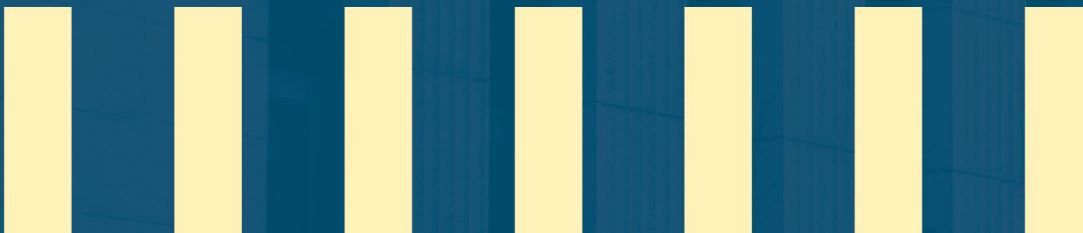


# How Do Import Tariffs Affect Aggregate Prices? Theory and Evidence from Canada

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# How Do Import Tariffs Affect Aggregate Prices?

## Theory and Evidence from Canada\*

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### Abstract

By how much do import tariffs raise aggregate prices? We develop a simple decomposition that separates the aggregate price effect of a tariff into three channels—cost pass-through, markup adjustments, and consumer substitution across varieties—and calibrate an oligopolistic competition model with endogenous markups to firm-level market shares for Canadian domestic producers, U.S. exporters, and rest-of-world suppliers. A 25% counter-tariff on U.S. imports raises Canada’s aggregate price index by 0.66%—well below the 1.25% that direct cost pass-through alone would predict. The dominant offsetting force is consumer substitution toward non-U.S. varieties, which reduces the price effect by 0.47 percentage points; markup adjustments, holding fixed pre-tariff market shares, contribute a further 0.26 percentage point decrease. The gap between cost pass-through and the true price effect widens sharply with the tariff rate: at a 50% tariff, cost pass-through alone predicts more than twice the true price effect.

*JEL classification:* E31, F13, F14, L11, L16

*Keywords:* tariffs, markups, price decomposition, reallocation, nonlinearity

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# 1 Introduction

Tariffs are back. In early 2025, the United States imposed 25% tariffs on nearly all imports from Canada and Mexico as part of the broadest U.S. trade action in nearly a century. In response, Canada levied tariffs of 25% on C\$155 billion worth of U.S. goods entering Canada. The significance of Canada–U.S. bilateral trade—exceeding C\$900 billion annually<sup>1</sup>—heightens the need to assess the impact on a wide range of issues, from government budgets, to producer and consumer welfare, to monetary policy responses. Central to all of these is a simple question: by how much do these tariffs raise aggregate prices?

A straightforward approach to assessing the impact of tariffs, often used in applied work, is to measure the effect by multiplying each tariff rate by the affected product’s expenditure share and then summing across products. This naive approach is simple and has low data requirements; however, it relies on the strong assumptions of fixed market shares and constant markups. But consumers substitute: when tariffs raise the price of some imports, buyers shift toward cheaper alternatives, reallocating expenditure across varieties. And firms adjust: under imperfect competition, tariff-affected firms lose market share, face more elastic demand, and compress their markups, while the opposite occurs for unaffected firms. The adjustments in market shares and firm markups lower the aggregate price effect relative to the fixed-share constant-markup prediction.

We demonstrate that these adjustments are quantitatively large. We develop a second-order decomposition that separates the aggregate price effect of tariffs into cost pass-through, markup adjustments, and expenditure reallocation, and calibrate a multi-industry oligopolistic competition model (Atkeson and Burstein, 2008; Edmond, Midrigan and Xu, 2015) to Canadian firm-level data. A 25% counter-tariff on U.S. imports raises the aggregate price index in the Canadian market by only 0.66%, compared with the 1.25% implied by direct cost pass-through. Two dominant forces drive this wedge: a reallocation of market shares as consumers substitute toward cheaper non-U.S. varieties within industries (−0.47%) and

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<sup>1</sup>See <https://ustr.gov/countries-regions/americas/canada>.

firm-level markup adjustments ( $-0.26\%$ ).<sup>2</sup> Together, these channels reduce the aggregate price effect by nearly half relative to direct cost pass-through.

Four findings stand out. First, we show that, under weak conditions and standard constant-elasticity-of-substitution (CES) demand, expenditure reallocation always reduces the aggregate price effect. Fixed-share methods therefore necessarily overstate the true price effect of the tariff (Proposition 1). The size of this reallocation effect depends on the dispersion of firm-level price changes and on the elasticities of substitution across varieties and industries: the more unevenly the tariff affects firms within an industry, and the more easily consumers can substitute across varieties, the larger the dampening effect (Proposition 2). In our setting, this dispersion comes from two sources: heterogeneity in cost changes, because the tariff applies only to imports of products sold by U.S. firms, and heterogeneity in markup responses, because firms with different market shares adjust their markups by different amounts. Quantitatively, the reallocation channel offsets about 38% ( $\approx -0.47/1.25$ ) of the direct cost effect.

Second, the overall reallocation effect increases nonlinearly with the size of the tariff. At a 5% tariff, ignoring reallocation overstates the price effect by about 9%, raising it from 0.20 to 0.22 percentage points. At a 50% tariff, however, a first-order approach—which combines direct cost pass-through with markup adjustments but holds market shares fixed—more than *doubles* the true price effect, raising it from 0.88 to 1.86 percentage points. This nonlinearity arises because reallocation operates through higher-order terms: variance components scale quadratically with the shock, while skewness components scale cubically. Our estimates suggest that standard approaches that infer aggregate price effects from firm-level pass-through rates, and therefore overlook higher-order reallocation effects, can substantially overstate the aggregate price impact of broad-based tariff increases, such as those observed in recent trade disputes.

