

Tariff Front-Running

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Abstract

We study firms' anticipatory response to tariffs and its macroeconomic implications, exploiting the one-year gap between the opening of trade investigations and the implementation of the 2018–2019 U.S. tariffs. Using a novel dataset linking shipment-level bills of lading to importing firms, we show that firms begin front-running the tariff a year ahead: they raise imports, accumulate inventories, and add sourcing countries that supply tariffed products. We develop a dynamic general-equilibrium trade model in which firms hold imports as inventories and choose countries to import from. Pre-tariff, front-running expands aggregate output and lowers prices, as larger imports and additional partners reduce the cost of imported inputs. Post-tariff, accumulated inventories keep aggregate output above and prices below the high-tariff steady-state levels for a year. Therefore, anticipation mitigates the short-run impact of the tariff. Relative to an unanticipated tariff, the present-value output gain is 0.21% of the annual final-steady-state output.

JEL codes: E30, F11, F13, F40.

Keywords: tariff, imports, dynamic trade model, extensive margin of trade, bill of lading

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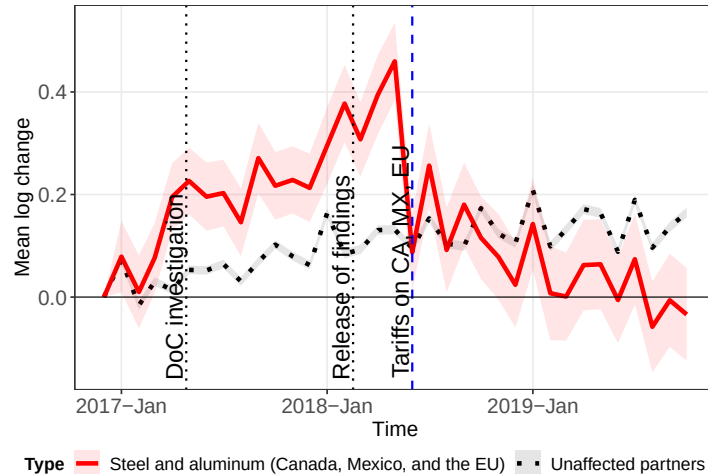
1 Introduction

For the past decade, the United States has imposed substantial tariffs on many of its imports. The economic effects of these tariffs on trade flows, prices, and production are debated in policy forums worldwide, and the aftermath of the tariff implementation has received considerable attention in the literature. However, less is known about the anticipatory dynamics of trade, where importers can respond to announced future tariffs, and whether these early reactions mitigate or exacerbate the short-run macroeconomic effects of tariffs.

In June of 2018, the U.S. implemented tariffs of 25% on steel and 10% on aluminum imports from Canada, Mexico, and the European Union. This tariff increase was the result of an investigation that began in April of 2017, and the findings were made public in February of 2018. In Figure 1, we show that for the 14 months between the investigation and the levy of the tariff, there was an increase in the imports of steel and aluminum, with a further rise in the four-month period after the release of the findings.

In this paper, we ask two questions. First, how do U.S. importers respond to an anticipated tariff? Second, what is the effect of their anticipatory response on the short-run dynamics of aggregate output and prices? We address the first question empirically for the wave

Figure 1: Steel and aluminum imports from Canada, Mexico, and the EU



Note: The figure plots the average log change in import volumes relative to the corresponding month in 2016 across HTS10 product-country pairs. It compares product-countries subject to the June 2018 steel and aluminum tariffs (red solid line), covering \$18B in 2016 imports and primarily affecting Canada, Mexico, and the EU, against those never subject to tariff increases during 2018–2019 (black dotted line). The shaded areas represent the 95% confidence intervals.

Source: Authors' calculations based on data from the Census Bureau and the U.S. International Trade Commission (USITC), compiled by [Amiti, Redding, and Weinstein \(2019, 2020\)](#).

of tariff increases in 2018 and 2019, which were concentrated on steel and aluminum and products from China. We exploit the roughly one-year window between the opening of a formal investigation and the implementation of the tariffs, giving firms time to respond to the future cost shock. We apply a local-projections difference-in-differences estimator to a novel shipment-level import dataset of U.S. public firms. We find that firms begin front-running a year ahead of the tariff: they raise imports, accumulate inventories, and expand the set of product-countries they source from. Further, prior to the tariff, firms adjust along the intensive and extensive margins towards the countries that supply the tariffed products.

To study the effect of the firms’ tariff front-running on the aggregate output and prices, we develop a dynamic general-equilibrium trade model that integrates the extensive margin of trade into an open-economy inventory model. We find that the firms’ anticipatory responses lead to higher output and lower prices, both in the run-up and the aftermath of the tariff. Output and prices converge to their high-tariff steady-state levels four quarters later. Pre-tariff front-running expands aggregate output and lowers prices because firms order larger imports and expand their set of partners, reducing the cost of the input. Post-tariff, the accumulated inventories keep aggregate output above and prices below the high-tariff steady-state level for up to a year. Therefore, anticipation mitigates the short-run impact of the tariff relative to an unanticipated tariff, and the present value of the output gain is 0.21% of the annual final-steady-state output.

We provide evidence of tariff front-running using a dataset that covers 5,255 U.S. importing firms from 2015Q1 to 2019Q4, linking shipment-level import records from the bill-of-lading data with product-country-level tariffs from the United States International Trade Commission (USITC) and firms’ financial information from Compustat. We focus our analysis on the waves of tariffs in 2018 and 2019, which were mostly on steel-and-aluminum products and China. We rely on a common timeline, where the tariffs had a roughly one-year gap between their investigation and implementation. In addition to the import dynamics surrounding the steel and aluminum tariff displayed in Figure 1, we also find similar aggregate import trends for the tariff waves for China, where imports began to rise six to twelve months before their tariff implementation.

We use the firm-level data to estimate U.S. importers’ response to an anticipated tariff with the local projections difference-in-differences estimator of [Dube et al. \(2025\)](#). We trace the response of imports, inventories, and the number of import partners (i.e., product-country pairs) both before and after the implementation of the tariff. We find that when firms are exposed to a tariff, they import and accumulate inventories four quarters prior, with levels

peaking just before implementation. The number of import partners also rises in anticipation of the tariff. Further, the pre-tariff increase in partners comes from adding countries that supply the tariffed product rather than substituting to different products. After the tariff, import volumes and the number of partners decrease, as firms have stockpiled inventories.

To the best of our knowledge, this is the first evidence that the firm’s anticipatory response extends to its extensive margin, where firms add suppliers ahead of the tariff. Aggregate front-running is established in the literature (Alessandria, Khan, and Khederlarian 2024; Khan and Khederlarian 2021), but there is little evidence on which firms do it and along which margins. We show that the anticipatory response is present across the entire size distribution of importers. Thus, the aggregate import trend reflects a broad-based firm response rather than a composition effect driven by the largest firms. Further, with the granularity of our data, we show that firms front-run tariffs by adjusting across countries rather than across products, a pattern that motivates the sourcing structure of the model.

To quantify the effect of the firm’s front-running on the aggregate output and prices, we develop a dynamic general-equilibrium trade model. We depart from the literature by incorporating an extensive margin choice of suppliers into an open-economy model with inventory, similar to Alessandria, Kaboski, and Midrigan (2010). Firms face uncertain demand shocks for their output and a one-period delivery lag for inputs, which creates an incentive to hold inventories. The input is a composite of a unit continuum of tradable varieties, each of which can be imported from different countries and face tariffs. We follow similar assumptions as Antras, Fort, and Tintelnot (2017) for the extensive margin: adding a supplier country incurs a fixed cost but lowers the unit cost of the input. Firms are forward-looking and take into account future tariffs in their trade choices today.

We calibrate the model to match aggregate and firm-level data moments from the 2016 U.S. economy and use the observed tariff changes between 2016 and 2019 to simulate the firm’s response. We study the perfect foresight transition from a low- to a high-tariff steady state. The model matches the untargeted firm-level anticipatory response detailed in our empirical findings. Anticipating an increase in their input price due to tariffs, firms increase their imports and accumulate inventories. The surge in import demand makes it profitable to incur the additional fixed costs of adding new supplier countries. The resulting expanded set of suppliers lowers the marginal cost of the input, which further increases imports. The firm’s anticipatory response impacts aggregate output and price dynamics. Prior to the tariff, the decrease in the marginal cost of the input creates a temporary economic expansion, where output expands by 0.16% and aggregate price drops by 0.05% in the period before

implementation.

After the tariff is implemented, imports collapse, and firms meet demand by drawing down their accumulated inventories over the following three to four quarters. This keeps aggregate output above, and aggregate price below, the high-tariff, steady-state level for up to a year, which mitigates the short-run impact of the tariff. In the quarter of implementation, aggregate output falls but stays 0.7% above its final steady-state level and remains higher for the next three quarters. The marginal cost of the foreign input incorporates the full tariff immediately, consistent with [Amiti, Redding, and Weinstein \(2019\)](#) and [Fajgelbaum et al. \(2020\)](#), but pass-through to the aggregate prices is incomplete in the short run. Prices rise upon implementation of the tariff but remain 0.2% below their final level. The incomplete pass-through is a result of firms that are able to avoid stock-outs due to the accumulated inventories prior to the tariff. The model-predicted aggregate effects are supported by cross-industry evidence. Industries more exposed to the tariffs observe higher output and lower price growth in the quarters before implementation and the opposite afterwards.

We quantify the gains from anticipation by comparing the benchmark model with one in which the tariff is unannounced ex-ante. We define the gain as the difference in aggregate output between the two transitions, relative to the high-tariff steady state. Front-running lets firms sustain higher output starting from the announcement of the tariff, so the cost of the tariff is borne more gradually: in present value, the output gain equals 0.21% of the annual final steady-state output.

Last, in line with the literature, we show that when the tariff is anticipated, the short- and long-run tariff elasticities are twice as large as when the tariff is unanticipated. Front-running raises imports ahead of the tariff, and they collapse right after, as firms draw down their accumulated inventories rather than importing. Yet, the model allows us to assess whether the bias can be undone. We show that even when measuring the elasticity from the period prior to any front-running, the short-run elasticity continues to be overstated, since the collapse of imports post-tariff is stronger when firms can anticipate the tariff.

The ability to anticipate a tariff matters. It leads to higher aggregate output and lower aggregate prices both in the run-up and the immediate aftermath of a tariff implementation. Thus, anticipation mitigates the economic impact of the tariff in the short run. This is important when studying optimal tariffs and assessing the cost of a tariff, since the first quarters of data understate it, a point that applies to the 2025–2026 tariff waves as well. More broadly, the model’s aggregate predictions can be applied to any anticipated cost increase,

such as regulatory changes, scheduled tax increases, or anticipated supply disruptions.

Our paper speaks to several strands of literature. First, we contribute to the literature on how agents respond to anticipated cost changes. The common finding is that activity is reallocated toward the cheaper period: anticipated tax changes move aggregate activity before they take effect (Mertens and Ravn 2012), households time purchases around sales-tax changes (Baker, Johnson, and Kueng 2021) and anticipated price changes (Hendel and Nevo 2006; Coglianesi et al. 2017), and importers back- and front-load ahead of trade-policy changes (Khan and Khederlarian 2021; Alessandria, Khan, and Khederlarian 2024) through the inventory channel of Khan and Khederlarian (2025). Our firm-level data add to these findings: we show that the anticipatory response extends to the extensive margin, with firms adding countries that supply the tariffed product, and that both the intensive and extensive margins of imports respond throughout the firm-size distribution.

Further, the literature on anticipated costs highlights how intertemporal reallocation distorts measurement: estimated demand elasticities confound the response of consumption to a price change with the re-timing of purchases (Hendel and Nevo 2006; Coglianesi et al. 2017), and anticipated trade-policy reforms bias trade elasticities (Khan and Khederlarian 2021; Alessandria et al. 2025a,b; Alessandria, Khan, and Lansley 2026). We add to this literature by showing that the short-run bias cannot be undone by measuring the elasticity relative to a period preceding any front-running.

Second, we contribute to the fast-growing literature on the macroeconomic impact of tariffs. Barattieri, Cacciatore, and Ghironi (2021), Auclert, Rognlie, and Straub (2025), and Ferrante et al. (2026) use New Keynesian open-economy models to study the transmission of tariffs to aggregates, through aggregate demand and monetary channels. Closer to our work, Alessandria and Mix (2021) use a dynamic trade model to show how changes in trade policy move aggregates through investment. On the empirical side, de Soyres, Goernemann, and Machol (2025) and Fajgelbaum and Khandelwal (2026) document import front-loading ahead of the 2025 tariffs, which accounts for a significant share of output growth. We add to this work by developing a model in which tariff transmission runs through firms' input costs and inventories, which lets us focus on isolating the role of front-running in shaping the short-run aggregate response. To our knowledge, the mitigating role of front-running is new.

Third, we contribute to the literature on the impact of the 2018–2019 U.S. import tariff; see Fajgelbaum and Khandelwal (2022) for a survey. This literature studies the consequences of

the tariffs *after* they take effect: tariff pass-through (Amiti, Redding, and Weinstein 2019; Fajgelbaum et al. 2020; Cavallo et al. 2021), the impact on U.S. manufacturing (Flaen and Pierce 2026), and the reallocation of U.S. imports away from China (Fajgelbaum et al. 2024; Freund et al. 2024; Alfaro and Chor 2025; Javorcik, Pierce, and Wisniewski 2026; Utar, Cebreros Zurita, and Torres Ruiz 2025). In contrast, we study the *ex-ante* response of U.S. firms and show tariff front-running in both aggregate and firm-level data.

2 Data

We combine three datasets, compiling information on firms’ imports, such as products imported, partner countries, and values; their inventories, sales, assets, and cash flows; and tariffs at the product-country level. First, the import data come from shipment-level bill-of-lading (BoL) data from S&P Global’s Port Import/Export Reporting Service (PIERS), which covers the near-universe of U.S. maritime imports and reports each shipment’s country of origin and the HS6 product it contains. While the data only cover maritime imports, they are the largest transportation mode by value, accounting for nearly 50% of U.S. imports in 2019.¹ Further, most tariffs during 2018–2019 were applied to products that arrive via ocean.

Second, the quarterly firm-level financial data come from the Compustat North America Fundamentals Quarterly. We gather information on inventories, sales, Tobin’s Q, and cash flow over assets for public firms. Inventories are a key variable of interest in our analysis, and we use the other variables as firm-level controls in the empirical analysis. We merge the BoL data with Compustat through a text-analysis algorithm, as there exist firm-name variations, both across shipments of the same firm within the BoL data and between firm names in the BoL and in Compustat. Details are provided in Online Appendix B. Third, the tariffs for the period between 2016 and 2019 are retrieved from Amiti, Redding, and Weinstein (2020, 2019), who compile the data from the USITC. We aggregate their data from the monthly-HTS10-country level to the quarterly-HS6-country level.²

¹Flaen et al. (2023) show that the aggregate value of U.S. maritime imports in Panjiva, another BoL dataset also managed by S&P, aligns closely with the values reported by the Census Bureau.

