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The Cost of Delivery Delays[†]

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Modern economies organize production along complex supply chains whose operation relies on the smooth functioning of logistics. Recent events have strained the international transport system and generated frequent supply disruptions. Yet measures of supply pressures or delivery delays are surprisingly difficult to estimate.

In this paper, we provide a model-based quantification of delivery delays in supply procurement and study their effects. We consider an economy in which firms face demand volatility and their foreign inputs face positive and stochastic delivery times. To produce, firms require inputs from China, the rest of the world (ROW), and domestic goods. Foreign inputs are subject to stochastic delivery times. Firms optimally hold inventories of their inputs due to the interaction between the demand shocks, the delivery days (first moment), and delays (second moment).

We target two trends in US manufacturing from 2018 to 2024: (i) The average distance traveled by US imports has declined, and (ii) the average input inventory to sales ratio has increased. We include the factual change in tariffs in the Trump–Biden trade war with China and estimate delays that jointly rationalize the trends. More details on these trends are shown in the Supplemental Appendix.

Using the increase in tariffs between 2018 and 2019, we show that the import substitution from Chinese to ROW inputs can rationalize the declining import distance. However, absent any other structural change, this would imply a reduction in the stock of inventories held by US firms since the average delivery times for Chinese imports are estimated to be larger than those of ROW imports. As a consequence, the model implies an increase in delays to rationalize the rising inventory stocks. We estimate that the average delay faced by US importers was between ten and five days when importing from China and ROW in 2018, respectively. These became 31 and 26 days at the onset of the global pandemic in 2020, and after a short decline, they are peaking again in 2024.

We compare our model-based measure of delivery delays to the private data on lead times reported by the Institute of Supply Management (ISM) used in its Manufacturing Purchasing Managers' Index. The lead times for maintenance, repair, and operating supplies (MRO); production materials; and capital expenditures feature a sharp increase in 2020 and remain higher in 2024 than pre-COVID levels. We find that our estimated delivery delays are consistent with lead times changes reported by the ISM: MRO supplies increased by a total of 11 days and production materials by 14 days, while our measure shows an increase of 11 days when we apply the ISM survey methodology to our generated data.

Finally, we compute the implications of the rise in delivery delays in terms of output and prices. First, we find that the combination of tariffs and delivery-delay increases generated an output drop of 7.3 percent and an increase in prices of 1.8 percent. These effects can be decomposed through the lens of the model. We estimate that the trade war alone induced a 5.1 percent drop in output and a 1.4 percent increase in prices, while the rising delivery delays alone would have generated a 2.6 percent drop in output and a 0.4 percent increase in prices.

I. Model

Following the framework in Carreras-Valle (2024), we introduce a model with stochastic delivery times for inputs and demand volatility to measure the rise in delays and quantify their cost in terms of output, prices, and sourcing choices. To produce the final good, firms require a domestic input, an

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input from China, and an input from ROW. We assume that domestic inputs are delivered within the period, while both foreign inputs face pair-specific and stochastic delivery times. Firms are able to stock inventories of foreign inputs to insure against the firm-specific i.i.d. demand shocks and delivery time shocks for each of the foreign inputs.

We consider a partial equilibrium analysis, where the economy is composed of a unit continuum of monopolistically competitive final-good producers, $j \in [0,1]$. They behave monopolistically and produce a unique variety of the final good, y_j. Final-good firms maximize profits subject to six constraints. First, each firm faces the demand from the representative consumer, $y_j(p_j) = \nu_j Y(P/p_j)^{\epsilon}$, where $\nu_j \sim_{\text{i.i.d.}} G(\mu_\nu, \sigma_\nu)$. Second, a firm's technology combines the domestic input, x_j^d; the input from China, x_j^c; and the ROW input, x_j^f, using a constant elasticity of substitution (CES) to produce the final good: $y_j = \left(\sum_{i \in \{c,f,d\}} \theta^{i\frac{1}{\sigma}} x_j^{i\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}$.