Third, endogenous markups affect both the magnitude and the interpretation of the

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<sup>2</sup>The remaining discrepancy comprises across-industry reallocation and higher-order terms.

reallocation effects. In a near-monopolistic-competition benchmark with many equal-sized firms, where markups are approximately constant, higher-order reallocation effects are nearly twice as large as in the oligopolistically competitive economy. As shown in the decomposition in Proposition 2, the overall effect depends on the correlation between markup and cost changes, which is zero when markups are constant. When firms absorb part of a cost increase by reducing markups, this induces a negative correlation between markup and cost changes; price dispersion falls, and the reallocation effect shrinks. Conversely, if firms were to raise markups when costs rise, the correlation would be positive, price dispersion would widen, and reallocation effects would be amplified. In the calibrated model, endogenous markups act as a shock absorber: tariff-affected firms compress their markups, reducing price dispersion, dampening consumer substitution, and cutting the reallocation effect by more than half.

Fourth, these aggregate patterns mask substantial cross-sector heterogeneity in both the magnitude of the price effect and the mix of channels that dampen it, driven primarily by differences in U.S. import exposure. In sectors where U.S. firms account for only a small share of the market, such as Wholesale Trade with a 1.7% U.S. share, the price effect is small, at 0.18%. The cost shock affects relatively few varieties, allowing consumers to substitute easily toward unaffected suppliers, so substitution accounts for almost all of the dampening. In high-exposure manufacturing sectors, where the U.S. share is 27–30%, the price effect is much larger, at around 3%. In these sectors, U.S. firms have substantial pre-tariff market power; the tariff erodes this market power, and their markup compression absorbs 23–32% of the cost shock alongside consumer substitution. The markup channel can even reverse direction in sectors where U.S. firms are marginal but their domestic competitors are concentrated. In Mining and Utilities, U.S. firms account for only 2.5–8% of the market, while domestic firms are relatively concentrated. The market share lost by U.S. firms is reallocated across non-U.S. firms, and because the markup gain from additional market share is much larger for already-large firms, even a modest reallocation toward dominant domestic incumbents raises their markups enough to outweigh the limited compression by U.S. firms. As a result, the

markup channel *amplifies* the cost shock by 12–21%, partially offsetting the relief consumers receive from substitution.

**Related literature.** A large empirical literature estimates tariff pass-through at the product level: [Amiti, Redding and Weinstein \(2019\)](#) and [Amiti, Redding and Weinstein \(2020\)](#) find nearly complete pass-through of 2018 U.S. tariffs; [Cavallo, Gopinath, Neiman and Tang \(2021\)](#) confirm this at retail; [Fajgelbaum, Goldberg, Kennedy and Khandelwal \(2020\)](#) document consumer losses and import reallocation; and [Flaaen, Hortaçsu and Tintelnot \(2020\)](#) show that tariffs trigger production relocation. These studies address a product-level question—by how much does the price of a given variety rise? The aggregate question is different: consumer substitution makes the expenditure-weighted average price rise by less than any individual variety’s increase, and the gap depends on the *distribution* of price changes, not just their mean.

A second line studies how variable markups shape the transmission of trade shocks. [Atkeson and Burstein \(2008\)](#) model endogenous markups that depend on market shares; [Amiti, Itskhoki and Konings \(2019\)](#) show this generates incomplete exchange rate pass-through; and [Edmond, Midrigan and Xu \(2015, 2023\)](#), [Arkolakis, Costinot, Donaldson and Rodríguez-Clare \(2019\)](#), [Firooz and Heins \(2025\)](#), and [Firooz, Heins and Mathur \(2025\)](#) study how variable markups affect the gains from trade and the welfare losses from tariffs. Closely related empirical work estimates how trade policy reshapes firm-level markups ([De Loecker, Goldberg, Khandelwal and Pavcnik, 2016](#); [Crowley, Han and Prayer, 2024](#)). This work establishes that markups respond endogenously to competitive pressure, but does not decompose the aggregate price response into markup, cost, and reallocation components—the decomposition that determines whether first-order methods over- or understate the full aggregate price impact of cost changes.

Third, our decomposition methodology builds on [Baqae and Farhi \(2019\)](#), who develop higher-order decompositions of aggregate productivity; we apply a similar expansion to CES

price indices in the tradition of [Dixit and Stiglitz \(1977\)](#) and [Krugman \(1980\)](#). The broader context includes firm heterogeneity models ([Melitz, 2003](#); [Bernard, Jensen, Redding and Schott, 2007](#); [Melitz and Ottaviano, 2008](#)), rising market power ([De Loecker, Eeckhout and Unger, 2020](#); [Alexander, Han, Kryvtsov and Tomlin, 2024](#); [Faryaar, Leung and Fortier-Labonté, 2023](#)), and frameworks connecting markups to welfare ([Feenstra and Weinstein, 2017](#); [Hottman, Redding and Weinstein, 2016](#); [Arkolakis, Costinot and Rodríguez-Clare, 2012](#)).

Our contribution is fourfold. First, we provide a tractable decomposition that separates markup, cost, and reallocation channels in the aggregate price response to tariffs. The decomposition is exact under CES and yields signed predictions: the reallocation effect is always non-positive, providing a theoretical bound on first-order errors. Second, we show that the sign of the markup-cost covariance determines whether endogenous markups amplify or dampen the reallocation effect—a qualitative distinction absent from constant-markup analyses. Third, we quantify the practical importance of higher-order terms using Canadian data, demonstrating that first-order approximation errors exceed 50% at a 25% tariff. Fourth, we identify U.S. import exposure as the primary cross-sectoral driver of both the magnitude of the price response and the direction of the markup channel—which can amplify the cost shock when U.S. firms are marginal and domestic incumbents are concentrated.

Section 2 derives the decomposition: Proposition 1 establishes the non-positivity of the reallocation effect, and Proposition 2 decomposes it into markup, cost, and covariance components. Section 3 applies the framework to Canadian retaliatory tariffs under the [Atkeson and Burstein \(2008\)](#) pricing rule. Section 4 presents the baseline decomposition, nonlinearity analysis, sectoral heterogeneity, and the role of endogenous markups. Section 5 concludes.