²HS6 codes are updated periodically (e.g., the 2017 revision), as are HTS10 codes, the country-specific extensions to HS codes used to set tariff rates. We utilize the method of Pierce and Schott (2012) to concord HS6 and HTS10 codes across time. To calculate the tariff of an HS6 product in a quarter, we take a simple average of HTS10 tariff lines within the HS6 code in the last month of the quarter (October 2019 for the final quarter, the last month covered by the tariff data), restricting to the tariff lines observed in all of these months so that quarterly tariff changes do not reflect changes in the composition of lines. For HS6 products not matched to any HTS10 line in the tariff data, we calculate tariffs as the average within the higher level of aggregation (i.e., HS4- or HS2-digit products).

Our final dataset consists of 5,255 importing public firms and 1,694,375 importing firm-product-country-quarter pairs from 2015Q1 to 2019Q4.³ Two data patterns are noteworthy for empirical analysis. First, trade is lumpy: across all 20 available quarters, the mean and median firm imported in only 12 and 15 quarters, respectively. Second, more than 75% of firm-quarters import an HS6 product from a single country. We report other summary statistics in Table A1 in Appendix A.

Table 1: Timeline of tariff increases on steel, aluminum, and Chinese products

Event	Date	Description	Source	Products or Countries ^b	Value (\$B) ^c
<i>(a) Section 232: national security (steel and aluminum)</i>					
Investigation	Apr 19 & 26, 2017	DoC initiates investigation.	82 FR 19205	Steel, Alum.	–
Report	Feb 16, 2018	DoC makes findings public.	DoC report	–	–
Announcement	Mar 1, 2018	Intent to impose global tariffs.	White House	All	–
Effective Date (I)	Mar 23, 2018	25% (Steel) / 10% (Alum.)	83 FR 11625	ROW ^a	13
Effective Date (II)	Jun 1, 2018	Expiration of exemptions	Proclamation 9759	Can, Mex, EU	18
<i>(b) Section 301: technology transfer (China)</i>					
Investigation	Aug 18, 2017	USTR initiates investigation.	82 FR 40213	–	–
Determination	Mar 22, 2018	President concurs with USTR.	83 FR 13099	–	–
List 1 Effective	Jul 6, 2018	25% tariff	83 FR 28710	Industrial Machinery	28
List 2 Effective	Aug 23, 2018	25% tariff	83 FR 40823	Chemicals	10
List 3 Effective	Sep 24, 2018	10% tariff	83 FR 47974	Consumer Products	159
List 3 Escalate	May 10, 2019	Rate raised to 25%	84 FR 20456	–	–
List 4A Effective	Sep 1, 2019	15% tariff	84 FR 43304	Apparel, Footwear, TVs	92
Phase One Deal	Dec 13, 2019	List 4B suspended*	84 FR 69447	Cell Phones, Laptops	–

Notes: “DoC” refers to the Department of Commerce. “USTR” refers to the United States Trade Representative. “FR” refers to the Federal Register. ^a “ROW” (Rest of World) includes countries not granted exemptions. South Korea, Brazil, and Argentina accepted quotas in lieu of tariffs.

^b This column denotes the products or countries mainly targeted by each event.

^c Values represent the 2016 annual import volume from the affected partners (in billions of USD), based on the authors’ calculations using the Census data.

* List 4B was scheduled to go into effect on Dec 15, 2019, covering roughly \$160 billion in imports, but was suspended indefinitely following the Phase One trade agreement.

During our sample period, the two main categories that faced tariff increases were (i) steel-and-aluminum products and (ii) products from China. The timeline for the key events for the tariffs is summarized in Table 1. Three notable points are as follows. First, the events that could lead firms to anticipate tariff increases in the future occur as early as a year prior. For example, the investigations by the Department of Commerce (for steel and aluminum) and by the United States Trade Representative (for Chinese products) began

³We identify the universe of importing firms from the 2005–2019 match between the bill-of-lading data and Compustat, and all estimates use data from 2015Q1 onward.

11 months before the first tariff increases.⁴ Second, there were multiple waves of tariffs implemented for different products at different magnitudes. The earlier tariff waves against China focused on intermediate inputs; the scope expanded to include consumption goods in the later lists. The largest waves were Lists 3 and 4A, which covered \$159 billion and \$92 billion in 2016 imports, respectively. Third, we find that tariff exposure was widespread across firms despite the limited number of targeted product-country pairs. Although no more than 4% of product-country pairs faced a tariff increase in any quarter, they impacted 62% of public firms in our sample. See Online Appendix A for more details on the tariff incidence. This finding complements [Handley, Kamal, and Monarch \(2025\)](#), who find that approximately one-quarter of total U.S. *exporting* firms were affected by the import tariff increases.

3 Empirical Analysis

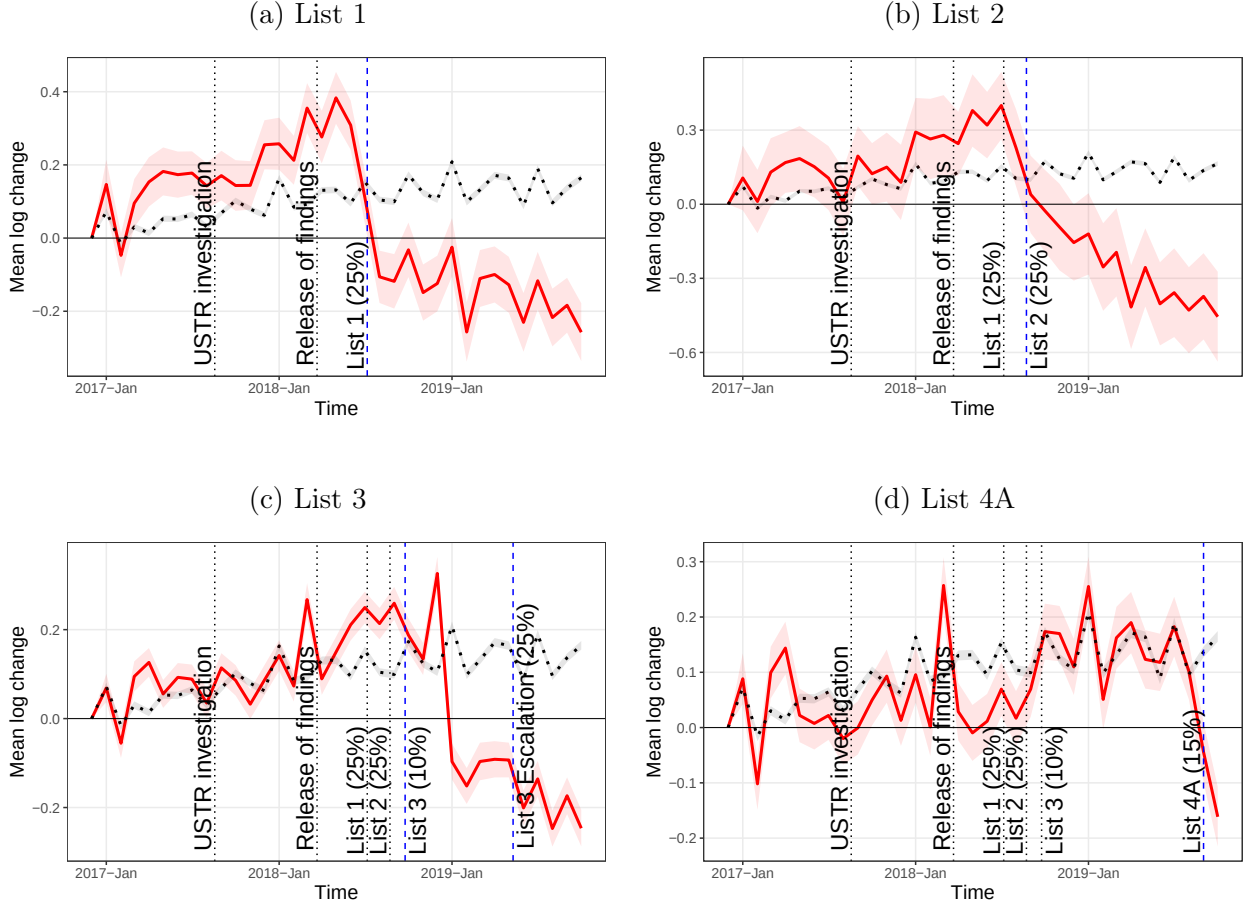
In this section, we present three sets of empirical findings. First, using *aggregate* data, we provide descriptive evidence of the front-loading of imports. Second, moving to our *firm-level* data, we show that prior to tariffs, firms increase their imports, the number of their import partners, and inventories. Third, we find that when a firm anticipates that the product-country partner that it imports from will face a higher tariff, it not only stockpiles imports from that product-country, but also starts to import from another country that supplies the same product.

3.1 Tariff Front-Running in the Aggregate Data

As previewed in Figure 1, we first examine tariff front-running by contrasting import changes for product-countries subject to specific tariff waves against those unaffected by any of the 2018–2019 tariffs. To do so, we use the aggregate, product-country-level import data from the Census Bureau compiled by [Amiti, Redding, and Weinstein \(2019, 2020\)](#). Let $X_{h,c,t}$ denote the import value for an HTS10 product-country pair (h, c) at time t . We analyze the log change of $X_{h,c,t}$ relative to the corresponding month in 2016, $\log(X_{h,c,t}) - \log(X_{h,c,2016m(t)})$, where $m(t)$ denotes the month of t to control for seasonality. We then take the average of the log change across all product-country pairs that are affected by a given tariff wave (red solid line) and compare it to the product-countries that were not affected by any tariff waves during 2018–2019 (black dotted line).

⁴During our sample period, there were tariff increases for solar panels and washers as well. For both, the investigations began more than eight months prior to the implementation. See Table A2 in Appendix A for the detailed timeline.

Figure 2: Import dynamics for products subject to China tariffs



Note: The figure plots the average log change in import volumes relative to the corresponding month in 2016 across HTS10 product-country pairs. Panels (a) through (d) contrast product-countries subject to Lists 1, 2, 3, and 4A of China tariffs (red solid lines), against those never subject to tariff increases during 2018–2019 (black dotted lines). The shaded areas represent the 95% confidence intervals. Vertical black dotted lines mark major “anticipatory” events (e.g., the initiation of Section 301 by the USTR or earlier tariff waves). Vertical blue dashed lines indicate the date of tariff increases.

Source: Authors’ calculations based on data from the Census and the USITC, compiled by [Amiti, Redding, and Weinstein \(2019, 2020\)](#).

Similar to the import responses for steel and aluminum in Figure 1, Figure 2 illustrates the anticipatory import dynamics for the Chinese products subject to each tariff wave. We find import front-loading here as well, since affected imports grew at a higher rate than never-tariffed imports before the tariff. For List 1 products in Panel (a), which were affected by the first China tariff wave, there is evidence of stockpiling for a year, from the USTR investigation to the tariff implementation (vertical blue dashed line). List 2 and List 3 imports in Panels (b) and (c) exhibit anticipatory dynamics from around six and seven months before the tariff implementation, which coincides with the timing of the public release of investigation

findings and the announcement of future tariffs in March 2018. Furthermore, in Panel (c), we observe the import surge for the List 3 products in late 2018, since their tariffs were originally scheduled to escalate to 25% in January 2019, but were eventually implemented in May 2019. Importers “raced against the clock” to lock in the 10% rate before the scheduled escalation in January 2019. However, for the List 4A tariffs, we do not observe significant stockpiling, except in March 2018, around the time of the public release of the USTR investigation. Further, we report the results for the steel and aluminum wave for countries other than Mexico, Canada, and the EU, and for solar panels and washers in Figure A1 of Appendix A.

Our findings are in line with previous studies, such as Alessandria, Khan, and Khederlarian (2024), who provide aggregate evidence of stockpiling of imports prior to China’s most favored nation tariff renewal voting; and Khan and Khederlarian (2021), who show an anticipatory slump before the introduction of NAFTA.

3.2 Tariff Front-Running in the Firm-Level Data

We now turn to the firm-level data to study how *firms* adjusted their imports in response to expected future tariff increases. We start by constructing an import-weighted tariff increase for a firm, which captures how exposed the firm is to a tariff change given its set of trade partners, defined by the product-country pairs. Given the lumpiness of trade, as discussed in Section 2, we consider the existing set of partners defined as the cumulative set of partners the firm imported from in the past four quarters, $E_{i,t} \equiv \bigcup_{k=-4,\dots,-1} C_{i,t+k}$.⁵ $C_{i,t}$ represents the current set of partners the firm traded with at time t . We define the tariff exposure over the entire network of the firm’s partners, since including only their current partners would miss partners that are needed for production but export infrequently to the firm. Then, we let $v_{i,h,c,t} = \sum_{k=-4,\dots,-1} x_{i,h,c,t+k}$ denote the existing import volumes, where $x_{i,h,c,t}$ represents the current import volume of firm i from product-country partner (h, c) at t .

Next, we define the firm-level tariff increase, $\hat{\tau}_{i,t}$, as the import-weighted average tariff change across the existing imports of the firm at time t :

$$\hat{\tau}_{i,t} \equiv \frac{\sum_{(h,c) \in E_{i,t}} v_{i,h,c,t} (\tau_{h,c,t} - \tau_{h,c,t-1})}{\sum_{(h,c) \in E_{i,t}} v_{i,h,c,t}}, \quad (1)$$

where $\tau_{h,c,t}$ represents the tariff on product-country (h, c) at time t . We define a dummy variable, $TI_{i,t} = 1$, if the firm-level tariff increases by at least 0.1 percentage points, $\hat{\tau}_{i,t} \geq$

⁵Online Appendix A reports the firm-level results with the existing set defined over the preceding two or six quarters instead of four.

0.001, and zero otherwise.⁶

To study the firm’s response to a future tariff, we need to consider two additional features of the data. First, many firms face multiple tariff increases throughout the sample period, since they import multiple products that were subject to different tariff waves. For such firms, the quarters before a later increase overlap with the quarters after an earlier one, so the anticipatory response to one wave would be entangled with the post-tariff response of another. We avoid this issue by considering the first tariff event for a firm. Second, from Figure 2, we observe that importers responded to a series of compounding signals, ranging from initial investigations to the delay of tariff escalation for the List 3 products, any of which could plausibly serve as the relevant news event. Thus, it is difficult to isolate a single, discrete news shock, so we use the realization of higher tariffs as our event time.

Specifically, we classify firms into treatment cohorts (groups) by the timing of their first tariff increase. For firm i , $g_i \equiv \min\{g \in \mathcal{G} : TI_{i,g} = 1\}$, where $\mathcal{G}$ is the set of event quarters; if a firm is never treated, $g_i \equiv \infty$ following the usual convention. With a slight abuse of notation, we let g denote both a treatment cohort and the quarter in which that cohort is treated. Note that a firm in cohort g may well face further tariff increases after g . Table 2 lists the six event quarters, the number of firms in each cohort, and the import volume impacted by each tariff wave.