Third, the inputs from China and ROW, $i \in \{c,d\}$, face stochastic delivery times. Only a fraction λ_j^i of the order of the inputs, n_j^i, is available for them to produce that period. Thus, inputs used to produce, x_j^i, are constrained to be less than or equal to the initial level of inventories, s_j^i, and the fraction λ_j^i of the order that arrives before production takes place, $x_j^i \leq s_j^i + \lambda_j^i n_j^i$, where $\lambda_j^i \sim_{\text{i.i.d.}} F(\mu_\lambda^i, \sigma_\lambda^i)$.

Fourth, firms are able to store inventories of each foreign input, which depreciates at a rate δ. Inventories tomorrow, $s_j'^i$, are equal to the discounted inputs left after production, plus the remaining order arriving next period, $s_j'^i = (1-\delta)(s_j^i + n_j^i - x_j^i)$. We assume that, on average, inputs from ROW face shorter delivery times than inputs from China, $E[\lambda^f] > E[\lambda^c]$. The domestic input, x_j^d, can be delivered entirely within the period, so the firm has no incentives to hold inventories for this input.

Last, firms face a timing constraint whereby they must place the order of the foreign inputs before the demand and delivery time shocks are realized for the period. Firms place their orders according to their initial level of inventories and expected shocks. After the firm-specific demand and delivery time shocks are realized, the fraction, λ^c, λ^f, of the orders arrive and can be used for production. Then firms decide on the amount of each of the inputs, x^d, x^c, x^f, they can use to produce and set the price, p. The recursive problem of the firm is detailed in the Supplemental Appendix.

When selecting a production input bundle, firms consider not only the relative prices of inputs but also their inventory costs. The amount of inventory needed for each input depends on their delivery time distribution. Sourcing inputs with long delivery times means that the firm receives only a small portion of the order placed today. To consistently meet demand, firms must maintain larger inventories of these inputs. Furthermore, if an input faces volatile delivery times, which we refer to as delays, where the share of the input order that arrives today is uncertain, firms hold additional inventory of the input. Hence, inputs that face long delivery times and delays are optimally more inventory intensive.

Before moving to the quantification of the model, we consider two useful mechanisms at play in the model: an increase in the price of an input and an increase in delays. As the price of an input rises, under our CES technology assumption, firms substitute away from that input and toward the remaining two inputs. If the price of an inventory-intensive input increases, then the total inventory stock decreases. Firms turn to inputs with shorter or less volatile delivery times that require less inventory. With rising tariffs on inputs from China, US firms are shifting away from these inputs and increasing their reliance on domestic and ROW inputs, which offer shorter and more stable delivery times. Consequently, total inventory holdings decrease.

Firms' incentives to store inventories are driven by not only the mean but also the variance of the distribution of delivery times or delays. An increase in the standard deviation of delivery times raises the value of holding an additional unit of inventories. Thus, inputs facing longer and more frequent delays have higher inventory costs. However, the effect of a change in delays on inventories is a priori ambiguous. On the one hand, as the firm substitutes away from that input, it needs to hold less of those inputs as inventories. On the other hand, higher delays increase the amount of inventories per utilized input that the firm needs to hold. As a consequence, the net change depends on how easily inputs can be substituted and whether firms are moving toward more or less inventory-intensive options.

II. Quantification

We calibrate the model to match moments of the US manufacturing sector in 2018. Then we use data on the US-China tariff increase, the decline in imports from China, and the rise in input inventories to calibrate the rise in delivery delays.

Delivery times for each of the foreign inputs in the model are determined by the stochastic parameter λ, which represents the proportion of days within a period that the firm is able to use the order to produce. Thus, given the number of days in a period, T, λ equals the maximum between the proportion of days of the period that the firm has the input in its warehouse and can use it to produce, $1 - delivery\ days/T$, and 0, which is a one-period delivery lag common in the literature; $\lambda_j^i = \max\left\{1 - delivery\ days_j^i/T,\ 0\right\}$, where $delivery\ days_j^i \sim G^i\left(\mu_i, \sigma_i\right)$.

We assume that each distribution for delivery $days_j^i$ is log-normal and estimate the geometric mean to be equal to the mean of delivery days in the data. Further, we calculate the geometric standard deviation such that two-thirds of the distribution lies within the observed delays. In this case, delays can be either early or late deliveries relative to the expected delivery date.