## 2 Decomposing Aggregate Price Changes

This section describes a standard CES environment and characterizes the impact of firm-level price changes through cost pass-through, markup adjustments, and expenditure reallocation on the response of aggregate prices to tariffs. The results in this section hold for any CES framework with heterogeneous firms and variable markups; the specific model of price setting and markup determination is introduced in Section 3. Full derivations are provided in Appendices A–E.

### 2.1 Setup

Consider an economy in which a competitive final consumption sector purchases product bundles from a large but finite set of industries, each denoted by  $i$ . The final consumption good is aggregated using a CES technology over industry-level output with an across-industry elasticity of substitution  $\rho > 1$ . The corresponding aggregate price index is

$$P_t = \left( \sum_i P_{it}^{1-\rho} \right)^{\frac{1}{1-\rho}}, \quad (2.1)$$

where  $P_{it}$  is the price of the industry- $i$  bundle at time  $t$  and the share of industry  $i$  in aggregate expenditures is  $s_{it} = P_{it}^{1-\rho} / P_t^{1-\rho}$ .

In each industry, a finite number of firms—indexed by  $f$  and located in origin country  $o$ —sell differentiated varieties that are bundled using a CES technology with a common within-industry elasticity of substitution  $\sigma > 1$ . The sectoral price index is

$$P_{it} = \left( \sum_f \sum_o P_{foit}^{1-\sigma} \right)^{\frac{1}{1-\sigma}}, \quad (2.2)$$

where  $P_{foit}$  is the price of the variety produced by firm  $f$  from origin  $o$ . Firms price at a markup  $\mu_{foit}$  over marginal costs  $C_{foit}$ —inclusive of any iceberg trade costs or ad valorem tariffs required to deliver goods from origin  $o$ —so  $P_{foit} = \mu_{foit} \cdot C_{foit}$ . Firm  $f$ 's market share

within industry  $i$  is  $\omega_{foit} = P_{foit}^{1-\sigma} / P_{it}^{1-\sigma}$ , where, by definition,  $\sum_f \sum_o \omega_{foit} = 1$ .

**Notation.** We use this framework to evaluate how tariff shocks affect aggregate prices through their effects on firm-level marginal costs and markups. We denote log changes in a variable by  $\hat{x}_t \equiv \ln x_t - \ln x_{t-1}$  and first-order approximations by  $\bar{x}_t^{(1)}$ . All weighted averages of firm- or industry-level variables use pre-shock market-share weights—within-industry shares  $\omega_{foit-1}$  or across-industry shares  $s_{i,t-1}$ , respectively.

## 2.2 Exact Price Decomposition and Reallocation Effects

The aggregate price effect of an import tariff—or any shock that shifts the relative price of purchasing products from different firms—equals the share-weighted average of firm-level price changes plus reallocation effects that capture how consumers substitute toward varieties that become relatively inexpensive. When varieties and industries are substitutes, the reallocation effects are always non-positive under CES. First-order methods therefore overstate the true aggregate price change whenever a tariff raises some firms' prices while leaving others unchanged. The following proposition formally states this result.

**Proposition 1** (Aggregate Price Decomposition). *Under the nested CES price index structure (2.1)–(2.2), the log change in the aggregate price index satisfies the exact identity*

$$\begin{aligned} \hat{p}_t = & \sum_i s_{i,t-1} \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit} \\ & + \sum_i s_{i,t-1} \frac{1}{\sigma-1} \sum_f \sum_o \omega_{foit-1} \hat{\omega}_{foit} + \frac{1}{\rho-1} \sum_i s_{i,t-1} \hat{s}_{it}, \end{aligned} \quad (2.3)$$

where  $\hat{\omega}_{foit} = (1-\sigma)(\hat{p}_{foit} - \hat{p}_{it})$  and  $\hat{s}_{it} = (1-\rho)(\hat{p}_{it} - \hat{p}_t)$  are log changes in firm- and industry-level market shares, respectively. The reallocation terms (the second and third terms) are non-positive whenever  $\sigma > 1$  and  $\rho > 1$  because, by Jensen's inequality,  $\sum_f \sum_o \omega_{foit-1} \hat{\omega}_{foit} \leq 0$  and  $\sum_i s_{i,t-1} \hat{s}_{it} \leq 0$  (and these hold with equality only when market shares are unchanged).

Consequently, the first-order (fixed-share) approximation

$$\bar{p}_t^{(1)} \equiv \sum_i s_{i,t-1} \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit} \quad (2.4)$$

overstates the aggregate price effect of a tariff (i.e.,  $\bar{p}_t^{(1)} - \hat{p}_t \geq 0$ ).

The identity (2.3) decomposes the aggregate price change into three terms (see Appendix A for the derivation). The first is the share-weighted average of firm-level price changes, holding market shares fixed—the standard first-order approximation used in most applied work. Because  $\hat{p}_{foit} = \hat{\mu}_{foit} + \hat{c}_{foit}$ , this first-order term can be further decomposed into the impacts of *direct cost pass-through* and *markup adjustments*, denoted by  $\bar{c}_t^{(1)}$  and  $\bar{\mu}_t^{(1)}$ , respectively, where

$$\bar{c}_t^{(1)} = \sum_i s_{i,t-1} \sum_f \sum_o \omega_{foit-1} \hat{c}_{foit} \quad (2.5)$$

and

$$\bar{\mu}_t^{(1)} = \sum_i s_{i,t-1} \sum_f \sum_o \omega_{foit-1} \hat{\mu}_{foit}. \quad (2.6)$$

The second term in equation (2.3) captures the impact of *within-industry reallocation* (holding fixed sectoral expenditure shares): when a tariff raises the price of some varieties, consumers substitute toward varieties that become relatively more inexpensive, shifting market shares within industries. The third term, which is analogous to the second but captures *across-industry reallocation*, reflects the impact of shifts in expenditure shares across sectors. Because market shares must sum to one within and across industries, the reallocation effects always reduce the aggregate price change when  $\sigma > 1$  and  $\rho > 1$ .