The six tariff waves constitute staggered treatments with dynamic and potentially heterogeneous treatment effects. We therefore employ the local-projections difference-in-differences (LP-DiD) estimator by Dube et al. (2025).⁷ Since our interest is firms’ anticipatory responses, we modify the estimator in two ways. First, our clean control group consists of never-treated firms, those with $\hat{\tau}_{i,g} \leq 0 \forall g \in \mathcal{G}$, rather than the usual not-yet-treated firms. This is because, as firms respond to tariffs before implementation, firms treated later in the sample are already contaminated by their own anticipatory response.⁸ Second, instead of differencing outcomes against the quarter before the event ($g - 1$), we difference against

⁶ We need a small positive threshold for the following reason. Because the ad valorem equivalents of specific and compound duties are re-estimated annually using unit values, they can change slightly even when statutory duties remain unchanged. Therefore, we impose cutoffs of 1 p.p. at the product-country level and 0.1 p.p. at the firm level. The former removes over 90% of non-trade-war tariff increases while preserving all trade-war cases, and our firm-level results are robust to alternative cutoffs, both higher and lower (Online Appendix A).

⁷Our implementation is equivalent to the stacked difference-in-differences estimator of Cengiz et al. (2019): we pool event-specific samples to estimate the baseline coefficients. Online Appendix B reports coefficients separately for each tariff wave and describes how they aggregate to the stacked baseline.

⁸Firms with a small positive exposure that never crosses the 0.1 p.p. threshold (328 firms) are neither treated nor clean controls and are excluded from the analysis.

Table 2: Tariff waves and event quarters

Event quarter	Effective date	Tariff waves	Count of firms	Imports (\$B) ^a
2018Q1	Feb 7, 2018	Solar panels and washers	469	10.3
2018Q2	Mar 23, 2018 ^b	Steel and aluminum (ROW)	453	30
	Jun 1, 2018	Steel and aluminum (Can, Mex, EU)		
2018Q3	Jul 6, 2018	China List 1	1,166	38
	Aug 23, 2018	China List 2		
2018Q4	Sep 24, 2018 ^b	China List 3	821	159
2019Q2	May 10, 2019	China List 3 escalation	231 ^c	—
2019Q3	Sep 1, 2019	China List 4A	142	92

^a Values represent the 2016 annual import volume from the affected partners (in billions of USD), based on the authors' calculations using the Census data. Quarters with two waves report the combined figure.

^b Effective in the last days of a quarter; the tariff data record the higher rate from the following month (the month during which it mostly applied), so the wave is assigned to the following quarter.

^c The List 3 escalation (2019Q2) can be a first tariff-increase event even though it raised existing List 3 tariffs (2018Q4). If a List 3 product was not part of the firm's existing partner set in 2018Q4 but became part of it by 2019Q2, the firm would be first treated in 2019Q2.

the same quarter of 2016, the year that predates the tariff investigations. This choice is consistent with the aggregate analysis in Section 3.1.

For each horizon $k = -6, \dots, +4$, we estimate the following.⁹

$$\Delta \tilde{y}_{i,g+k} = \beta_k D_{i,g} + \Gamma'_{g,k} X_i^{2016} + \alpha_{j(i),g,k} + \epsilon_{i,g,k}. \quad (2)$$

$\Delta \tilde{y}_{i,t} \equiv \text{asinh}(y_{i,t}) - \text{asinh}(y_{i,2016:q(t)})$ is the outcome's inverse-hyperbolic-sine deviation from the same quarter of 2016.¹⁰ $D_{i,g} \equiv \mathbb{1}(g_i = g)$ indicates whether firm i belongs to cohort g .¹¹ X_i^{2016} is a vector of firm-level controls measured in 2016—log sales, Tobin's Q, and cash flow over assets—with event-horizon-specific coefficients $\Gamma_{g,k}$.¹² $\alpha_{j(i),g,k}$ is a NAICS6 industry-event-horizon fixed effect, with $j(i)$ denoting the industry of firm i . The estimation is horizon-by-horizon: at each horizon k , we stack all event- g -treated firms at quarter $g + k$ and never-treated firms observed at $g + k$ across all events $g \in \mathcal{G}$. Standard errors are

⁹Since our data end at 2019Q4, horizons beyond +4 are only identified from the earlier tariff waves and exclude List 3, the largest wave in terms of volumes of imports affected.

¹⁰The inverse hyperbolic sine, $\text{asinh}(y) \equiv \log(y + \sqrt{y^2 + 1})$, enables us to include zeros, unlike the logarithmic specification. This is particularly relevant in our data, since 43% of importers' firm-quarters report zero imports. The inverse hyperbolic sine is approximately linear for small values of y and approximately equal to $\log(2y)$ for large positive values.

¹¹In addition to this dummy-variable specification of treatment, in Appendix B, we show that our results remain robust when we replace it with a continuous measure of the firm-level tariff increase.

¹²Tobin's Q and cash flow over assets are winsorized at a 99% level.

clustered at the firm level across all events.

The key coefficient of interest β_k reflects the differential outcome path of treated firms k quarters around their first tariff increase at g . Identification comes from two differences. The first difference compares treated firms with never-treated firms within the same NAICS6 industry. The second difference compares each firm with its own 2016 baseline, which removes permanent firm heterogeneity and seasonality.

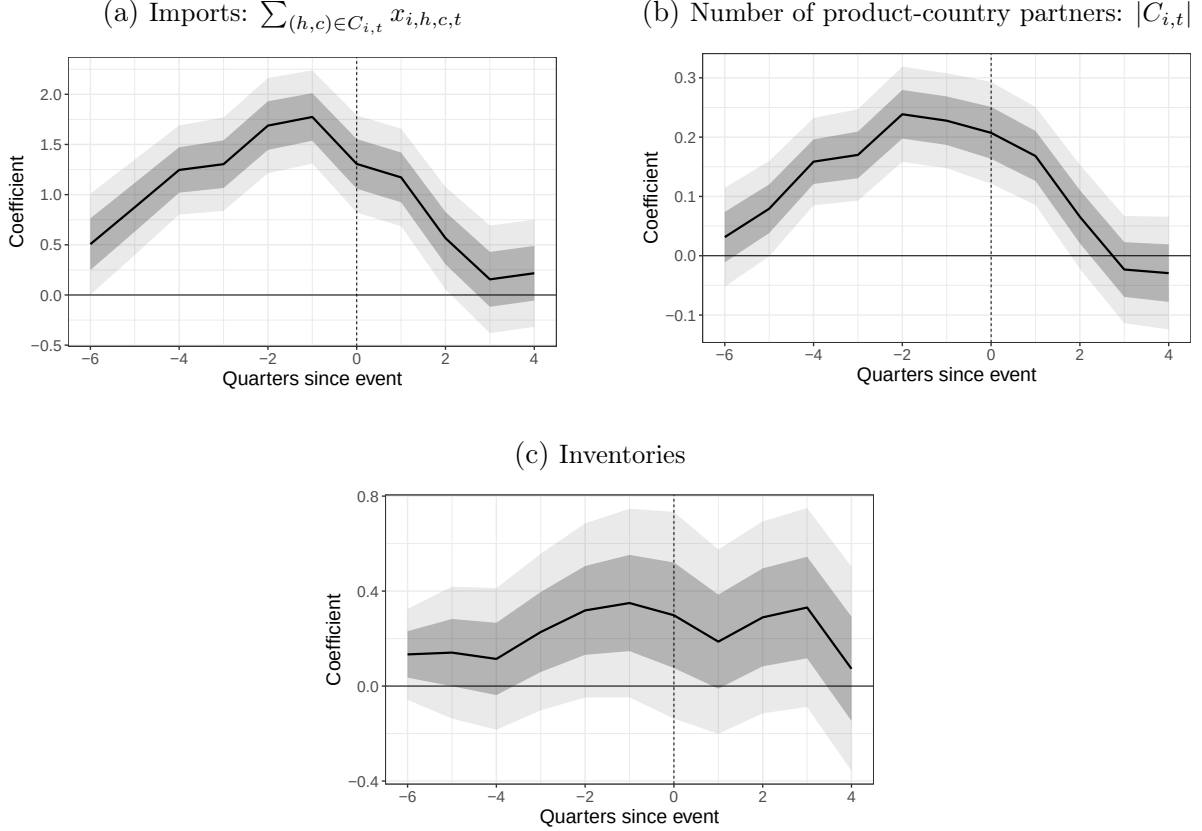
We estimate Equation (2) for three outcomes: (a) the firm’s current import volume, defined as the sum of $x_{i,h,c,t}$ across its current partners $(h, c) \in C_{i,t}$; (b) the number of current product-country partners, $|C_{i,t}|$; and (c) its inventories. The results are in Figure 3, which illustrates the dynamic response of each variable before and after the first tariff increase, summarized by the estimated $\{\beta_k\}_{k=-6,\dots,4}$. In Panel (a), firms that face a tariff increase at g steadily build up their imports over the preceding year, and the imports peak a quarter before the shock. Notably, this timing coincides with the periods between the start of the formal investigations and the first tariff implementations (see Table 1). After the tariff, imports decrease.

Next, Panel (b) shows that the number of current import partners also increases before the tariffs. It starts to rise five quarters before the tariff, peaks one quarter before the event, and then decreases. In Panel (c), we estimate the impact of the tariff on the firm’s inventories, measured as the sum of raw materials, work-in-process, and finished goods.¹³ Firms affected by the tariff stock their rising imports as inventories over the preceding year, and slowly use them for production after the tariff. Compustat records inventories at cost, so the value of the stock reflects the most recent price. The tariff raises the cost of imported inventories, which dampens the post-tariff transition of the book value of inventories. Using our model, we show that the decline in the value of inventories is therefore more muted than the decline of the physical stock.

Furthermore, we report the specification check, altered to fit our analysis. Since we are measuring the pre-trend to the tariff increase, the conventional requirement of flat pre-event coefficients cannot serve as a specification check. We mitigate this issue with two points. First, at the far end of the estimation window ($k = -6$), well before the start of the investigations, we show the estimated deviations are close to zero in the stacked estimates (our

¹³In Online Appendix A, Figure A2 reports the response by the type of inventories. Moreover, Figure A3 shows the inventory response under coarser industry fixed effects, which enable more treated-control comparisons within cells and thus deliver more precisely estimated responses with quantitatively similar point estimates.

Figure 3: Imports, number of partners, and inventories around the first tariff increase



Note: The figures describe the estimated $\{\beta_k\}_{k=-6,\dots,4}$ in Equation (2). The dark and light shaded areas are the ± 1 and ± 1.96 standard-error bands (68% and 95% confidence intervals), respectively. Standard errors are clustered at the firm level.

baseline) and for the per-wave estimates (Online Appendix B) alike. Second, we show that treated and never-treated firms were not on different import trajectories before our 2016 anchor year: cohort by cohort, their 2015–2016 import growth is statistically indistinguishable (Online Appendix B).

Our firm-level analysis reveals patterns of tariff front-running that cannot be observed through aggregate analysis. To the best of our knowledge, this is the first paper to show that the firms’ anticipatory response extends to their extensive margin, where they expand their partner set prior to the tariff. Furthermore, the firm-level data allow us to study how pervasive the response is. Appendix C shows that the pre-tariff increase in imports, the build-up of inventories, and the expansion of the partner set are present across the entire size distribution of firms. This shows that our results are not driven solely by large firms,

but instead reflect a broad-based response among importers.

3.3 Who Do Firms Turn To?

We have shown that, in anticipation of tariffs, firms respond on the intensive margin by raising their imports and on the extensive margin by expanding their partner set. The granularity of the data lets us look one layer deeper, at the firm-partner level, and ask which partners the adjustment runs through. Does the firm adjust its trade with the partners about to be affected by the tariff, or does it substitute toward alternatives, such as the same product from a different country, or a different product altogether?

To study these adjustments, we classify each firm’s partners into four types: (i) affected product–affected country, (ii) affected product–unaffected country, (iii) unaffected product–affected country, and (iv) unaffected product–unaffected country. For example, suppose that a firm imports small direct current (DC) motors (HS6: 850131) from China. If these motors will be subject to a tariff (as they were under the List 1 tariff), we study whether the firm adjusts its imports of (i) the DC motors from China, (ii) the DC motors from Vietnam, (iii) single-phase alternating current (AC) motors (HS6: 850140) from China (which were not subject to the List 1 tariff), or (iv) the AC motors from Vietnam.

We classify all import partners of a tariff-affected firm—i.e., every product-country the firm imports from at some point in our 2015–2019 sample—into each of the four types event-by-event. For each event $g \in \mathcal{G}$, we denote by a dummy variable whether a partner belonging to the firm’s existing set faces a tariff at g : $TI_{i,h,c,g} \equiv \mathbb{1}((h, c) \in E_{i,g} \text{ and } \tau_{h,c,g} \geq \tau_{h,c,g-1} + 0.01)$.¹⁴ (i) The affected product–affected country partners (e.g., DC motors from China) are those whose own tariff increases at g : $AA_{i,h,c,g} \equiv \mathbb{1}(\tau_{h,c,g} \geq \tau_{h,c,g-1} + 0.01)$.¹⁵ Before classifying partners into the remaining three types, we exclude product-country partners whose tariff increased at an earlier event (unless it increases again at g), so as not to confound the post-tariff response to earlier waves with the anticipatory response to later ones. (ii) The affected product–unaffected country partners (e.g., DC motors from Vietnam) are the ones that supply a product the firm is importing from an affected country: $AU_{i,h,c,g} \equiv (AA_{i,h,c,g} = 0) \wedge (\max_{c'} TI_{i,h,c',g} = 1)$. (iii) The unaffected product–affected country partners (e.g., AC motors from China) supply an unaffected product from a country that faces tariffs on other supplied products: $UA_{i,h,c,g} \equiv (AA_{i,h,c,g} = 0) \wedge (\max_{h'} TI_{i,h',c,g} = 1)$.¹⁶ (iv) The unaffected

¹⁴See Footnote 6 for why a small positive threshold is needed.

¹⁵This is regardless of whether they currently belong to the existing set. A firm can also front-run a dormant affected partner.

¹⁶This type consists mostly of partners from China (88%). A partner can, in principle, satisfy the conditions

product-unaffected country type represents the remaining partners (e.g., AC motors from Vietnam).