To estimate the delivery-day distribution for the inputs from China, we use data on ocean transportation times. Around 80 percent of total imports that arrive from China use ocean transportation, which takes on average 30 days to arrive in the United States according to the logistics company Freightos. The delays reported by Sea Intelligence, defined as days before or after the expected delivery, are approximately ten days. Thus, the geometric mean, μ_f, equals 30, and the standard deviation equals $\sigma_f = \left(\mu_f + delay\right)/\mu_f = 4/3$.

To estimate the parameters of the distribution of delivery days for the ROW imports, we compare the distance traveled by imports from China to the import-weighted distance of imports from ROW. According to the distance reported by CEPII, imports from ROW travel 65 percent of the kilometers traveled by imports from China; thus, $\mu_c = 0.65\,\mu_f$ and $\sigma_c = 0.65\,\sigma_f$.

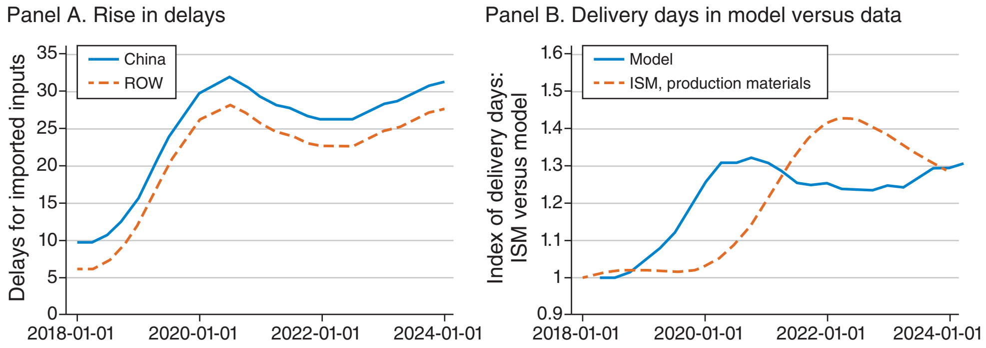
A period is equal to a quarter, $T = 90$ days. The discount factor is set to $\beta = 0.96^{1/4}$, which corresponds to a 4 percent annual interest rate. The depreciation rate for inventories, δ, equals 7.5 percent, which implies a 30 percent annual rate following the work by Richardson (1995). In line with the literature, we set the elasticity of demand for a firm's variety of the final good, ϵ, equal to 4 to generate markups of 1.33.

The remaining parameters are jointly determined to match four moments from the data. First, we set the weight of inputs from China, $\theta_c = 0.089$, and the weight of inputs from ROW, $\theta_f = 0.444$, to match the imports from China over sales of 8.9 percent and imports from ROW over sales of 27.7 percent. Second, we assume that the demand shocks, ν, are drawn from an i.i.d. log-normal distribution, where the standard deviation, σ_ν, equals 0.638 to match the input inventories over quarterly sales of 28.8 percent in 2018.

Last, we calibrate the elasticity of substitution between inputs, σ, to match the decline in imports from China over sales of 3.2 percentage points from 2018 to 2024. To do so, we first measure the import-weighted rise in tariffs for imports from China, as in Amiti, Redding, and Weinstein (2020), which equals 15 percentage points. Given the rise in the tariffs, we then calibrate the elasticity of substitution required to match the decline in imports from China over sales. The elasticity, σ, equals 4.51. Robustness exercises for different parameters are detailed in the Supplemental Appendix.

III. Quantifying the Rise in Delays

To quantify the rise in delays, we internally calibrate the change in the relative price of inputs from China and the standard deviation of the delivery times for foreign inputs from China and ROW for each quarter from 2018 to 2024. We do so by matching the HP-filtered decline in the manufacturing imports from China over sales and the rise in input inventories over quarterly sales observed in the data. We start by computing the steady state in 2024, where we calibrate the rise in the delivery delays to match the input inventory over sales. To do so, we adjust the geometric standard deviation of the delivery days of both the inputs from China and ROW as follows: $\sigma_t^i = \left(\mu^i + delays_{inital} + \Delta delays_t\right)/\mu^i$. We find that a rise in delays of an additional 21.25 days matches the 2024 input inventory data.