**Why reallocation effects are non-positive.** The exact identity (2.3) admits two useful second-order representations of price changes that make the sign of the reallocation effects transparent.<sup>3</sup> In terms of squared market-share changes, industry-level price changes are

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<sup>3</sup>We focus here on within-industry reallocation effects as analogous expressions hold for the across-industry reallocation terms. See Appendices B and C for full derivations.

given by

$$\hat{p}_{it} = \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit} - \frac{1}{2(\sigma-1)} \sum_f \sum_o \omega_{foit-1} \hat{\omega}_{foit}^2 + \mathcal{O}(\|\hat{p}\|^3). \quad (2.7)$$

The effect of within-industry reallocation, which is summarized in the second term, is non-positive and proportional to the weighted sum of squared market share changes in the industry. Industry-level price changes can also be expressed in terms of the dispersion of firm-level price changes:

$$\hat{p}_{it} = \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit} - \frac{\sigma-1}{2} \text{Var}_\omega(\hat{p}_{it}) + \mathcal{O}(\|\hat{p}\|^3), \quad (2.8)$$

where  $\text{Var}_\omega(\hat{p}_{it}) \equiv \sum_f \sum_o \omega_{foit-1} (\hat{p}_{foit} - \bar{p}_{it}^{(1)})^2$  is the within-industry variance of firm-level log price changes around the first-order mean  $\bar{p}_{it}^{(1)} \equiv \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit}$ .

The variance form in equation (2.8) makes the economic mechanism clear. The reallocation effect within a given industry is equal to the negative of the share-weighted variance of firm-level log price changes scaled by the factor  $(\sigma-1)/2$ , so greater price-change dispersion and higher within-industry substitutability both amplify the effect. Intuitively, a higher value of  $\sigma$  implies that consumers are more willing to substitute away from varieties that become relatively more expensive, so any given dispersion in prices induces a stronger reallocation. The effect vanishes only when all firms experience identical price changes; for tariffs targeting a specific country, such homogeneity is unlikely, and the reallocation effect is therefore strictly negative. A similar approximation obtains for the across-industry reallocation effect, whose strength is governed by the dispersion of changes in industry-level price indices and the degree of across-industry substitution  $\rho$ .

## 2.3 Markup-Cost Decomposition of Reallocation Effects

The approximation in equation (2.8) and its extension to aggregate price changes in Appendix C characterize the effects of reallocation in terms of dispersion in underlying firm-

level price changes. But the variation in price changes that gives rise to reallocation can reflect changes in both markups and tariff-inclusive costs of selling products in the importing country. Separating price changes into markup and cost changes, the reallocation terms in the identity (2.3) can each be further decomposed into three economically interpretable components: the dispersion of markup changes, the dispersion of cost changes, and their covariance. The covariance is particularly informative—its sign reveals whether firms absorb or amplify cost shocks through markup adjustments, thereby affecting the degree of expenditure reallocation.

**Proposition 2** (Markup-Cost Decomposition). *The second-order approximation to the aggregate price change decomposes as:*

$$\begin{aligned}
\hat{p}_t \approx & \underbrace{\bar{\mu}_t^{(1)} + \bar{c}_t^{(1)}}_{\text{first-order}} \\
& - \underbrace{\frac{\sigma - 1}{2} \sum_i s_{i,t-1} \left[ \text{Var}_\omega(\hat{\mu}_{it}) + \text{Var}_\omega(\hat{c}_{it}) + 2\text{Cov}_\omega(\hat{\mu}_{it}, \hat{c}_{it}) \right]}_{\text{within-industry second-order}} \\
& - \underbrace{\frac{\rho - 1}{2} \left[ \text{Var}_s(\bar{\mu}_t^{(1)}) + \text{Var}_s(\bar{c}_t^{(1)}) + 2\text{Cov}_s(\bar{\mu}_t^{(1)}, \bar{c}_t^{(1)}) \right]}_{\text{across-industry second-order}}, \tag{2.9}
\end{aligned}$$

where, for  $x \in \{\mu, c\}$ ,  $\text{Var}_\omega(\hat{x}_{it}) \equiv \sum_f \sum_o \omega_{foit-1} (\hat{x}_{foit} - \bar{x}_{it}^{(1)})^2$  is the share-weighted variance of changes in  $x$  computed across firms  $f$  and origins  $o$  within industry  $i$  using pre-shock shares  $\omega_{foit-1}$ ,  $\text{Cov}_\omega(\hat{\mu}_{it}, \hat{c}_{it}) \equiv \sum_f \sum_o \omega_{foit-1} (\hat{\mu}_{foit} - \bar{\mu}_{it}^{(1)}) (\hat{c}_{foit} - \bar{c}_{it}^{(1)})$  is the within-industry covariance of markup and cost changes, and these variances and covariances are centered on the relevant fixed-share industry-level average markup and cost changes ( $\bar{x}_{it}^{(1)} \equiv \sum_f \sum_o \omega_{foit-1} \hat{x}_{foit}$ ). The across-industry second-order variance term, for  $x \in \{\mu, c\}$ , is  $\text{Var}_s(\bar{x}_t^{(1)}) \equiv \sum_i s_{i,t-1} (\bar{x}_{it}^{(1)} - \bar{x}_t^{(1)})^2$  and the covariance is defined analogously.

The sign of the markup-cost covariance is informative:  $\text{Cov}_\omega(\hat{\mu}_{it}, \hat{c}_{it}) < 0$  is consistent with incomplete pass-through (firms that face larger cost increases tend to compress markups

more), while  $Cov_{\omega}(\hat{\mu}_{it}, \hat{c}_{it}) > 0$  indicates pro-cyclical markups that amplify the negative reallocation effect.