We extend the LP-DiD of Equation (2) to the firm-product-country level. Unlike the firm-level analysis, which dates a firm’s treatment by its first tariff increase, a firm and its partners enter event g whenever the firm’s tariff increases at g ($TI_{i,g} = 1$). This allows us to capture the firm-partner-level response to the tariff increase at the same granular level. Within event g , the firm’s partners are classified into the four types defined above. Product-country partners of a never-treated firm whose own tariff never rises during the sample period serve as clean controls.¹⁷ For each horizon k , we estimate

$$\begin{aligned} \Delta \hat{y}_{i,h,c,g+k} = & \beta_{AA,k} AA_{i,h,c,g} + \beta_{AU,k} AU_{i,h,c,g} + \beta_{UA,k} UA_{i,h,c,g} + \beta_{UU,k} UU_{i,h,c,g} + \\ & \Gamma'_{g,k} X_i^{2016} + \alpha_{h,g,k} + \epsilon_{i,h,c,g,k}, \end{aligned} \quad (3)$$

where $\Delta \hat{y}_{i,h,c,g+k}$ denotes the outcome’s deviation from its own level in the same calendar quarter of 2016, and X_i^{2016} is the firm-level control vector as in Equation (2). Standard errors are clustered at the firm level. As before, we trace k from six quarters before to four quarters after the event.

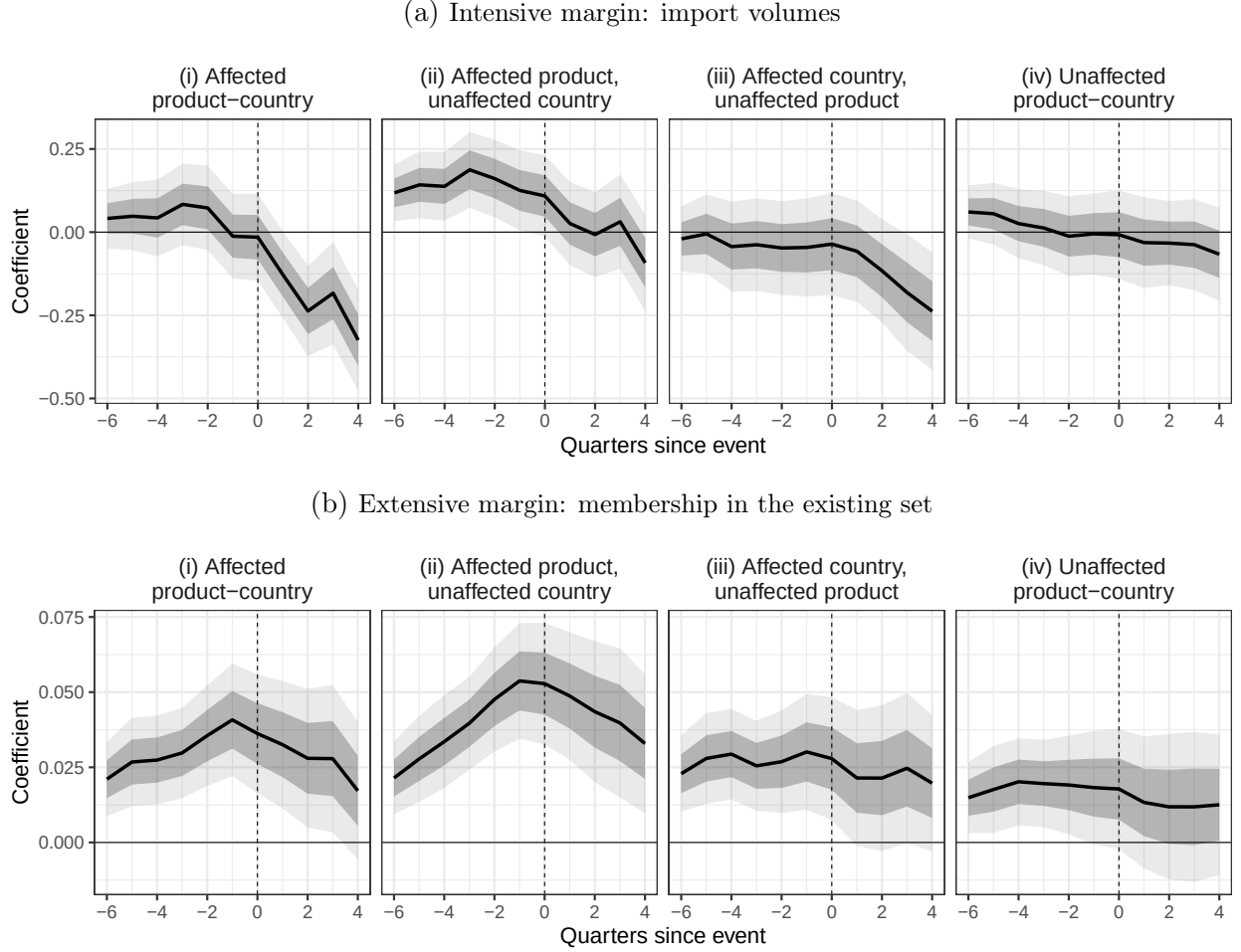
The coefficients of interest are $\{\beta_{m,k}\}_{m \in \{AA, AU, UA, UU\}, k=-6, \dots, 4}$. The identification is analogous to Equation (2) with two following differences. First, the 2016 differencing is now partner by partner, which removes partner-specific levels and seasonality. Second, whereas Equation (2) compares treated and never-treated firms within the same NAICS6 industry, we now compare their partners within the same product: $\alpha_{h,g,k}$ is an HS6 product-event-horizon fixed effect.

We first study the intensive margin response, $\Delta \hat{y}_{i,h,c,t} = \text{asinh}(x_{i,h,c,t}) - \text{asinh}(x_{i,h,c,2016:q(t)})$, defined as the deviation of the partner’s imports from its own level in the same quarter of 2016. Second, for the extensive margin, we track the partner’s membership in the firm’s existing set: $\Delta \hat{y}_{i,h,c,t} = \mathbb{1}((h, c) \in E_{i,t}) - \mathbb{1}((h, c) \in E_{i,2016:q(t)})$. Recall that the existing set $E_{i,t}$ collects the partners the firm imported from during the preceding four quarters (Section 3.2), thus a partner enters the set through new or resumed shipments and leaves it after four consecutive quarters of inaction. This measure captures the churning of partners and the timing of imports. Figure 4 reports the results.

of both types (ii) and (iii): at the 2018Q2 event, a firm holding affected Turkish steel and affected Korean aluminum finds its Korean steel partner—exempt under Korea’s quota—meeting both conditions. Such cases are rare (0.02% of the partner-events classified into types (ii)–(iv)) and are assigned to type (ii).

¹⁷As in Section 3.2, firms with a positive firm-level tariff increase below 0.1 p.p. at g are excluded from event g .

Figure 4: Intensive- and extensive-margin adjustments across partner types



Note: Each panel reports the estimated $\{\beta_{m,k}\}$ in Equation (3) for each partner type. In Panel (a), the outcome is the partner’s import volume (asinh deviation from the same quarter of 2016); in Panel (b), the partner’s membership in the firm’s existing set (deviation from the same quarter of 2016). The dark and light shaded areas are the ± 1 and ± 1.96 standard-error bands (68% and 95% confidence intervals), respectively. Standard errors are clustered at the firm level.

Our granular data allow us to show that firms front-run tariffs through stockpiling imports from soon-to-be-tariffed product-country and through cross-country, rather than cross-product, sourcing adjustments. On the intensive margin, we show that firms increase imports from the targeted partner in anticipation of the tariff, and also from other countries that supply the product being targeted by the tariff (Panels (a)(i) and (a)(ii)). Once the tariff takes effect, imports from the affected partners fall sharply. Similarly, on the extensive margin, firms are more likely to trade with the affected partner before the tariff (Panel (b)(i)), where the probability that they belong to the firm’s existing set rises steadily ahead of the event, peaking one quarter before the tariff. Further, firms are also more likely to trade with other

countries that supply the affected product pre-tariff (Panel (b)(ii)). While this result echoes [Flaaen, Hortaçsu, and Tintelnot \(2020\)](#), who show sourcing relocation to other countries *after* antidumping duties on washing machines took effect, we provide evidence that this cross-country adjustment begins *before* the tariffs. By contrast, we find little cross-product adjustment (Panels (iii) and (iv) of Panels (a) and (b)). Imports of other products sourced from the affected country and from completely unaffected product-countries never rise, and their membership response is muted.

Lastly, Online Appendix B puts the results into perspective by providing descriptive statistics. On the intensive margin, it shows that for firm-products affected by tariffs, their import volumes for the to-be-tariffed country increase by 16% from the year before active adjustment ($k = -8, \dots, -5$) to the year of adjustment ($k = -4, \dots, -1$) at the median, and 8% for the non-tariffed country. On the extensive margin, recall that firms source each product, on average, from a single country in a given quarter. Among the affected products sourced from a single country, 22% expand to two or more source countries during the year prior to the tariff, compared to 10% for the same products of the never-affected firms.

4 Model of Inventories and Sourcing Choices

To study the effect of tariff front-running on macroeconomic aggregates, we build a dynamic trade model where firms choose their imports in a multi-country sourcing environment ([Antras, Fort, and Tintelnot 2017](#)) and can stock them as inventories to ensure they meet demand ([Alessandria, Kaboski, and Midrigan 2010](#)). We depart from the literature by allowing firms to adjust both the intensive margin, where firms can stock up on their foreign inputs via inventories, and the extensive margin, where firms choose which foreign countries to import from.

4.1 Environment

Time is discrete and indexed by t . The economy is composed of a representative domestic consumer, a firm that produces a domestic homogeneous good, a unit continuum of monopolistically competitive firms that produce differentiated final goods, and a set of foreign countries, each with a continuum of foreign input suppliers. Uncertainty in the model arises from firm-specific, independent and identically distributed (i.i.d.) demand shocks.

Representative consumer. The representative domestic consumer has preferences over aggregate output, Y , which is a constant elasticity of substitution (CES) aggregate of a

homogeneous good, y_d , and the bundle of differentiated final goods, y_i , as in Equation (4). The unit continuum of final goods are CES-aggregated with elasticity ϵ and i.i.d. demand shocks ν_i . Then, the CES aggregate of the differentiated final goods is combined with the domestic homogeneous good, with an elasticity of substitution σ . To purchase the final and domestic goods, the consumer has access to labor income, wL , where labor L is inelastically supplied to firms; profits from the final-good firms, π_i ; and a transfer from abroad that is equal to the trade balance, $\mathcal{T}$; as in Equation (5).¹⁸ The aggregate price is a function of the price of the domestic good, p_d , and the continuum of final good prices, p_i , as shown in Equation (6).

$$Y = \left(\mu^{\frac{1}{\sigma}} y_d^{\frac{\sigma-1}{\sigma}} + (1-\mu)^{\frac{1}{\sigma}} \left(\left(\int_0^1 \nu_i^{\frac{1}{\epsilon}} y_i^{\frac{\epsilon-1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}} \right)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}. \quad (4)$$

$$\int_0^1 p_i y_i di + p_d y_d = wL + \int_0^1 \pi_i di + \mathcal{T}. \quad (5)$$

$$P = \left(\mu p_d^{1-\sigma} + (1-\mu) \left(\int_0^1 \nu_i p_i^{1-\epsilon} di \right)^{\frac{1-\sigma}{1-\epsilon}} \right)^{\frac{1}{1-\sigma}}. \quad (6)$$

Domestic good firms. There is a competitive domestic producer, who uses a constant-returns-to-scale technology to produce the domestic homogeneous good with labor, $y_d = \ell$. Therefore, $p_d = w$.

Final good firms. The model is centered around the decisions of the final-good firm, which, for exposition, we present as two managers: an inventory manager and an import manager.¹⁹ The inventory manager faces a dynamic problem. In each period, they set the price of the final good and place orders for the foreign inputs with the import manager. They are forward-looking and take into account the future tariffs in their order. The import manager solves a static cost-minimization problem. They produce the foreign input by aggregating a unit continuum of foreign varieties, which can be sourced from a set of foreign countries, C . Importing from a specific country incurs a per-period fixed cost; however, it grants the import manager one additional cost draw for the unit of foreign varieties. We assume a fixed continuum of varieties and allow the extensive-margin choice to be across countries, consistent with our empirical finding that sourcing adjustments occur across countries rather than across products.

¹⁸We include the exogenous transfer because our model abstracts from exports.

¹⁹The two-manager problem is isomorphic to a single manager who solves the joint optimization.

Import manager. For each final-good firm, indexed by $i \in [0, 1]$, its import manager fulfills the foreign input order, placed by the firm's inventory manager. They aggregate a unit continuum of foreign varieties, $x_i(v)$, where $v \in [0, 1]$. Production of the foreign input, x_i , follows a CES technology with an elasticity of substitution ρ :

$$x_i = \left(\int_0^1 x_i(v)^{\frac{\rho-1}{\rho}} dv \right)^{\frac{\rho}{\rho-1}}. \quad (7)$$

Each variety v can be sourced from C potential countries. To access the suppliers from the country c , the import manager needs to pay a common per-period fixed cost, f , denoted in domestic labor, whose price is given by w , as in [Blaum, Lelarge, and Peters \(2018\)](#). The suppliers producing varieties $v \in [0, 1]$ in each country $c \in C$ behave competitively and produce the variety with unit labor requirements $a_c(v)$. The import manager can procure variety v from the country c at cost $\tau_c a_c(v) w_c$, where w_c denotes the wage in country c , and τ_c the tariff imposed on varieties from country c . We assume that a tariff is applied to a country and therefore uniform across varieties from each country. This assumption delivers a closed-form solution for the import manager's problem.

Given the set of countries the import manager sources from, denoted by $\mathcal{C}_i \subset C$, the cost of purchasing a variety v , $z_i(v, \mathcal{C}_i)$, is the minimum of the price across the suppliers from the countries in the sourcing set, $z_i(v, \mathcal{C}_i) = \min_{c \in \mathcal{C}_i} \{\tau_c a_c(v) w_c\}$. Last, as described in Equation (8), the import manager chooses the optimal set of sourcing countries, $\mathcal{C}_i$, to minimize the sum of their marginal and fixed costs, subject to meeting the demand from the inventory manager, denoted by n_i . The sourcing set, $\mathcal{C}_i$, is defined with the indicator variables, I_c , which equals one if the country c belongs to the optimal set. The problem below shows the extensive-margin trade-off that the import manager faces: adding country c to the set $\mathcal{C}_i$ incurs fixed cost, f ; however, it also grants an additional cost draw for every variety $v \in [0, 1]$, which weakly lowers $z_i(v, \mathcal{C}_i)$.

$$\begin{aligned} \min_{\{x_i(v)\}_{v \in [0, 1]}, \{I_c \in \{0, 1\}\}_{c \in C}} & \int_0^1 z_i(v, \mathcal{C}_i) x_i(v) dv + w \sum_{c=1}^C I_c f, \\ \text{s.t.} \quad & x_i \geq n_i, \\ & x_i = \left(\int_0^1 x_i(v)^{\frac{\rho-1}{\rho}} dv \right)^{\frac{\rho}{\rho-1}}, \\ & z_i(v, \mathcal{C}_i) = \min_{c \in \mathcal{C}_i} \{\tau_c a_c(v) w_c\}, \\ & \mathcal{C}_i = \{c \in C : I_c = 1\}. \end{aligned} \quad (8)$$

We impose an additional assumption for the foreign suppliers. The unit labor requirements for producing variety v are drawn from a country-specific Fréchet distribution, as in [Eaton and Kortum \(2002\)](#), where $\Pr(a_c(v) \geq a) = e^{-T_c a^\theta}$. The state of technology in the country c is summarized by T_c , and θ controls the variability in the productivity draws across varieties. Given this assumption, the marginal cost of producing the foreign input is given by

$$z_i(\mathcal{C}_i) = \gamma \left(\sum_{c \in \mathcal{C}_i} T_c (\tau_c w_c)^{-\theta} \right)^{-\frac{1}{\theta}}, \quad (9)$$

where $\gamma = \Gamma\left(\frac{\theta+1-\rho}{\theta}\right)^{\frac{1}{1-\rho}}$ is a constant with $\Gamma(\cdot)$ denoting the gamma function. Note a slight abuse of notation, in which $z_i(\cdot)$ denotes the cost of the foreign input bundle and each foreign variety.