Panel A. Rise in delays

Panel B. Delivery days in model versus data

Figure 1. Delays and Growth of Delivery Days

Notes: Panel A shows the 21-day rise in the delays for inputs from China and ROW quantified in the model. Panel B shows the comparison between the growth in delivery days in the model and the production materials reported by the ISM. The growth from 2018 to 2024 is consistent for both series.

Next, we obtain the calibrated change in delays, $\Delta delays_t$, and the price of the input from China, $\tau_t p^f$, for each quarter from 2018 to 2024. We use backward induction under the assumption of perfect foresight along the transition. Panel A of Figure 1 shows the rise in delays for both foreign inputs. The rise in delays has an initial peak of 21.4 days in the second quarter of 2020, following the rise in the inventory data. Then delays decline to around an additional 16 days during the first quarter in 2022, but they rise back to 21.2 days in 2024. Delays remain high in 2024 since imports from China continue to decline and delays rise to match the increase in inventories.

IV. Comparing Our Delivery Delays to the Data

We compare our model measure of delivery times to the private data on lead times reported by the ISM. To do so, we replicate the ISM methodology to obtain average delivery days, and focus on the series for production materials. The ISM details the number of manufacturing firms in its sample that report their lead times in a bin of time, bin_j, for $j = \{5, 30, 60, 90, 180, 365 \text{ or more}\}$ days. Then they compute the average lead time by taking the average across bins.

For our measure of delivery days, we take a large number of draws, N, from our estimated distributions of delivery times for each input, $i \in \{c, f\}$, for each quarter from 2018 and 2024. Then we classify each draw in a bin_j, and take the import-weighted average using data on imports from China and ROW as follows: $days_t = \sum_{i \in \{c,f\}} \frac{x_t^i}{x_t^c + x_t^f} \sum_j bin_j \sum_{k=bin_j}^{N} \frac{days_k^i}{N}$.

Panel B in Figure 1 shows the comparison between the growth in our model-based measure and the production-material days reported by ISM. We find that while the model-based days grow faster than the ISM days at the beginning, the growth from 2018 to 2024 is consistent for both series. The model-based measure grew by 11 days and by 14 days for the ISM data. More details and comparisons to MRO lead times are shown in the Supplemental Appendix.

V. The Costs of Delays

In our model, the combination of the rise in a 21-day delay and an increase in tariffs for inputs from China leads to a drop in output of 7.3 percent and an increase in prices of 1.8 percent. Inventories are influenced by two opposing factors. On one hand, the increase in tariffs prompts firms to shift away from Chinese inputs, which have the longest delivery times and delays, reducing the need for inventories. On the other hand, as delays grow, firms are compelled to hold more inventories per unit used. Given our calibration strategy, the impact of delays will outweigh the substitution effect,

Table 1—Quantify Costs of Tariffs and Delays

	2018 benchmark (1)	Tariffs $\uparrow \tau^c$ (2)	Delays $\uparrow$ delay (3)	2024 $\uparrow \tau^c +$ delay (4)	Tariffs vs. 2018 (5)	Delays vs. 2018 (6)	2024 vs. 2018 (7)
Tariff	$\tau^c p^c = 0.87$	$\tau^c p^c = 1.0$	$\tau^c p^c = 0.87$	$\tau^c p^c = 1.0$			
Change delays	$\Delta\text{delay} = 0$	$\Delta\text{delay} = 0$	$\Delta\text{delay} = 21$	$\Delta\text{delay} = 21$			
Output	0.915	0.868	0.891	0.848	−5.1%	−2.6%	−7.3%
Prices	1.350	1.368	1.355	1.374	1.4%	0.4%	1.8%
Inputs China/sales	0.089	0.057	0.087	0.057	−35.4%	−1.9%	−36.1%
Inventories China/sales	0.078	0.051	0.090	0.060	−34.9%	14.6%	−23.2%
Inputs ROW/sales	0.278	0.292	0.272	0.286	5.2%	−2.1%	3.0%
Inventories ROW/sales	0.21	0.221	0.248	0.261	5.2%	18.0%	24.0%
Inputs domestic/sales	0.368	0.386	0.376	0.393	4.9%	2.0%	6.7%
Inventories/sales	0.289	0.272	0.338	0.321	−5.7%	17.1%	11.2%