The decomposition follows from expanding  $\hat{p}_{foit} = \hat{\mu}_{foit} + \hat{c}_{foit}$  in the variance expression in equation (2.8) and its across-industry counterpart.<sup>4</sup> The first-order terms capture direct cost pass-through and markup adjustments at fixed market shares. The within-industry second-order terms capture reallocation. Since the variance of any sum is non-negative (i.e.,  $Var_{\omega}(\hat{p}_{it}) = Var_{\omega}(\hat{\mu}_{it} + \hat{c}_{it}) \geq 0$ ), the within-industry effect is always non-positive (as shown in Proposition 1) regardless of the sign of the covariance of markup and cost changes; a negative covariance reduces the reallocation effect's magnitude but cannot change its sign.

The covariance plays a key role in the importance of reallocation for the aggregate price effect of tariffs. When firms facing tariff increases compress their markups while those unaffected by the tariffs increase their markups (i.e.,  $Cov_{\omega}(\hat{\mu}_{it}, \hat{c}_{it}) < 0$ ), the dispersion of price changes is smaller than the sum of the markup- and cost-change dispersions, and the reallocation effect is dampened—incomplete pass-through reduces the scope for consumer substitution. When markups amplify tariff-induced cost shocks (i.e.,  $Cov_{\omega}(\hat{\mu}_{it}, \hat{c}_{it}) > 0$ ), consumers substitute across varieties to a greater extent and reallocation has a larger negative impact on aggregate prices.

## 2.4 Third-Order Extension

When markups respond endogenously to market shares, the feedback loop between prices, shares, and markups can make the approximation errors of the second-order calculation of aggregate price changes non-negligible. A third-order expansion adds skewness and co-

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<sup>4</sup>See Appendix D for the full derivation.

skewness corrections:<sup>5</sup>

$$\begin{aligned}
\hat{p}_t \approx & \underbrace{\bar{\mu}_t^{(1)} + \bar{c}_t^{(1)}}_{\text{first-order}} \\
& - \underbrace{\frac{\sigma - 1}{2} \sum_i s_{i,t-1} \left[ \text{Var}_\omega(\hat{\mu}_{it}) + \text{Var}_\omega(\hat{c}_{it}) + 2\text{Cov}_\omega(\hat{\mu}_{it}, \hat{c}_{it}) \right]}_{\text{within-industry second-order}} \\
& + \underbrace{\frac{(\sigma - 1)^2}{6} \sum_i s_{i,t-1} \left[ \text{Skew}_\omega(\hat{\mu}_{it}) + 3\text{CoSkew}_\omega(\hat{\mu}_{it}^2, \hat{c}_{it}) \right.}{\text{within-industry third-order}} \\
& \quad \left. + 3\text{CoSkew}_\omega(\hat{\mu}_{it}, \hat{c}_{it}^2) + \text{Skew}_\omega(\hat{c}_{it}) \right]}_{\text{within-industry third-order}} \\
& - \underbrace{\frac{\rho - 1}{2} \left[ \text{Var}_s(\bar{\mu}_t^{(1)}) + \text{Var}_s(\bar{c}_t^{(1)}) + 2\text{Cov}_s(\bar{\mu}_t^{(1)}, \bar{c}_t^{(1)}) \right]}_{\text{across-industry second-order}} \\
& + \underbrace{\frac{(\rho - 1)^2}{6} \left[ \text{Skew}_s(\bar{\mu}_t^{(1)}) + 3\text{CoSkew}_s((\bar{\mu}_t^{(1)})^2, \bar{c}_t^{(1)}) \right.}{\text{across-industry third-order}} \\
& \quad \left. + 3\text{CoSkew}_s(\bar{\mu}_t^{(1)}, (\bar{c}_t^{(1)})^2) + \text{Skew}_s(\bar{c}_t^{(1)}) \right]}_{\text{across-industry third-order}}, \tag{2.10}
\end{aligned}$$

The skewness terms capture asymmetry in firm-level price changes. Tariffs that affect only one origin country create a highly skewed cost-change distribution—a few firms face large increases while most are unaffected—and the skewness correction can therefore be quantitatively important. Right-skewed cost shocks generate a positive third-order term that partially offsets the negative second-order reallocation effect. The coefficient  $(\sigma - 1)^2/6$  implies that third-order effects are amplified in markets with high substitutability. The intuition is straightforward: doubling the tariff roughly doubles each affected firm's costs of selling in the importing country, which roughly quadruples the variance of price changes across all firms—making the second-order reallocation effect four times as large. Skewness grows even faster (cubically), so the third-order correction becomes important at large tariff rates. Small tariffs need only first-order methods to precisely evaluate their aggregate price

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<sup>5</sup>Third-order terms are defined analogously to the second-order terms. See Appendix E for their formal definitions.

impact, but large tariffs require higher-order corrections.

### 3 Application to Canadian Retaliatory Tariffs

To illustrate the quantitative importance of accounting for reallocation effects and higher-order effects on the aggregate price impact of large increases in tariffs, we apply the decomposition to a stylized counterfactual motivated by the 2025 Canada–U.S. tariff episode. The exercise focuses on Canada as the focal importing country that applies a uniform ad valorem tariff to all U.S. varieties in affected sectors which can be viewed as a sector-level approximation to the actual product-level tariff schedule.

#### 3.1 Data

We construct firm-industry-origin market shares in the Canadian market by combining three data sources described below. All estimation and decomposition exercises are carried out at the three-digit NAICS level, but results are aggregated to the two-digit level for presentation.

**Import shares.** U.S. and rest-of-world (ROW) market shares are derived from Canadian administrative import records as of 2022, which report import values by product and country of origin. We map Harmonized System (HS) codes to three-digit NAICS industries to obtain industry-level import flows, from which we compute each industry’s expenditure share in total Canadian imports and the share attributable to U.S. and ROW origins. Since the import data do not identify individual foreign firms, we allocate aggregate import shares across firms using the 2022 ITA U.S. Exporter Database, which reports the number of U.S. exporting firms and their export values by manufacturing sector across five size categories. We assume five representative firms per origin per sector—one for each size group—and distribute import shares proportionally to each group’s export value. The same size distribution is applied to ROW firms.