Given these assumptions, the import manager's extensive-margin choice problem can be rewritten as below, where $r_i(n_i)$ denotes the price of the input:

$$r_i(n_i) n_i = \min_{\{I_c \in \{0,1\}\}_{c \in C}} z_i(\mathcal{C}_i) n_i + w \sum_{c \in C} I_c f, \quad (10)$$

subject to Equation (9). Two remarks are in order. First, the import manager is more inclined to include countries with high *sourcing potential*, $T_c (\tau_c w_c)^{-\theta}$, which implies a higher technology level, T_c , lower tariffs, τ_c , or lower wages, w_c , since it reduces the marginal cost of the input, $z_i(\mathcal{C}_i)$. Second, an import manager facing higher demand finds it optimal to expand $\mathcal{C}_i$, since the gains from a lower marginal-cost scale with the quantity imported while the fixed cost does not. The following proposition formalizes these two points.

Proposition 1. *Given the input demand n_i , the optimal sourcing set $\mathcal{C}_i(n_i)$ satisfies the following properties:*

- (i) *If $c \in \mathcal{C}_i(n_i)$ and $T_c (\tau_c w_c)^{-\theta} \leq T_{c'} (\tau_{c'} w_{c'})^{-\theta}$, then $c' \in \mathcal{C}_i(n_i)$.*
- (ii) *If $n_{low} < n_{high}$, then $\mathcal{C}_i(n_{low}) \subset \mathcal{C}_i(n_{high})$, and $z_i(\mathcal{C}_i(n_{low})) \geq z_i(\mathcal{C}_i(n_{high}))$.*

The proof is provided in Online Appendix C. Part (i) highlights that the countries are added in the order of their ranking in sourcing potential. Part (ii) shows that the optimal sourcing set is increasing with foreign input demand. Therefore, the optimal sourcing set can be arranged according to input demand thresholds: the import manager adds country c_k , which represents the k -th country in the sourcing-potential ranking, if the demand is higher than a specific threshold, n_k . Further, the marginal cost of the foreign input is constant within

each interval of input demand, as outlined in Proposition 2. This proposition allows us to solve the dynamic problem of the inventory manager, which is described later, in a tractable way.

Proposition 2. *Let c_k denote the k -th country according to the sourcing-potential ranking, n_k the associated demand threshold for the country to be added to the optimal sourcing set, and z_k the marginal cost when sourcing from the top k countries in the ranking. Then, from Equation (10),*

$$\frac{\partial(r_i(n_i) n_i)}{\partial n_i} = z_k, \text{ if } n_i \in [n_k, n_{k+1}).$$

Note that $n_{C+1} = \infty$.

The proof follows directly from Proposition 1 and Equation (10).

Last, we show that the price of the foreign input is weakly increasing in tariffs. We let $\boldsymbol{\tau}$ denote the vector of tariffs across countries $[\tau_1, \tau_2, \dots, \tau_C]$ and allow the price of the foreign input to be a function of this vector, $r_i(n_i, \boldsymbol{\tau})$.

Proposition 3. *Suppose that for country c , its tariff strictly increases from τ_c to τ'_c , and let $\boldsymbol{\tau}$ and $\boldsymbol{\tau}'$ denote the tariff vectors before and after this increase, respectively. Then, for all $n_i \geq 0$, $r_i(n_i, \boldsymbol{\tau}') \geq r_i(n_i, \boldsymbol{\tau})$.*

The proof is in Online Appendix C. A tariff increase on a country outside the initial sourcing set leaves the price unchanged; a tariff increase on a country inside it raises the price strictly, whether or not that country survives in the set. The reason is that a small increase leaves the set unchanged and raises the marginal cost directly, while a larger increase leads the import manager to replace the affected country with one whose sourcing potential was previously lower.

Inventory manager. The inventory manager of the final-good firm $i \in [0, 1]$ produces a unique final good, y_i , using the foreign input, q_i , procured by the import manager. The foreign input has a one-period delivery lag to account for the timing friction of imports. This, along with the i.i.d. demand shock from the consumer for their variety, ν_i , creates incentives to hold inventories. The inventory depreciates at a constant rate if carried over to the next period. They solve the following dynamic problem, where they maximize the discounted value of current and expected future profits, taking into account the future path of tariffs for all foreign countries, $\vec{\boldsymbol{\tau}} = [\boldsymbol{\tau}', \boldsymbol{\tau}'', \dots]$.²⁰

²⁰We can incorporate uncertain tariffs into the model by adding a probability distribution over future tariff paths.

$$\begin{aligned}
V(s_i, \nu_i, \vec{\tau}) &= \max_{p_i, y_i, s'_i, n_i} p_i y_i - r_i(n_i, \tau) n_i + \beta \mathbb{E}_{\nu'_i} [V(s'_i, \nu'_i, \vec{\tau}')] \\
&\text{s.t.} \\
y_i &= \nu_i p_i^{-\epsilon} (1 - \mu)^{\frac{\epsilon}{\sigma}} Y^{\frac{\epsilon}{\sigma}} P^{\epsilon} y_M^{1 - \frac{\epsilon}{\sigma}}, \quad (\text{demand}) \\
y_i &= q_i, \quad (\text{linear technology}) \\
q_i &\leq s_i, \quad (\text{input constraint}) \\
s'_i &= (1 - \delta)(s_i - q_i + n_i). \quad (\text{law of motion for inventory})
\end{aligned} \tag{11}$$

The inventory manager's constraints are as follows. First, they face the demand from the consumer, which is a function of the i.i.d. firm-specific demand shock, ν_i , the aggregate output, Y , the aggregate price, P , and the final-good aggregate bundle $y_M = \left(\int_0^1 \nu_i^{\frac{1}{\epsilon}} y_i^{\frac{\epsilon-1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}}$. Second, they have a linear technology that transforms the foreign input, q_i , into the final good. Third, the amount of inputs they can use to produce is constrained by their start-of-period inventory, s_i , which captures the one-period delivery lag of the order, n_i . Fourth, the next period's inventory stock, s'_i , equals the sum of the input order today, n_i , and the amount of inventory that is left over after production today, $s_i - q_i$, which depreciates at a constant rate δ .

The first-order condition with respect to the order, together with Proposition 2, shows that the discounted value of an additional unit of inventory is equal to the marginal cost of the foreign input, for $n_i \in [n_k, n_{k+1})$:

$$\beta(1 - \delta) \frac{\partial \mathbb{E}_{\nu'_i} [V(s'_i, \nu'_i, \tau')]}{\partial s'_i} = z_k. \tag{12}$$

Combining Equation (12) with the first-order condition with respect to the price of the final good, p_i , provides the inventory manager's pricing rule,

$$p_i = \frac{\epsilon}{\epsilon - 1} (z_k + \lambda_i), \tag{13}$$

where λ_i is the Lagrange multiplier on the input constraint. If the firm is unconstrained in the amount of inputs it needs to meet demand ($\lambda_i = 0$), then the price is equal to the standard monopoly pricing of markup, $\epsilon/(\epsilon - 1)$, times the marginal cost. If the inventory manager is constrained due to the high demand relative to its inventories ($\lambda_i > 0$), then the price of the final good rises above the markup until the demand equals the inventory stock. Further, since a large input order, n_i , implies a lower marginal cost, z_k , there are incentives for the inventory manager to place large orders intermittently, consistent with the lumpiness

of trade discussed in Section 2.

Competitive equilibrium. We treat foreign wages $\{w_c\}_{c \in C}$ as exogenous and solve for the general equilibrium of the domestic economy, similar to the assumptions of a standard small open economy.

The competitive equilibrium is given by the state-contingent policy functions for the final-good firms' inventory manager $i \in [0, 1]$: $\{p_{it}(s, \nu, \vec{\tau}_t), y_{it}(s, \nu, \vec{\tau}_t), n_{it}(s, \nu, \vec{\tau}_t), s'_{it}(s, \nu, \vec{\tau}_t)\}_{t=0}^{\infty}$, and for the import manager $\{\mathcal{C}_{it}(\tau_t)\}_{t=0}^{\infty}$; the allocations for the domestic input firm $\{\ell_t\}_{t=0}^{\infty}$; the allocation for the consumer $\{Y_t, y_{dt}, \{y_{it}\}_{i \in [0,1]}\}_{t=0}^{\infty}$; and prices $\{w_t, P_t, p_{dt}, \{p_{it}\}_{i \in [0,1]}, \mathcal{T}_t\}_{t=0}^{\infty}$ such that:

- The policy functions and allocations solve the final-good firm problem, the domestic homogeneous good firm problem, and the representative consumer problem;
- The final good market clears for all $i \in [0, 1]$;
- The domestic homogeneous good market clears;
- The labor market clears, in which the fixed labor supply by the consumer is equal to the labor demand from the domestic homogeneous good firm and the final-good firm's fixed costs of sourcing, $L = \ell_t + \int_0^1 |\mathcal{C}_{it}| f \, di$;
- The transfer term $\mathcal{T}_t$ equals the import volumes.

4.2 Discussion of the Model Mechanism

The final-good firm's intensive- and extensive-margin decisions depend on the path of future tariffs. An anticipated tariff increase gives the inventory manager an incentive to front-load its inputs while they remain relatively cheap, thereby adjusting its intensive margin. The higher foreign input demand leads the import manager to expand the sourcing set, which lowers the marginal cost of the input, as shown in Proposition 1. The lower marginal cost raises the desired order further, so the two margins reinforce one another and amplify the front-loading response. The decline in the marginal cost passes through to the aggregates: the aggregate price declines, and output expands before the tariff.

In the model, the decline in marginal cost comes from the efficiency gains from a larger supplier base, a channel documented by Antras, Fort, and Tintelnot (2017), Gopinath and Neiman (2014), Halpern, Koren, and Szeidl (2015), and Blaum, Lelarge, and Peters (2018),

among many others. The decline in marginal cost due to larger imports admits a second microfoundation, where the larger orders from front-running come with quantity discounts from foreign suppliers; [Ganapati and Hottman \(2026\)](#) find such discounts for imports over the 2018–2019 tariff episode.

Once the tariff is implemented, the price of the varieties from the targeted foreign countries immediately rises, which increases the marginal cost of the foreign input. By Equation (13), this puts upward pressure on the price of the final goods. Final-good prices, however, also depend on whether the firm is stocked out: because firms entered the period with additional inventories, fewer of them are constrained, and the constrained firms are those that set a price higher than the markup rule. Aggregate price therefore rises by less than the tariff when it is implemented and remains lower than its final steady-state level during the transition, as firms draw down the inventories accumulated in anticipation of the tariff. Tariff pass-through to aggregates is thus initially incomplete, tempered by the strength of the firm’s anticipatory response.

5 Effects of Tariff Front-Running

To study the effect of front-running on macroeconomics, we first calibrate the model to match data moments in 2016. Second, using the model, we quantify firms’ responses to the observed tariff changes from 2016 to 2019. Third, through counterfactuals, we quantify the gains from anticipation in the aggregate output and price dynamics. Last, we show how the firm’s anticipatory response overstates the tariff elasticity.

5.1 Benchmark Calibration

We calibrate the model to firm-level and aggregate moments of the U.S. economy in 2016; Table 3 summarizes the parameter values. A period is a quarter, matching the frequency of the Compustat data. The discount factor is $\beta = 0.96^{1/4}$, a 4% annual interest rate, and the quarterly storage cost is $\delta = 0.05$, an annual rate of 18.5%, following [Richardson \(1995\)](#). The elasticity of demand across final-good varieties, $\epsilon = 4$, corresponds to a markup of roughly 33%. Two parameters come from [Antras, Fort, and Tintelnot \(2017\)](#): the elasticity of substitution across foreign input varieties, $\rho = 2$, and the Fréchet parameter governing the dispersion of productivity draws, $\theta = 1.789$. The elasticity of substitution between domestic inputs and the foreign input bundle is $\sigma = 1.5$, from [Boehm, Levchenko, and Pandalai-Nayar \(2023\)](#). Finally, the number of available foreign countries, $C = 8$, matches the third quartile of the distribution of sourcing countries per firm-quarter. Online Appendix C shows that the

aggregate output and price dynamics are robust to alternative values of these parameters.

Using the simulated method of moments, we internally calibrate the remaining eleven parameters: the standard deviation of the demand shock, σ_ν ; the fixed cost of importing, f ; the weight on the aggregate of domestic goods, μ ; and the eight Fréchet technology parameters, $\{T_c\}_{c \in C}$, for each foreign country in the set. These are matched to eleven moments: the aggregate inventory-to-sales ratio in Compustat, the average number of sourcing countries in the bills-of-lading (BoL) data, the share of domestic inputs in total intermediate usage reported by the Bureau of Economic Analysis (BEA)²¹, and the eight U.S. import shares for the seven largest source countries and a rest-of-the-world aggregate that are reported by the U.S. Census Bureau.

Demand shocks are drawn from a log-normal distribution normalized to have unit mean, $\mathbb{E}[\nu] = 1$, so that σ_ν alone governs dispersion. The calibration gives $\sigma_\nu = 1.002$, a fixed cost of adding a country to the sourcing set $f = 0.002$, and a weight on the domestic goods of $\mu = 0.859$. Because foreign wages enter the firm's problem only through the sourcing potential, $T_c (\tau_c w_c)^{-\theta}$, the technology parameters, initial tariff levels, and the foreign wages are not separately identified. We therefore normalize $w_c = 1$ and initial tariffs $\tau_c = 1$ for all foreign countries and let T_c absorb all initial cross-country differences in sourcing costs. Similarly, σ_ν is interpreted as a reduced-form summary of all the sources of uncertainty facing the firm, including productivity shocks.

5.2 Anticipated Tariff Increase

We quantify the final-good firm's response to an anticipated tariff and its impact on aggregate output and price dynamics. Firms begin in the initial, low-tariff steady state and learn with certainty, three quarters in advance, that the tariffs of the foreign countries will rise. We normalize the tariff implementation date to $t = 0$, so the news arrives at $t = -3$ to match the observed lag between the opening of the Sections 301 and 232 investigations and the first tariffs on imports from China and on steel and aluminum. Tariffs then rise permanently to the observed import-weighted average levels using 2016 imports as weights, as reported in Table 4. Then, firms converge to the final, high-tariff steady state over the next ten quarters.

