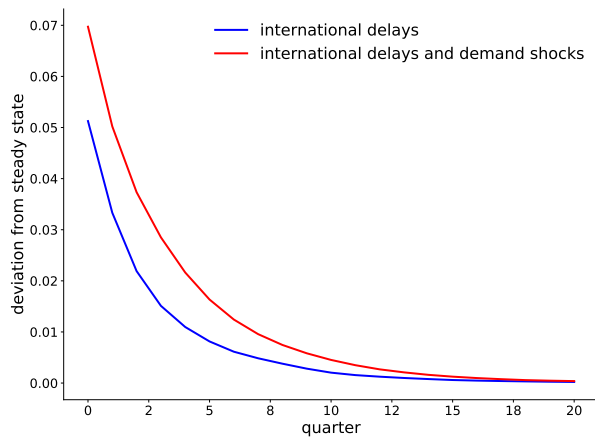
(d) Prices

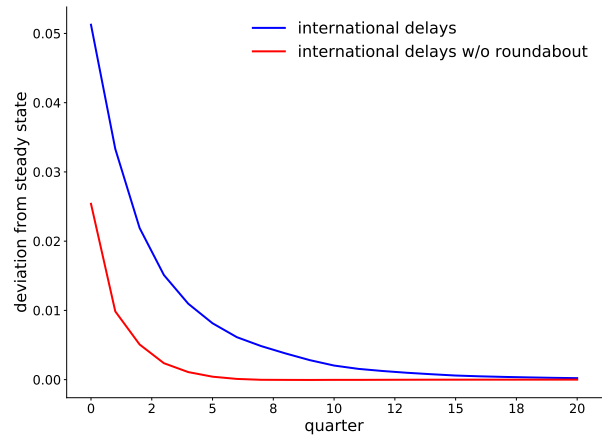Figure 12: International delay shock without production linkages
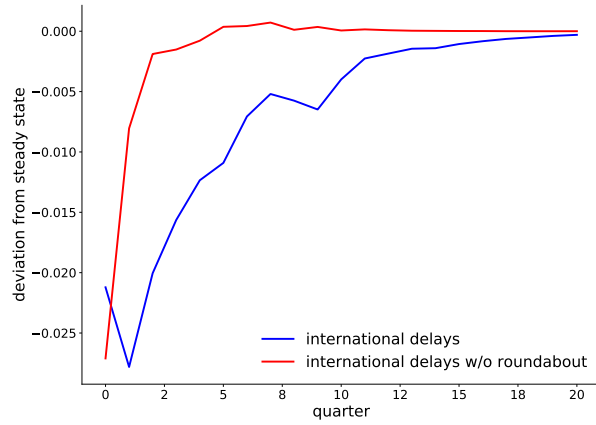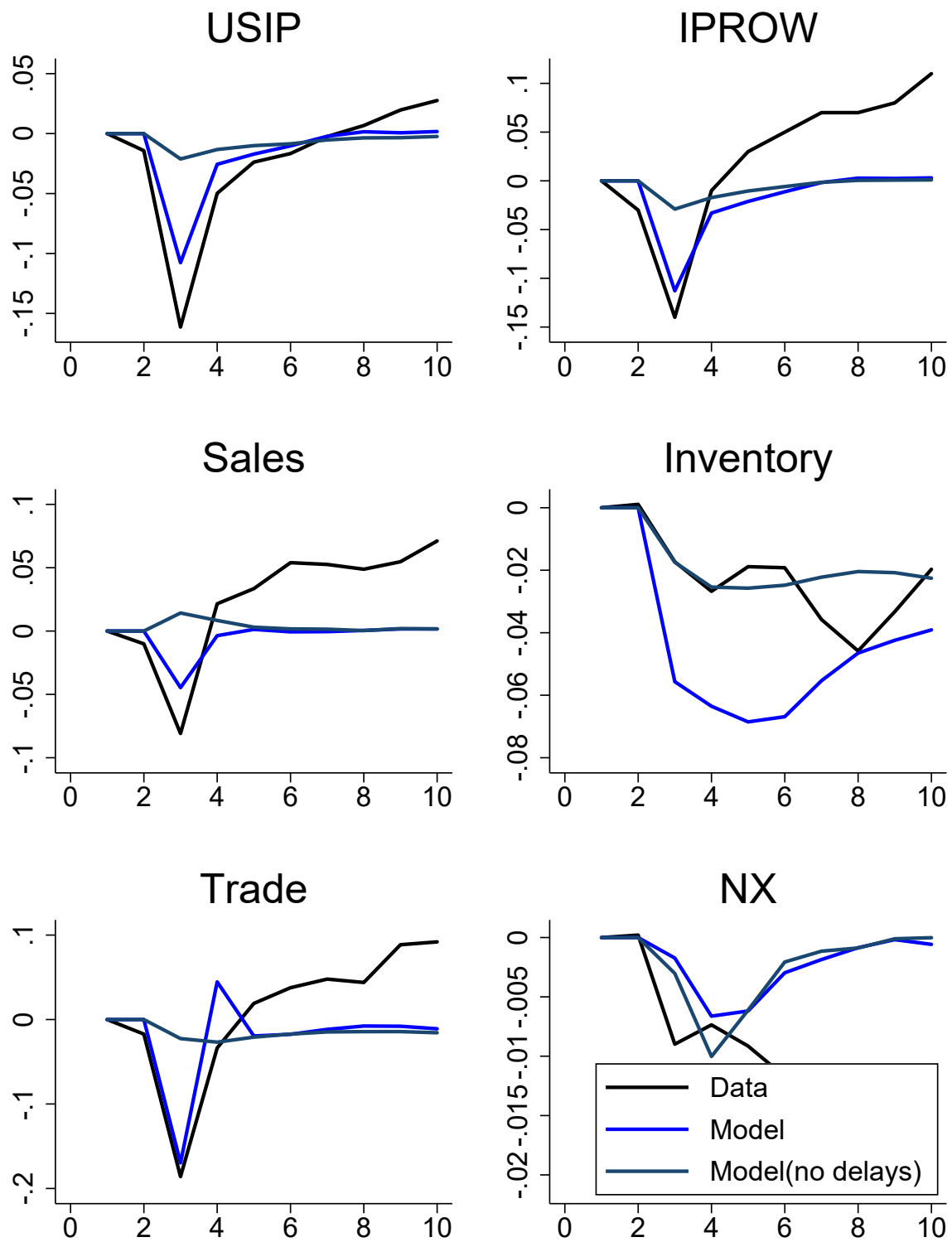
(a) Consumption
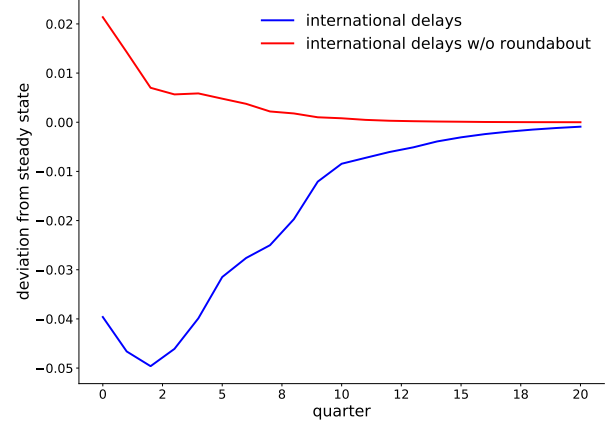
(b) Inventory

(c) Labor

(d) Prices

Figure 13: Aggregate Dynamics: Data and Model

Period 1 is 2019q4