**Canadian firm sales.** Data on Canadian firms come from the National Account Longitudinal Microdata File (NALMF, 2022), which provides firm-level total revenue, exports, and domestic sales by sector. We subtract exports from total revenue to obtain each firm’s domestic market share.

The tariff shock is applied to all three-digit industries within seven NAICS two-digit groups with a substantial U.S. import presence.<sup>6</sup> The seven groups are Agriculture, Forestry, Fishing & Hunting (11); Mining, Quarrying & Oil/Gas Extraction (21); Utilities (22); three manufacturing groups—Food & Textile Manufacturing (31), Chemical & Materials Manufacturing (32), and Metals & Machinery Manufacturing (33); and Wholesale Trade (41). The baseline specification assigns 5 U.S. firms per three-digit industry, with import shares distributed based on U.S. export data.

Table 1 summarizes the seven affected sectors. U.S. import exposure varies widely, from 1.7% in Wholesale Trade to 30.1% in Chemical & Materials Manufacturing. The two most exposed sectors—Chemical & Materials and Metals & Machinery—together account for 15.7% of total revenue. Concentration also varies: Metals & Machinery has the highest concentration as measured by the Herfindahl-Hirschman Index (HHI), with an HHI of 13.6%, while Agriculture is the least concentrated (an HHI of 4.0%).

### 3.2 Model and Identification Strategy

We adopt a workhorse oligopolistic competition model developed by [Atkeson and Burstein \(2008\)](#) and [Edmond, Midrigan and Xu \(2015\)](#) to specify price-setting behavior in the environment described in Section 2. For a given set of structural parameters, we recover the model-implied firm-level marginal costs by matching observed market shares, and then compute counterfactual equilibria under alternative tariff regimes.

Our identification strategy exploits the fact that, conditional on values of  $\sigma$  and  $\rho$ , ob-

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<sup>6</sup>Two additional two-digit groups—Information (51) and Arts, Entertainment & Recreation (71)—also have U.S. import shares above 1% but are excluded due to limited data coverage in our firm-level sources.

Table 1: Descriptive Statistics: Tariff-Affected Sectors

| NAICS | Sector                  | Exp. Weight<br>(%) | U.S. Share<br>(%) | HHI<br>(%) |
|-------|-------------------------|--------------------|-------------------|------------|
| 11    | Agriculture             | 0.68               | 7.60              | 4.04       |
| 21    | Mining                  | 5.91               | 8.03              | 11.53      |
| 22    | Utilities               | 0.67               | 2.49              | 9.50       |
| 31    | Food & Textile Mfg.     | 3.28               | 11.49             | 7.53       |
| 32    | Chem. & Materials Mfg.  | 5.54               | 30.08             | 9.83       |
| 33    | Metals & Machinery Mfg. | 10.18              | 27.10             | 13.60      |
| 41    | Wholesale Trade         | 16.36              | 1.66              | 5.26       |

*Note:* Seven NAICS two-digit groups with substantial U.S. import presence (see text). Expenditure weight: sector share of total Canadian market revenue (the seven sectors account for 42.6% of total revenue). U.S. Share: U.S. imports as a fraction of total revenue. HHI: Herfindahl-Hirschman Index of firm-level market shares within each sector. All statistics computed at the three-digit NAICS level and aggregated to two-digit groups.

served firm-level market shares within each sector uniquely determine relative prices via the CES share formula and markups via the pricing rule presented below. Given these objects, we recover marginal costs as the residual values consistent with equilibrium.

**Markup structure.** Each firm’s perceived demand elasticity, and hence its markup, depends on its within-industry market share.<sup>7</sup>

$$\mu_{foit} = \frac{\varepsilon_{foit}}{\varepsilon_{foit} - 1}, \quad (3.1)$$

where

$$\frac{1}{\varepsilon_{foit}} = \frac{\omega_{foit}}{\rho} + \frac{1 - \omega_{foit}}{\sigma}. \quad (3.2)$$

When a firm’s share  $\omega_{foit}$  approaches 0, it faces the within-sector elasticity  $\sigma$  and charges the markup  $\sigma/(\sigma - 1)$ ; when  $\omega_{foit}$  approaches 1, it faces the across-industry elasticity  $\rho$  and charges the markup  $\rho/(\rho - 1)$ . Following [Edmond, Midrigan and Xu \(2015\)](#), we set the within-industry elasticity to  $\sigma = 10.5$  and the across-industry elasticity to  $\rho = 1.24$ , so that

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<sup>7</sup>We focus on a Cournot competition equilibrium in which firms take the aggregate price index as given.

firms with larger market shares charge higher markups. A tariff raises costs of purchasing goods from affected firms, which reduces their market shares, raises their perceived demand elasticities, and leads them to compress their markups. This feedback loop implies an incomplete pass-through of the tariff costs and generates a negative markup-cost covariance that is central to the magnitude of the reallocation effects as highlighted in Proposition 2.

**Calibrating sectoral prices.** The pre-tariff aggregate price index is normalized to  $P_t = 1$ . Given the CES aggregator (2.1), observed sectoral expenditure shares  $s_{it}$  then determine sectoral prices:

$$P_{it} = s_{it}^{1/(1-\rho)}. \quad (3.3)$$

This ensures that the model’s cross-sector price structure reproduces the expenditure distribution observed in the data, so that sectors with larger total expenditure receive proportionally more weight in the aggregate decomposition.