We assume firms have perfect foresight over the path of aggregate output, prices, and wages, $\{Y_t, P_t, w_t\}_{t=-6}^{10}$. To solve the transition, we use backward induction, starting from the final, high-tariff steady state, and guess the path of output, prices, and wages. Then we simulate

²¹Note that, in the calibration, we treat the aggregate of final goods in the model as foreign inputs for the aggregate output in the data, since the final goods are produced solely using foreign inputs.

Table 3: Moments for the U.S. economy and parameters

Panel A. Jointly calibrated parameters

Parameter	Value	Data	Model	Target moment (2016)			
Fixed cost of importing, f	0.002	6.00	6.06	Number of sourcing countries (BoL)			
Std. deviation of demand shocks, σ_ν	1.002	0.690	0.697	Inventory-to-sales ratio (Compustat)			
Weight on domestic goods, μ	0.859	0.858	0.858	Domestic input share (BEA)			
Fréchet technology, $\{T_c\}_{c \in C}$				Share of total imports, % (U.S. Census)			
Country	T_c	Data	Model	Country	T_c	Data	Model
Rest of the world	0.85	35.8	36.0	Japan	0.31	6.0	5.8
China	0.70	21.1	21.3	Germany	0.28	5.2	5.2
Mexico	0.49	13.4	13.8	South Korea	0.16	3.2	2.8
Canada	0.46	12.7	13.0	U.K.	0.12	2.5	2.1

Panel B. Predetermined parameters

Parameter	Value	Description
Discount factor, β	$0.96^{1/4}$	4% annual interest rate
Storage cost, δ	0.050	18.5% annual rate (Richardson 1995)
Elasticity: final goods, ϵ	4	Firm's markup of 33%
Elasticity: inputs for agg. output, σ	1.5	Boehm, Levchenko, and Pandalai-Nayar (2023)
Elasticity: foreign varieties, ρ	2	Antras, Fort, and Tintelnot (2017)
Fréchet shape parameter, θ	1.789	Antras, Fort, and Tintelnot (2017)
Number of source countries, C	8	Third quartile of number of sourcing countries (BoL, 2016)

Table 4: Change in average applied tariffs, 2016–2019

Country	$\Delta \tau_c$	Country	$\Delta \tau_c$
Rest of the world	0.57	Japan	0.44
China	14.26	Germany	0.46
Mexico	0.25	South Korea	0.60
Canada	0.01	U.K.	0.29

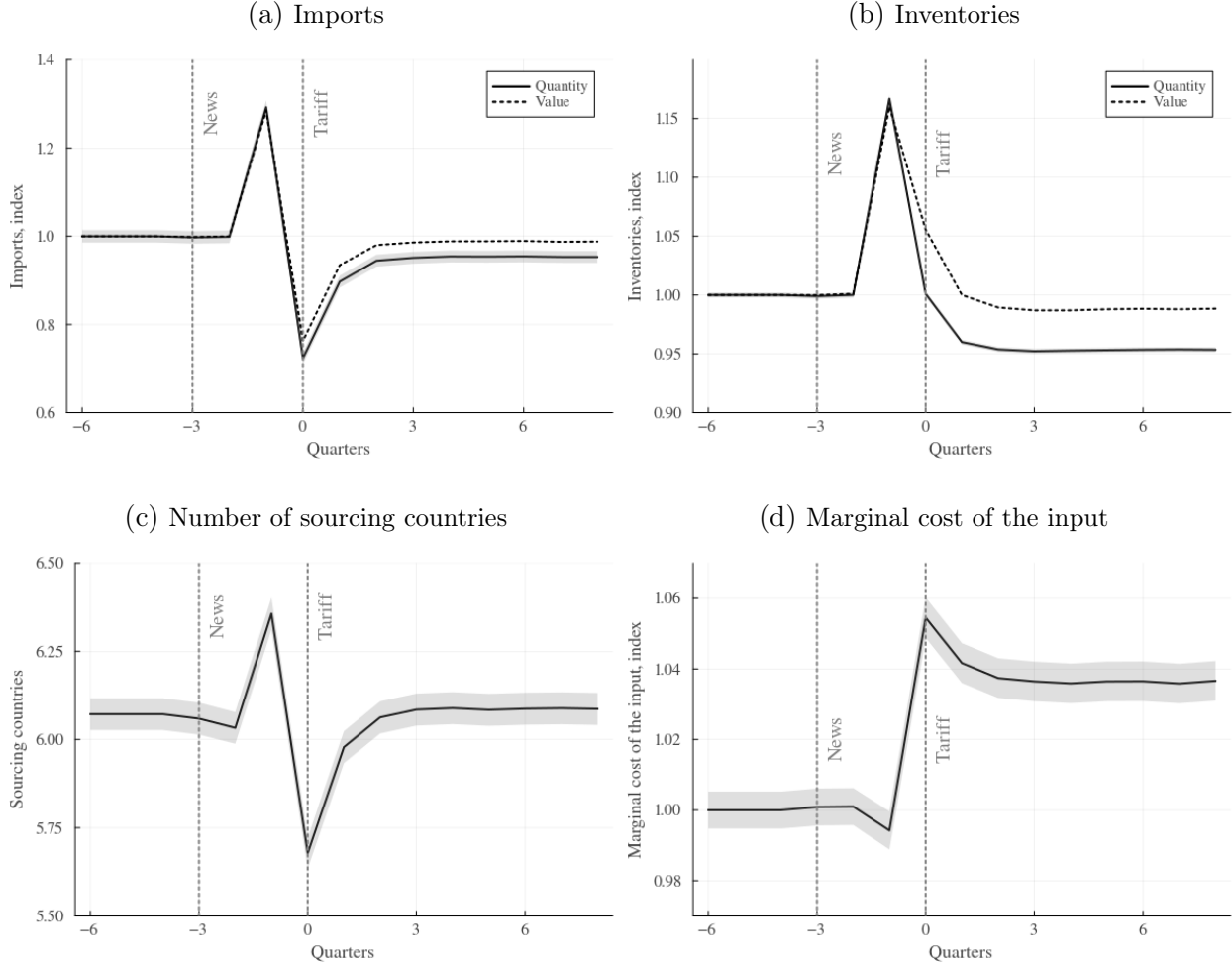
Note: The table covers the 7 largest sources of U.S. imports in 2016, and the rest of the world. The tariff for country c is given by $\tau_{c,t} \equiv \frac{\sum_h x_{h,c,2016} \tau_{h,c,t}}{\sum_h x_{h,c,2016}}$, where $x_{h,c,2016}$ is the aggregate import from product-country (h, c) in 2016. For each country, the tariff change is the difference between the 2016 and 2019 average tariff levels, $\Delta \tau_c = \tau_{c,2019} - \tau_{c,2016}$, in percentage points.

the economy over the path and update our guess on the aggregates until they converge. Online Appendix C provides more details on the algorithm.

Final-good firm's anticipatory response. Figure 5 shows the firm-level transition of imports, denoted by the foreign input order, n_i , end-of-period inventories, s'_i , the number of partners, $|\mathcal{C}_i|$, and the marginal cost of the foreign input, $z_i(\mathcal{C}_i)$, from the low- to the high-tariff steady-state levels.

Firms in the model front-load imports between the announcement and the implementation of

Figure 5: Firm-level anticipatory response to a tariff



Note: The figures show the transition path of the average imports, inventories, sourcing set, and marginal cost of the foreign input, and the shaded region shows the 95% confidence interval. Firms learn at period $t = -3$ that the tariffs will increase at period $t = 0$ with certainty.

the tariff when inputs are still cheap relative to their future price. Imports (quantity) peak in the quarter before the tariff takes effect, increasing by 29%. These additional imports are stocked as inventories, which rise by 17% in the period before the tariff increase. Firms pay the additional fixed costs of expanding their sourcing set, as the gains from a lower marginal cost are greater when imports rise. The number of sourcing countries, on average, increases by 0.3. The expansion of the extensive margin lowers the marginal cost of the imported input by 0.6%, consistent with Proposition 1. The model matches the untargeted anticipatory response of imports, inventories, and the number of partners in our empirical findings, and Table 5 in the next section provides a formal comparison.

After the tariff is implemented, imports collapse and slowly recover to their final, high-tariff steady state.²² Firms enter the period with additional inventories and therefore need not import as much in the short run; they draw down their stocks to meet demand over the following four quarters, as inventories converge to their final steady-state level.²³ The collapse of imports in the periods after the tariff shrinks the sourcing set, and thus, the marginal cost of the foreign input overshoots its final steady-state level in the short run.

In the final, high-tariff steady state, the marginal cost of the foreign input increases by 3.6% compared to its initial steady state, in line with the 3.3% increase in the firm’s import-weighted average tariff. The quantity of imports declines by 4.7%, and inventories fall by 4.6%, since a lower level of sales requires smaller stocks. The values of imports and inventories decline less sharply, since the tariff raises their price after implementation. The decline in imports, however, is not large enough to contract the sourcing set, and the average number of sourcing countries is unchanged in the new steady state.

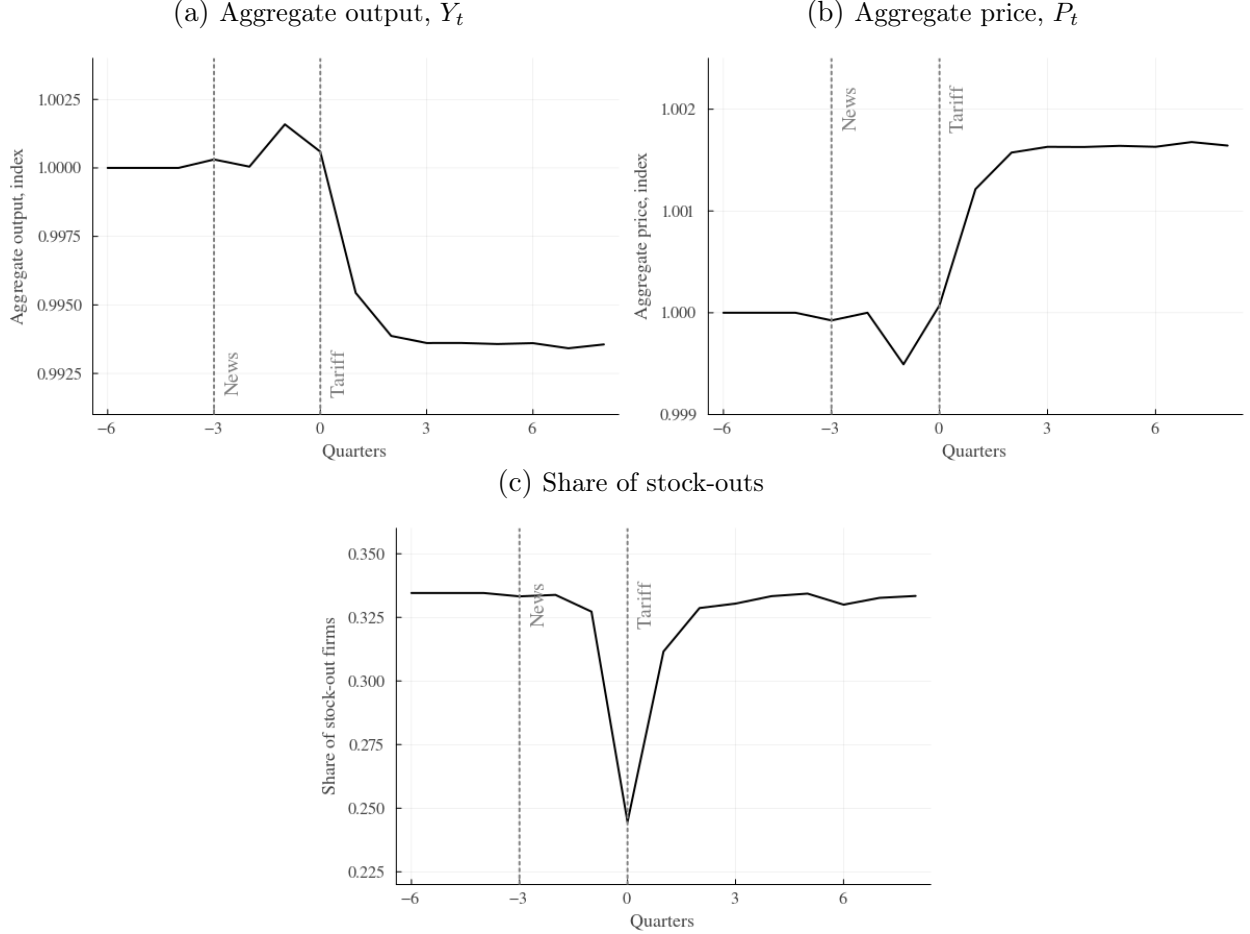
Impact on aggregate output and price dynamics. Figure 6 plots the transition of aggregate price, aggregate output, and the share of final-good firms that stock out. Ahead of the tariff, front-running lowers the marginal cost of the foreign inputs, and this decline passes through to the aggregate price, which declines by 0.05% relative to the initial steady state. Similarly, aggregate output expands by 0.16% in the period prior to the tariff. The model implies that the firm’s anticipatory response creates a temporary economic expansion before the tariff, and Table 6 provides empirical support for these aggregate predictions.

From implementation onward, the economy takes four quarters to reach the high-tariff steady state. Throughout this transition, front-running keeps output above and prices below their final steady-state levels. In the long run, the tariff lowers aggregate output by 0.6% and raises prices by 0.2%. The transition, however, mitigates the short-run impact of the tariff. In the quarter the tariff takes effect, output stands 0.7% above its final steady-state level and remains above it for the next three quarters. Aggregate prices converge just as gradually, where they rise after the tariff but remain 0.2% below their final steady state. The marginal cost of the foreign input incorporates the full tariff on impact, consistent with Fajgelbaum et al. (2020) and Amiti, Redding, and Weinstein (2019); however, the pass-through to the aggregate price is incomplete in the short run, dampened by the added inventories which imply a lower share of stock-outs in the short run (Panel (c), Figure 6). The aggregate

²²The collapse of trade due to the additional inventories has also been studied by Alessandria, Khan, and Khederlarian (2024) and Khan and Khederlarian (2021).

²³Compared to import and inventory quantities, import values post-tariff show a dampened decline since they are values at the price that includes the tariff.

Figure 6: Aggregate response to a tariff



Note: The figures show the transition path for the aggregate price, aggregate output, and the share of final-good firms that stock out. Firms learn at period $t = -3$ that the tariffs will increase at period $t = 0$ with certainty.

output and price transition is robust to different predetermined parameter values, as shown in Online Appendix C.