Notes: Columns 1 to 4 in the table report the average of the stationary distribution for different variables. Column 1 represents the benchmark economy of 2018 with the low initial tariffs and no additional delays. Column 2 isolates the effects of tariffs and computes the steady-state average of an economy with the raise in tariffs and initial delays. Column 3 shows an economy with high delays and the initially low tariffs. Then column 4 shows an economy with the rise in both tariffs and delays. The last three columns compare the economies relatively to the benchmark 2018 economy to show the effects of tariffs in column 5, the effect of delays in column 6, and both changes in column 7.

resulting in an 11 percent increase in total inventories relative to sales. Isolating the effects of delays, we show that output drops by 2.6 percent and the final-good prices increase by 0.4 percent. In this case, inventories rise 17 percent.

To disentangle the cost of the rise in tariffs from the cost of the rise in delays, we compare the moments of the stationary distributions of different economies, shown in Table 1. The first column shows the benchmark economy, obtained by matching the moments of US manufacturing in 2018. The second column isolates the role of the trade war, where delays remain at 2018 levels but firms face the increase in tariffs of 15 percentage points ("Tariffs"). The third column outlines the moments of an economy in which delays increase by 21 days but tariffs remain at their 2018 level ("Delays"). The last column shows the effect of both the tariff increase and the rise in delays that match the moments of the 2024 economy. The last three columns of Table 1 show the comparison across the different economies.

Column 5 of Table 1 isolates the cost of the rise in tariffs, where output declines 5.1 percent and the final-good prices increase 1.4 percent. As the tariffs imposed in imports from China increase, firms substitute away from these inputs and toward ROW and domestic inputs, which grow 5.2 percent and 4.9 percent, respectively. The higher cost of the input bundle raises the final price, and output declines in response. As firms substitute toward domestic and ROW inputs, which are more readily available and require fewer inventories per unit used, the total inventories over sales drop 5.7 percent. As expected, when firms reduce their dependence on imports from faraway sources, inventories decrease in response.

A 21-day delay leads to an output decline of 2.6 percent, and the final-good price increases 0.4 percent, as shown in column 6. As the standard deviation of the delivery times increases, the added uncertainty in the share of the order a firm can access before production increases the firm's incentives to hold additional inventories per unit of input used. Further, the rise in volatility increases the share of firms that are constrained at a given period, which forces the firm to suboptimally increase its reliance on the more expensive domestic inputs, which raises their price and lowers output. These results are comparable to Alessandria et al. (2023), who report a 3 percent drop in output and a 2 percent increase in final prices due to delays. As the delays for foreign inputs increases, firms substitute away from inputs from China and ROW (−1.9 percent and −2.1 percent, respectively) and toward domestic inputs. Even though firms are using less of the foreign inputs, inventories for each of these inputs increase, as the delays raise the need for inventories per unit used. Thus, total inventories increase by 17.1 percent.

The output costs considering the increase in both tariffs and delays equals 7.3 percent, and the final-good prices rise 1.8 percent from 2018 to 2024. In this case, the combined effect of increased tariffs and delays drives up the final price, causing a sharper drop in output. Inputs from China observe a steep decline because of the increase in their price and their more volatile delivery times. Yet their inventory holdings face opposing forces. As firms substitute away from these inputs, they carry fewer inventories, but the increase in delays raises the need for inventories per unit used. Quantitatively, the substitution effect is stronger, and inventories of inputs from China decline by 23 percent. Inputs from ROW increase by 3 percent since the effect of firms substituting toward these inputs is larger than the drop of the inputs due to the rise in delays. Thus, inventories over sales of ROW inputs increase by 24 percent. The increase in ROW inventories mitigates the fall of the inventories from inputs from China, and total inventories increase by 11 percent.

VI. Conclusions

In this paper, we study the effect of rising delays in supply chains and their economic cost. We use a model of international sourcing matched to import flows and the stock of input inventories over time. Accounting for the US-China trade war that started in 2018, we estimate a rise of 21 days in the average US import shipping delay. The combination of rising tariffs and delays induces an output loss of 7.3 percent and a price increase of 1.8 percent. We decompose these into the part driven by the trade war (5.1 percent and 1.4 percent, respectively) and the contribution of rising delivery delays (2.6 percent and 0.4 percent, respectively).

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