**Recovering firm-level marginal costs.** Within each sector, firm-level marginal costs must be consistent with both the markup rule (3.1) and the calibrated sectoral price. The CES share formula implies  $\omega_{f_{oit}} = (P_{f_{oit}}/P_{it})^{1-\sigma}$ , where  $P_{f_{oit}}$  is the variety price entering the CES aggregator (2.2). Under the pricing rule (3.1), however, prices depend on markups, markups depend on market shares, and shares depend on prices—so the pre-tariff equilibrium is a fixed point in the set of prices charged in each industry. We solve for these prices iteratively: starting from constant markups  $\mu = \sigma/(\sigma - 1)$  for all firms, we compute market shares from prices via (2.2), update markups via (3.1), recompute prices, and repeat until convergence. The resulting firm-level prices aggregate to the calibrated sectoral price using equation 2.2. Given the equilibrium prices and markups, we recover the implied marginal costs for each firm as:

$$C_{f_{oit}} = \frac{P_{f_{oit}}}{\mu_{f_{oit}}} \quad (3.4)$$

This procedure pins down the full cross-section of firm-level marginal costs without requiring an independent wage normalization.

**Counterfactual under new tariffs.** The tariff enters as a multiplicative wedge on marginal costs for U.S.-origin varieties. For U.S. varieties in affected sectors,

$$C_{foit}^* = (1 + \tau) C_{foit}, \quad (3.5)$$

where  $\tau$  is the ad valorem tariff rate. Underlying (pre-tariff) marginal costs are held fixed—a partial-equilibrium assumption that rules out wage and productivity responses—so the tariff wedge is the only source of cost changes. As a result, all that matters for the decomposition of the aggregate price effects of the tariff is the distribution of cost changes, not the levels of pre-tariff costs. Given the new costs, we re-solve the fixed-point problem to find new prices  $P_{foit}^*$ , market shares  $\omega_{foit}^*$ , and markups  $\mu_{foit}^*$  such that prices satisfy  $P_{foit}^* = \mu_{foit}^* \cdot C_{foit}^*$ , market shares satisfy the CES formula  $\omega_{foit}^* = (P_{foit}^*/P_{it}^*)^{1-\sigma}$ , and markups satisfy the pricing rule (3.1) evaluated at  $\omega_{foit}^*$ .

New sectoral and aggregate price indices follow from (2.2)–(2.1). Comparing the pre- and post-tariff equilibria gives the firm-level log changes  $\hat{p}_{foit}$ ,  $\hat{\mu}_{foit}$ ,  $\hat{c}_{foit}$ , and  $\hat{\omega}_{foit}$  that enter the decomposition in Propositions 1 and 2. Because the decomposition uses only log changes, the results are invariant to the choice of price numeraire.

## 4 Quantification: Markups and Reallocation Effects

We impose a 25% tariff on all U.S. imports in the seven affected sectors and compute the counterfactual equilibrium. This section presents the baseline aggregate price decomposition, examines how the results change with the size of the tariff, and examines the robustness of the quantitative results to alternative specifications.

## 4.1 Aggregate Price Change Decomposition

Table 2: Aggregate Price Change Decomposition: 25% Tariff on U.S. Imports

| Component                                                  | Value         |
|------------------------------------------------------------|---------------|
| <b>Exact aggregate price change <math>\hat{p}_t</math></b> | <b>+0.66%</b> |
| Order 1: Direct effects                                    | <b>+1.00%</b> |
| Cost pass-through, $\bar{c}_t^{(1)}$                       | +1.25%        |
| Markup adjustments, $\bar{\mu}_t^{(1)}$                    | −0.26%        |
| Order 2: Within-industry reallocation                      | <b>−0.47%</b> |
| Cost dispersion                                            | −0.97%        |
| Markup dispersion                                          | −0.18%        |
| Markup–cost covariance                                     | +0.67%        |
| Order 3: Within-industry skewness                          | <b>+0.17%</b> |
| Other Components                                           |               |
| Orders 2 & 3: Across-industry reallocation                 | $\approx 0\%$ |
| Higher-order residual                                      | −0.04%        |

*Notes:* Estimation at the three-digit NAICS level, aggregated. Baseline: 5 U.S. firms per industry, 7 tariff-affected two-digit groups, 25% tariff. Orders 1–3, across-industry reallocation, and the residual sum to  $\hat{p}_t$ . Order 1 is the share-weighted mean of firm-level log price changes at fixed shares. Order 2 equals  $-\frac{\sigma-1}{2}$  times the share-weighted variance of firm log price changes and decomposes into  $\text{Var}_\omega(\hat{c})$ ,  $\text{Var}_\omega(\hat{\mu})$ , and  $2\text{Cov}_\omega(\hat{\mu}, \hat{c})$ . Order 3 is the corresponding skewness / co-skewness correction. Across-industry reallocation is governed by  $\rho = 1.24$  and is quantitatively negligible.

Table 2 presents the aggregate price change decomposition for a 25% tariff on U.S. imports under the baseline specification. The first-order approximation predicts a 1.00% price increase. Cost pass-through is +1.25%, partially offset by markup compression of −0.26%. The exact price change is only 0.66%, so the first-order method overstates the actual price impact of the tariffs by more than half in proportional terms. Markup adjustments absorbs about 20% of the direct cost effect. The mechanism works through market shares: as the tariff raises U.S. firms’ costs and prices, they lose customers to cheaper alternatives. With a smaller market share, each U.S. firm faces stiffer competition—its demand becomes more elastic—so it optimally charges a lower markup. This compression of markups by U.S. firms more than offsets any corresponding increase in markups by other firms that increase their market shares, and hence the net direct effect of markup adjustments is negative.