To the best of our knowledge, this is the first paper to study the impact of the firm's anticipatory response on the short-run aggregate dynamics. This matters for how the effects of tariffs are quantified. Because front-running sustains a higher output in both the run-up and the short-run aftermath of the tariff, an economy that has just imposed a tariff will not look like one under strain. Assessing the cost of a tariff from the first few quarters of data therefore understates it, and the larger the anticipatory response, the longer the mismeasurement lasts. This is relevant for the 2025–2026 U.S. tariff episodes, where front-loading was common. More broadly, the mechanism is not specific to tariffs. The same logic applies to announced regulatory changes, scheduled tax increases, and anticipated supply

disruptions.

5.3 Matching the Model to the Data

In this section we first show that the model matches the untargeted firm’s anticipatory response and then provide data evidence that supports the model’s predictions for the aggregate price and output dynamics. Our empirical findings presented in Figure 3 show that firms front-run tariffs by increasing their imports, inventories, and number of sourcing partners before the tariff is implemented, and in Table 5 we compare the findings to the model’s response.

Table 5: Firm’s anticipatory response, model vs. data

	Response the quarter before implementation	
	Data	Model
Value of imports	0.09 (0.22)	0.28
Number of partners	0.03 (0.10)	0.05
Value of inventories	0.20 (0.09)	0.16

Note: Column 1, *Data*, reports the LP-DiD estimates and their standard error using the log specification (i.e., $\log(y_{i,t}) - \log(y_{i,2016:q(t)})$) for the period before the tariff, for the value of imports, value of inventories, and number of partners (product-countries). Column 2, *Model*, shows the change in the quarter prior to the tariff relative to the initial steady state.

Column 1 reports the firm-level estimated response in the quarter before implementation, using the LP-DiD estimator with a log specification rather than the inverse hyperbolic sine of Section 3, whose coefficients do not translate into percentage changes. The log specification drops observations with zero imports or zero partners, which are frequent in our sample given the lumpiness of trade. Thus, these estimates are less precise. Column 2 reports the model counterpart for the quarter before implementation. Imports and inventories are measured as values, so they correspond to what is observed in the data, and the extensive margin is measured as the number of sourcing countries. In the data, the extensive margin counts product-country pairs; however, since we find no adjustment along the product dimension, we compare them to the count of sourcing countries in the model.

The model reproduces the qualitative pattern in the data but overstates the import response: imports grow by 28% in the model in the quarter before implementation, against 9% in the data. This gap may reflect a modeling choice, since we raise all tariffs at once, whereas

in the data firms faced a sequence of tariffs. The increase in the number of partners and inventories lines up more closely. The number of sourcing countries rises by 5% in the model and 3% in the data; given a mean of approximately six source countries, these correspond to increases of 0.31 and 0.20 countries, respectively. Inventories grow by 16% in the model against 20% in the data. The model’s anticipatory response is concentrated in the quarter before the tariff and thus fails to match the adjustment in the data, which starts several quarters before implementation. Adjustment costs on inventory changes could spread the response over the announcement window and bring the model closer to the observed path. Further, in Table A3 of Appendix A, we show the model matches the observed change in import shares between 2016 and 2019.

Last, we take the model’s aggregate prediction to the data: ahead of the tariff, the firms’ anticipatory response raises output and lowers prices, and both reverse once the tariff takes effect. To do so, we interpret the economy in the model as an industry and compare the model’s paths with industry-level indices of output and prices. Then, we ask whether industries more exposed to the tariffs observe higher output and lower price growth in the quarters before implementation and the opposite afterwards. Because industries use many inputs, all industries were exposed to all of the tariff waves, and at the industry level we cannot isolate each wave separately. Therefore, we center the analysis on the China List 3 tariffs, which affected the largest volume of imports (Table 1). We split the sample into three windows to compare the average growth of output and price across industries with different tariff exposures. The *initial* period runs from January 2016 to July 2017, ending just before the USTR opened its Section 301 investigation. The *pre-tariff*, or anticipatory, period runs from August 2017 to August 2018, ending before the List 3 tariffs were implemented. The *post-tariff* period runs from September 2018 to December 2019, which predates the COVID-19 pandemic.

We compute two tariff exposure measures across industries, leveraging our firm-level data. First, we consider the share of firms in each NAICS 6-digit industry that observed a tariff increase in their imports from the List 3 tariffs, defined by $M1_j \equiv \frac{\sum_{i \in j} TI_{i,g}^{L3}}{\text{number of firms in } j}$, where j denotes an industry, i a firm, and g^{L3} denotes the List 3 event quarter. Second, we compute the average magnitude of the tariff shock across the firms in each industry, denoted by $M2_j$.²⁴ We obtain data on industry output from the Industrial Production Index (IPI), provided by the Federal Reserve Board, which measures the real output of all establishments in the United States. Aggregate price data come from the Bureau of Labor Statistics (BLS)

²⁴For the magnitude, we use the log growth factor of firm-level tariffs from before the tariff to when it was the highest. See Appendix B for more details and rationale behind this choice.

Producer Price Index (PPI), which measures the average selling prices received by domestic producers for their output. We use the seasonally adjusted series of the IPI and apply seasonal adjustments to the raw PPI data.

Table 6: Correlation between tariff measures and output and price growth

Panel A. Output		$M1_j$	$M2_j$
(1)	$\log(IPI_{j,pre-\tau}/IPI_{j,initial})$	0.052 (0.030)	0.333 (0.224)
(2)	$\log(IPI_{j,post-\tau}/IPI_{j,pre-\tau})$	-0.036 (0.022)	-0.222 (0.165)
Observations		131	131
Panel B. Prices		$M1_j$	$M2_j$
(3)	$\log(PPI_{j,pre-\tau}/PPI_{j,initial})$	-0.017 (0.007)	-0.117 (0.053)
(4)	$\log(PPI_{j,post-\tau}/PPI_{j,pre-\tau})$	0.011 (0.006)	0.081 (0.046)
Observations		299	299

Note: The table shows the regression results for $\log(y_{j,t}/y_{j,t-1}) = \beta_0 + \beta M_j + \epsilon_j$ and reports the estimated coefficient, β , and its standard error.

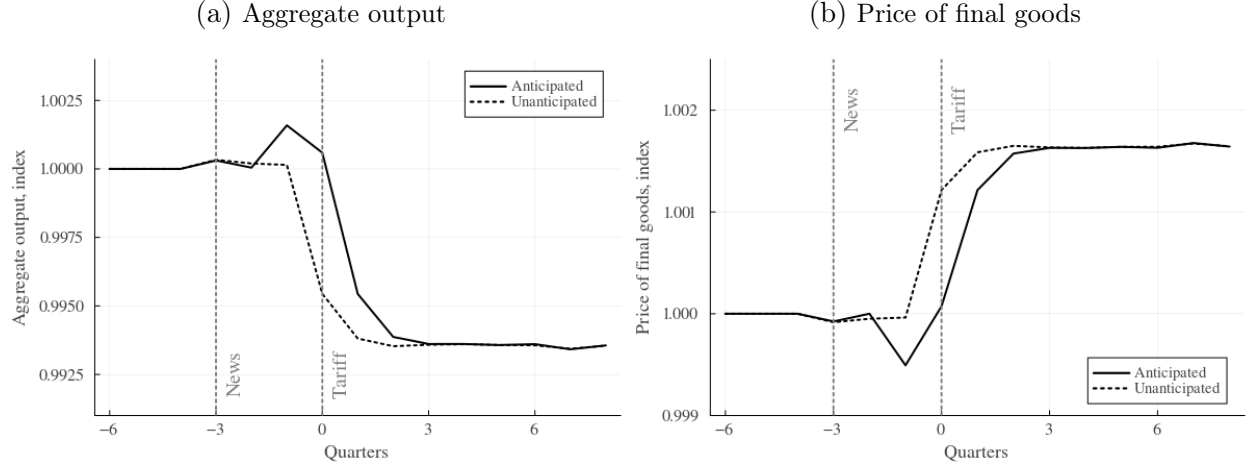
Table 6 shows evidence consistent with the model’s predictions. We find that in the period between investigation and implementation, the output of industries more exposed to the tariff grew by more (row 1) relative to less tariff-exposed industries, and prices by less (row 3), in line with the model’s implication that the firms’ anticipatory response generates a temporary expansion. Then, after the tariff, the output of tariff-exposed industries grows by less (row 2) and their prices by more (row 4) relative to less-exposed industries. Further, new studies on the 2025 U.S. tariffs by [de Soyres, Goernemann, and Machol \(2025\)](#) and [Fajgelbaum and Khandelwal \(2026\)](#) find evidence that import front-loading leads to output growth prior to the tariff.

5.4 Gains from Anticipation

We quantify the gains from anticipation in Figure 7 by comparing our benchmark model, where firms know and can respond to the tariff in advance (*anticipated*), to a counterfactual where firms learn about the tariff in the period it is implemented (*unanticipated*). Front-running leads to higher output and lower prices both in the run-up and aftermath of the tariff. The expansion between announcement and implementation is absent when the tariff is unanticipated, where the economy remains in the initial, low-tariff steady state until the tariff

takes effect. In the quarter before implementation, output is 0.16% higher and aggregate price is 0.05% lower under anticipation.

Figure 7: Aggregate response, anticipated vs. unanticipated tariff



Note: The figures show the transition path of aggregate output and prices. The solid line represents the transition under the anticipated assumption, where firms learn about the tariff in period $t = -3$. The dotted line shows the transition for an unanticipated tariff increase, where firms learn about the tariff change when it is implemented at $t = 0$.

Post-tariff, the anticipatory response sustains a higher level of output and lower prices along the short-run transition compared to the case where the tariff is unanticipated. In the quarter of implementation, when the tariff is anticipated, aggregate output is 0.7% above the final, high-tariff steady state, against only 0.2% when the tariff is unanticipated, and remains higher until they converge three quarters after. Aggregate prices show the same pattern. They are 0.2% below the final steady state under anticipation but only 0.04% below it when the tariff is unanticipated.

Even when the tariff is unanticipated, in a model with inventories, the aggregate output and price will observe a transition that sustains higher output relative to the final steady state. The tariff raises the cost of the input and lowers the final steady-state output, which requires less inventory. Therefore, when tariffs rise, firms already have an excess of inventories to draw down and smooth out the transition. Yet, the excess of inventory is lower than when the tariff is anticipated, creating a faster and sharper transition.

Table 7 computes the gains from anticipation. Starting from the period of announcement ($t = -3$), it reports the gap between the anticipated and unanticipated transitions as a share of the final steady state, $(X_t^a - X_t^u)/X^{\text{final}}$, for aggregate output and prices. Tariff anticipation allows for the cost of the tariff to be borne more gradually in the short run,

and the present-value output gain equals 0.82% of the quarterly final steady-state output, or equivalently 0.21% of its yearly level.

Table 7: Gains from anticipation

	Pre-tariff			Post-tariff				PV, %
	$t = -3$	-2	-1	$t = 0$	1	2	3	
Output, $(Y_t^a - Y_t^u)/Y^{\text{final}}$	0.00	-0.02	0.16	0.52	0.16	0.03	0.00	0.82
Prices, $(P_t^a - P_t^u)/P^{\text{final}}$	0.00	0.00	-0.05	-0.11	-0.04	-0.01	0.00	

Note: Entries are in percent. Superscripts a and u denote the anticipated and unanticipated transitions; Y^{final} and P^{final} are the final, high-tariff steady-state levels. The PV column is the present value of these gaps discounted at the quarterly factor $\beta = 0.96^{1/4}$, calculated from the period of news, $t = -3$.

5.5 Tariff Elasticity Bias

The firm’s anticipatory response overstates the estimates of how trade responds to tariff changes, relative to an unanticipated tariff. Following [Boehm, Levchenko, and Pandalai-Nayar \(2023\)](#), we compute the horizon- h response of imports to the tariff change as $\epsilon^h = \frac{\log(x_{g+h}) - \log(x_{g-1})}{\log(\tau_{g+h}) - \log(\tau_{g-1})}$, where g is the quarter of implementation, and x_g and τ_g denote the imports from China and their tariffs. Table 8 shows the short- and long-run tariff elasticities under the anticipated tariff (Column 1) and unanticipated tariff assumption (Column 2).

Under anticipation, the short-run elasticity ($h = 0$) is 2.6 (5.7/2.2) times larger than the unanticipated tariff elasticity (Column 2), and the long-run elasticity is 2.1 (3.7/1.8) times larger. Front-running raises imports ahead of the tariff, and they collapse right after, as firms draw down their accumulated inventories to meet demand rather than importing, as shown in Figure 8. This leads to an overstatement of both the short- and long-run elasticities relative to the unanticipated case. This bias was previously shown by [Khan and Khederlarian \(2021\)](#), who study NAFTA’s phased tariff reductions and find that the trade-flow elasticities are 56% larger than their anticipation-adjusted measure.

The model lets us go further and ask whether the bias can be undone. Column 3 shows that the short-run elasticity is overstated even when we measure it relative to a period preceding the announcement, prior to any front-running. The short-run elasticity is 1.7 (3.8/2.2) times larger than in the unanticipated case, since the collapse of imports post-tariff is stronger when firms can anticipate the tariff. However, with a far enough initial point, we can recover the same long-run tariff elasticity.

The tariff elasticity is a central parameter in quantitative trade models, where it governs the

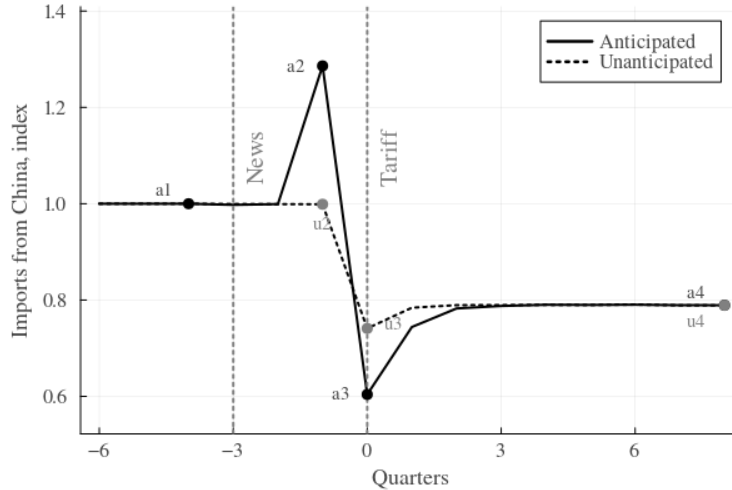
computed gains from trade. If elasticities estimated from anticipated tariff changes are twice as large as their unanticipated counterparts, calibrated models would overstate how readily firms substitute away from the tariffs in the short run, and therefore understate the cost of a tariff. The bias may also account for part of the dispersion in published estimates. How anticipated the tariff is might vary across episodes, and the level of uncertainty surrounding implementation events adds to the mismeasurement.

Table 8: Tariff elasticity bias

	Anticipated tariff	Unanticipated tariff	Anticipated, prior to news
Short run, $h = 0$	-5.7 (a2 $\rightarrow$ a3)	-2.2 (u2 $\rightarrow$ u3)	-3.8 (a1 $\rightarrow$ a3)
Long run, $h = 7$	-3.7 (a2 $\rightarrow$ a4)	-1.8 (u2 $\rightarrow$ u4)	-1.8 (a1 $\rightarrow$ a4)

Note: The table shows the model's response of imports to a one-time change in tariff where $\epsilon^h = \frac{\log(x_{g+h}) - \log(x_{g-1})}{\log(\tau_{g+h}) - \log(\tau_{g-1})}$ and x_g and τ_g are the imports from China and their tariff. Column 1, *anticipated tariff*, reports the tariff elasticity when firms can front-run, and column 2, *unanticipated tariff*, where the tariff is announced when it is implemented, both computed relative to the quarter before implementation, $g-1 = -1$. Column 3 reports the anticipated tariff elasticity relative to the period prior to the announcement, $g-1$ is fixed at quarter -4 . In each entry, $(x \rightarrow y)$ conveys that the elasticity is calculated based on points x and y on Figure 8.

Figure 8: Response of imports from China to an increase in tariff



Note: The figures show the transition path of the mean of imports from China in response to their increase in tariffs, for both the anticipated and unanticipated tariff assumptions.

6 Conclusion

The 2018–2019 U.S. import tariffs did not arrive unannounced: formal investigations began about a year before the tariffs took effect. We show empirically that over the year before

the tariff, importing firms raised imports of the soon-to-be-tariffed products, accumulated inventories, and added source countries for those products rather than switching to untariffed ones. Our open-economy general-equilibrium model with both intensive and extensive margins of trade shows that this firm-level anticipatory behavior leads to higher output and lower prices both in the run-up and the aftermath of the tariff, until they converge to their high-tariff steady-state level four quarters later. Front-running mitigates the short-run impact of the tariff. Relative to an unanticipated tariff of the same size, anticipation raises the present value of output by 0.21% of the annual steady-state output.

Our results have two main implications. First, not only the level of a tariff but also how it is implemented matters for economic outcomes. Giving firms time to adjust allows them to front-load part of the response, leading to the output gain quantified above. Second, anticipation changes how the effects of a tariff should be measured. Aggregate output and prices in the first quarters after the tariff are cushioned by stockpiled inventories, so early data understate the long-run cost. More broadly, the implications of our results are not limited to tariffs; any anticipated increase in future costs—such as scheduled tax increases, announced regulatory changes, or foreseeable supply chain disruptions—produces the same aggregate dynamics.

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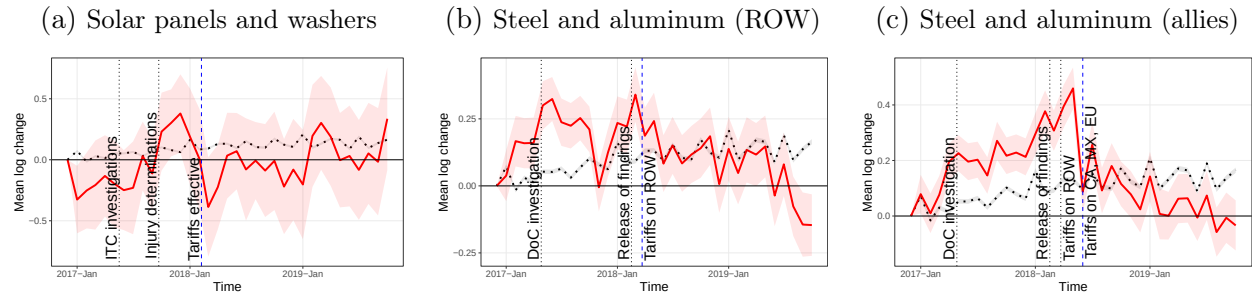
Appendix

A Additional Tables and Figures

Table A1: Summary statistics (2015Q1–2019Q4)

	Mean	Stdev	P10	P25	P50	P75	P90
<i>(a) All firm-quarters ($N = 93,910$)</i>							
Sales (\$ millions; $N = 71,184$)	1,472	5,521	1	17	155	740	2,903
Inventories (\$ millions; $N = 43,762$)	330	1,518	0	0	6	138	641
<i>(b) Importing firms ($N = 5,255$)</i>							
Importing quarters (count)	12	8	1	4	15	20	20
Importing products (count)	68	142	1	4	16	65	187
Importing countries (count)	11	14	1	2	6	16	31
<i>(c) Importing firm-quarters ($N = 65,509$)</i>							
Importing products (count)	19	40	1	2	6	19	48
Importing countries (count)	6	7	1	1	3	7	15
<i>(d) Importing firm-product-quarters ($N = 1,241,898$)</i>							
Imports (\$ thousand)	1,533	47,751	2	11	50	208	848
Importing countries (count)	1	1	1	1	1	1	2
<i>(e) Importing firm-country-quarters ($N = 383,984$)</i>							
Imports (\$ thousand)	4,959	59,548	5	24	121	676	3,509
Importing products (count)	4	12	1	1	2	4	9
<i>(f) Importing firm-product-country-quarters ($N = 1,694,375$)</i>							
Imports (\$ thousand)	1,124	24,644	2	10	44	175	681

Figure A1: Import dynamics for products subject to the solar/washer safeguards and the steel and aluminum tariffs



Note: The figure plots the average log change in import volumes relative to the corresponding month in 2016 across HTS10 product-country pairs. Panels (a) through (c) contrast, in chronological order of the tariff waves, product-countries subject to the Section 201 safeguard tariffs on solar panels and washers, the Section 232 steel and aluminum tariffs on countries without exemptions (ROW), and the same tariffs upon the expiry of the exemptions for Canada, Mexico, and the EU (red solid lines), against product-countries never subject to tariff increases during 2018–2019 (black dotted lines). The shaded areas represent the 95% confidence intervals. Vertical black dotted lines mark major “anticipatory” events (e.g., the ITC and Department of Commerce investigations). Vertical blue dashed lines indicate the date of tariff increases.

Table A2: Timeline of Section 201 safeguard tariffs on solar panels and washing machines

Event	Date	Description	Source	Products	Value(\$B) ^a
(a) Solar panels (crystalline silicon photovoltaic cells and modules)					
Investigation	May 17, 2017	ITC institutes investigation following petition by Suniva.	82 FR 25331	Solar Cells/Modules	–
Determination	Sep 22, 2017	ITC votes 4-0 finding imports caused serious injury.	82 FR 45313	–	–
Announcement	Jan 23, 2018	President signs Proclamation 9693 imposing tariffs.	83 FR 3541	–	–
Effective Date	Feb 7, 2018	30% tariff on modules; TRQ on cells (2.5GW exempt).	Proclamation 9693	CSPV Modules	8.7
(b) Large residential washers					
Investigation	Jun 5, 2017	ITC institutes investigation following petition by Whirlpool.	82 FR 27075	Washers	–
Determination	Oct 5, 2017	ITC votes 4-0 finding imports caused serious injury.	82 FR 48113	–	–
Announcement	Jan 23, 2018	President signs Proclamation 9694 imposing tariffs.	83 FR 3553	–	–
Effective Date	Feb 7, 2018	TRQ: 20% on first 1.2M units; 50% on excess.	Proclamation 9694	Res. Washers	1.7

Notes: “ITC” refers to the U.S. International Trade Commission. “FR” refers to the Federal Register. “TRQ” refers to Tariff-Rate Quota.

^a Values represent the 2016 annual import volume (in billions of USD).

Table A3: Tariffs and changes in import shares, 2016–2019

Country	$\Delta \tau_c$	Δ import share		Country	$\Delta \tau_c$	Δ import share	
		Data	Model			Data	Model
Rest of the world	0.57	2.44	2.11	Japan	0.44	−0.28	0.45
China	14.26	−2.92	−4.74	Germany	0.46	−0.13	0.41
Mexico	0.25	0.93	0.77	South Korea	0.60	−0.11	0.11
Canada	0.01	0.04	0.79	U.K.	0.29	0.02	0.09

Note: The table covers the 7 largest sources of U.S. imports in 2016, and the rest of the world. The tariff for country c is given by $\tau_{c,t} \equiv \frac{\sum_h x_{h,c,2016} \tau_{h,c,t}}{\sum_h x_{h,c,2016}}$, where $x_{h,c,2016}$ is the aggregate import from product-country (h, c) in 2016. For each country, the tariff change is defined as the difference between the 2016 and 2019 average tariff levels, $\Delta \tau_c = \tau_{c,2019} - \tau_{c,2016}$. The Δ import share columns report the change in percentage points in each country’s share of U.S. imports in the data and in the model. The model qualitatively matches the direction of the change for the largest source countries—China, Mexico, Canada, the U.K., and the rest of the world—but not for Japan, Germany, and South Korea, where the size of the tariff increase leads the model to predict a decline in import shares that the data do not show.

B Continuous Measure of Tariff Increase

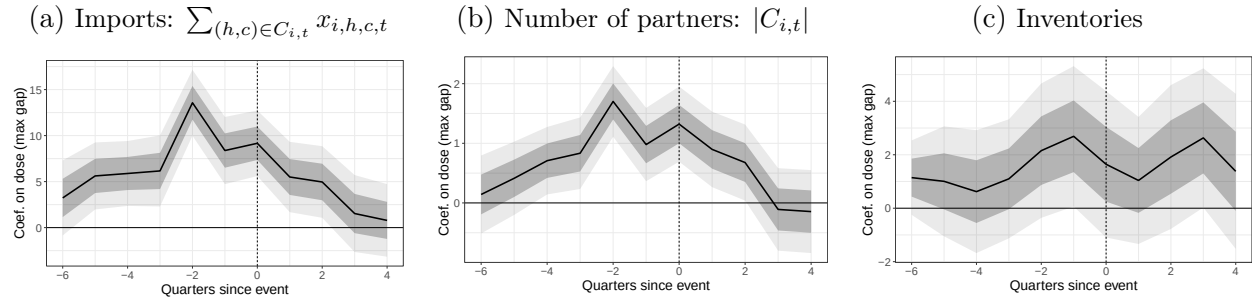
We have focused on the tariff-increase dummies for our analyses. However, since the magnitude of shocks can affect the quantitative results, here we explore a continuous measure of tariff-increase shocks. In Equation (2), instead of $D_{i,g}$, we utilize $D_{i,g}MS_i$. The magnitude

of the tariff increase for firm i , MS_i , is defined as follows. For a firm with $g_i < \infty$,

$$MS_i \equiv \max_{t' \geq g_i} \left\{ \log \left(\frac{1 + \tilde{\tau}_{i,t'}}{1 + \tilde{\tau}_{i,g_i-1}} \right) \right\},$$

and $MS_i \equiv 0$ for never-treated firms. In the above, $\tilde{\tau}_{i,t}$ denotes the existing-import-weighted tariff level for firm i at time t . MS_i measures, for a firm that ever experienced a tariff increase, the maximum log-average tariff factor relative to the quarter just before its first tariff increase; it thereby captures the firm's exposure to the full tariff trajectory. The rationale for not using a time-varying magnitude of the shock is as follows. Suppose that we utilized $MS_{i,g_i+k} \equiv \log \left(\frac{1 + \tilde{\tau}_{i,g_i+k}}{1 + \tilde{\tau}_{i,g_i-1}} \right)$. For the period before the tariff hike (i.e., $k < 0$), if both the import composition and tariffs are stable, MS_{i,g_i+k} will be close to zero. This makes the study of anticipatory effects not possible. We re-run the exercise in Figure 3, utilizing $D_{i,g}MS_i$ instead of $D_{i,g}$. Figure B1 reports the results.

Figure B1: Imports, number of partners, and inventories around the first tariff increase (continuous measure)



Note: The figures re-conduct the exercise in Figure 3 utilizing the continuous measure $D_{i,g}MS_i$ instead of the dummy variable $D_{i,g}$. The dark and light shaded areas are the ± 1 and ± 1.96 standard-error bands (68% and 95% confidence intervals), respectively. Standard errors are clustered at the firm level.

C Heterogeneity Across Firm Sizes

In this section, we study whether the main empirical results in Figure 3 vary across firm sizes. We measure the size of firm i by s_i , the logarithm of its average quarterly sales in 2016. For each horizon $k = -6, \dots, +4$, we estimate

$$\Delta \tilde{y}_{i,g+k} = \beta_k D_{i,g} + \gamma_k D_{i,g} (s_i - \bar{s}) + \Gamma'_{g,k} X_i^{2016} + \alpha_{j(i),g,k} + \epsilon_{i,g,k}, \quad (C1)$$

where $\bar{s}$ is the median of s_i among the treated firms and the remaining terms are as in Equation (2). β_k is the response of a treated firm of median size, and γ_k is the size gradient: the response of a treated firm of size s is $\beta_k + \gamma_k(s - \bar{s})$. Because s_i is part of X_i^{2016} ,

γ_k is identified from the differential response of larger treated firms rather than from size differences between treated and never-treated firms.

Table C1 reports the estimated $\{\gamma_k\}$ for the three outcomes. The size gradient is not statistically significant at any horizon for any outcome; the smallest p -value across the 33 horizon–outcome pairs is 0.10.

Table C1: Size gradient of the anticipatory responses

Horizon k	Imports		Number of partners		Inventories	
	γ_k (S.E.)	p -value	γ_k (S.E.)	p -value	γ_k (S.E.)	p -value
−6	−0.050 (0.087)	0.56	−0.013 (0.015)	0.38	0.000 (0.068)	1.00
−5	−0.027 (0.086)	0.75	−0.007 (0.014)	0.63	−0.064 (0.067)	0.34
−4	0.012 (0.072)	0.86	−0.004 (0.013)	0.76	−0.049 (0.070)	0.49
−3	−0.099 (0.081)	0.22	−0.017 (0.013)	0.20	−0.072 (0.075)	0.34
−2	−0.058 (0.080)	0.47	−0.013 (0.014)	0.35	−0.055 (0.084)	0.52
−1	−0.051 (0.081)	0.53	−0.011 (0.014)	0.43	−0.108 (0.087)	0.21
0	−0.032 (0.081)	0.69	−0.016 (0.015)	0.28	−0.104 (0.091)	0.25
1	−0.122 (0.085)	0.15	−0.024 (0.015)	0.10	−0.086 (0.082)	0.29
2	−0.039 (0.086)	0.65	−0.014 (0.015)	0.34	−0.077 (0.091)	0.40
3	0.081 (0.089)	0.36	−0.001 (0.016)	0.96	−0.099 (0.096)	0.30
4	0.030 (0.087)	0.73	−0.014 (0.017)	0.42	−0.076 (0.092)	0.41

Notes: Each row reports, for each outcome, the estimated size gradient γ_k in Equation (C1)—the change in the response per unit of log 2016 sales—with the standard error in parentheses and the two-sided p -value of $\gamma_k = 0$. Standard errors are clustered at the firm level.