The leading second-order reallocation effect, the total impact of within-industry substitution away from U.S. varieties that become relatively more expensive, contributes  $-0.47\%$  to the aggregate price change and reduces the direct cost pass-through effect by 38%. Higher-order terms (primarily the third-order skewness correction of  $+0.17\%$ ) offset part of this effect. Table 2 decomposes this effect into three components. Cost dispersion ( $-0.97\%$ ) is the dominant force: because only U.S. varieties face the tariff, cost heterogeneity within industries is large, driving substantial consumer substitution. Markup dispersion ( $-0.18\%$ ) contributes a smaller but non-trivial share: firms with higher pre-tariff market shares charge higher markups under oligopolistic competition, and the tariff widens these differences. Because firms facing the largest cost increases also compress their markups the most ( $\text{Cov}_\omega(\hat{\mu}_{it}, \hat{c}_{it}) < 0$ ), markup and cost changes partially cancel at the firm level, reducing the overall dispersion of price changes. This incomplete pass-through is quantitatively important: the positive covariance contribution ( $+0.67\%$ ) offsets 59% of the combined markup and cost dispersion ( $0.67/(0.97 + 0.18)$ ). Without this covariance offset, the within-industry effect would be  $-1.14\%$ —more than double its actual magnitude—underscoring the quantitative importance of endogenous markup adjustments.

The third-order skewness correction ( $+0.17\%$ ) partially offsets the second-order term, reflecting the right-skewed cost distribution: only U.S. varieties face the tariff. Together, these corrections reduce the approximation error from +33.4 basis points (first-order) to +3.3 basis points (third-order). Across-industry reallocation is negligible given the low across-industry elasticity  $\rho$ .

**Comparison with existing pass-through estimates.** Product-level studies find nearly complete pass-through of U.S. tariffs to border prices (Amiti, Redding and Weinstein, 2019, 2020). Our decomposition shows that aggregate pass-through is substantially lower: the 33-basis-point gap between the first-order prediction and the exact effect arises from higher-order reallocation terms absent from product-level analysis. Fajgelbaum, Goldberg, Kennedy and

Khandelwal (2020) document significant import reallocation across source countries, consistent with the substitution mechanism we quantify. Our estimates confirm that reallocation and markup compression together account for the bulk of the gap between product-level and aggregate pass-through.

## 4.2 Nonlinearity: Tariff Size Matters

The accuracy of first-order approximations deteriorates rapidly as tariff rates increase. Table 3 presents exact and approximate price changes for tariffs from 5% to 50%.

Table 3: Nonlinearity: Price Effects Across Tariff Sizes

| Tariff | Exact           | First-order components     |                                | Reallocation bias |          |
|--------|-----------------|----------------------------|--------------------------------|-------------------|----------|
|        | $\hat{p}_t$ (%) | Cost $\bar{c}_t^{(1)}$ (%) | Markup $\bar{\mu}_t^{(1)}$ (%) | Basis pts         | Relative |
| 5%     | 0.20            | +0.27                      | −0.05                          | +1.8              | +9.0%    |
| 10%    | 0.36            | +0.53                      | −0.11                          | +6.7              | +18.7%   |
| 25%    | 0.66            | +1.25                      | −0.26                          | +33.4             | +50.5%   |
| 50%    | 0.88            | +2.28                      | −0.42                          | +97.6             | +110.6%  |

*Note:* Estimation at the three-digit NAICS level, aggregated. Baseline specification across tariff rates. The *first-order components*  $\bar{c}_t^{(1)}$  and  $\bar{\mu}_t^{(1)}$  are the share-weighted averages of firm-level cost and markup changes, holding market shares fixed; their sum is the first-order prediction of  $\hat{p}_t$ . *Reallocation bias* is the gap between that first-order prediction and the exact  $\hat{p}_t$ , i.e., the price movement that first-order methods miss by ignoring consumer substitution across varieties. Basis points: (first-order − exact)  $\times 10^4$  (1 bp = 0.01 pp). Relative: (first-order/exact − 1)  $\times 100\%$ .

At a 5% tariff, the first-order error is only +1.8 basis points, corresponding to a relative overstatement of 9.0%. For most policy purposes, this level of approximation error is acceptable. However, the error grows super-linearly with the tariff rate: a 5-fold increase in the tariff (from 5% to 25%) produces an 18-fold increase in the absolute error (from 1.8 to 33.4 basis points). At a 50% tariff, the first-order approximation predicts a price increase of 1.86%, more than double the exact value of 0.88%. The relative error exceeds 110%, meaning that standard first-order methods are essentially uninformative at this tariff level.

The nonlinearity has a simple source: when the tariff doubles, each affected firm’s cost change roughly doubles, but the *dispersion* of cost changes across firms—which drives

reallocation—roughly *quadruples*. The reallocation effect, proportional to this dispersion, therefore grows much faster than the tariff itself.

Standard analyses that rely on constant-markup models or first-order approximations are adequate for small tariffs (below 10%) but become increasingly misleading for large retaliatory tariffs such as those imposed in 2025. For tariffs of 25% or higher, accounting for reallocation and higher-order nonlinearities is essential for accurate welfare and price impact assessments.

**Policy relevance.** The nonlinearity has direct policy implications. Canada’s 2018 retaliatory tariffs on steel and aluminum (10–25%) and the broad-based 25% tariffs imposed in 2025 fall squarely in the range where first-order errors are 19–50%—large enough to materially affect welfare calculations. Policymakers using constant-markup or fixed-share models would overestimate the consumer price impact of retaliatory tariffs by approximately one-half. Standard cost-based assessments should not be taken at face value: the actual price burden, while non-trivial, is considerably smaller after accounting for substitution and markup compression.

### 4.3 Sectoral Heterogeneity

The aggregate results mask substantial variation across industries. We apply the decomposition from Propositions 1–2 at the three-digit NAICS level and aggregate to two-digit groups, computing each sector’s exact price change, first-order approximation ( $\bar{\mu}_i^{(1)} + \bar{c}_i^{(1)}$ ), and second-order reallocation effect. Exact sectoral price effects range from 0.18% in Wholesale Trade—where U.S. imports account for only 1.7% of the sector—to 3.31% in Metals & Machinery Manufacturing, where the U.S. share is 27%. Figure 1 explores what drives cross-sectoral differences in the approximation error.

Panel (A) confirms that the first-order approximation overstates the sectoral price effect in every affected industry: all seven points lie above the 45-degree line. The absolute over-

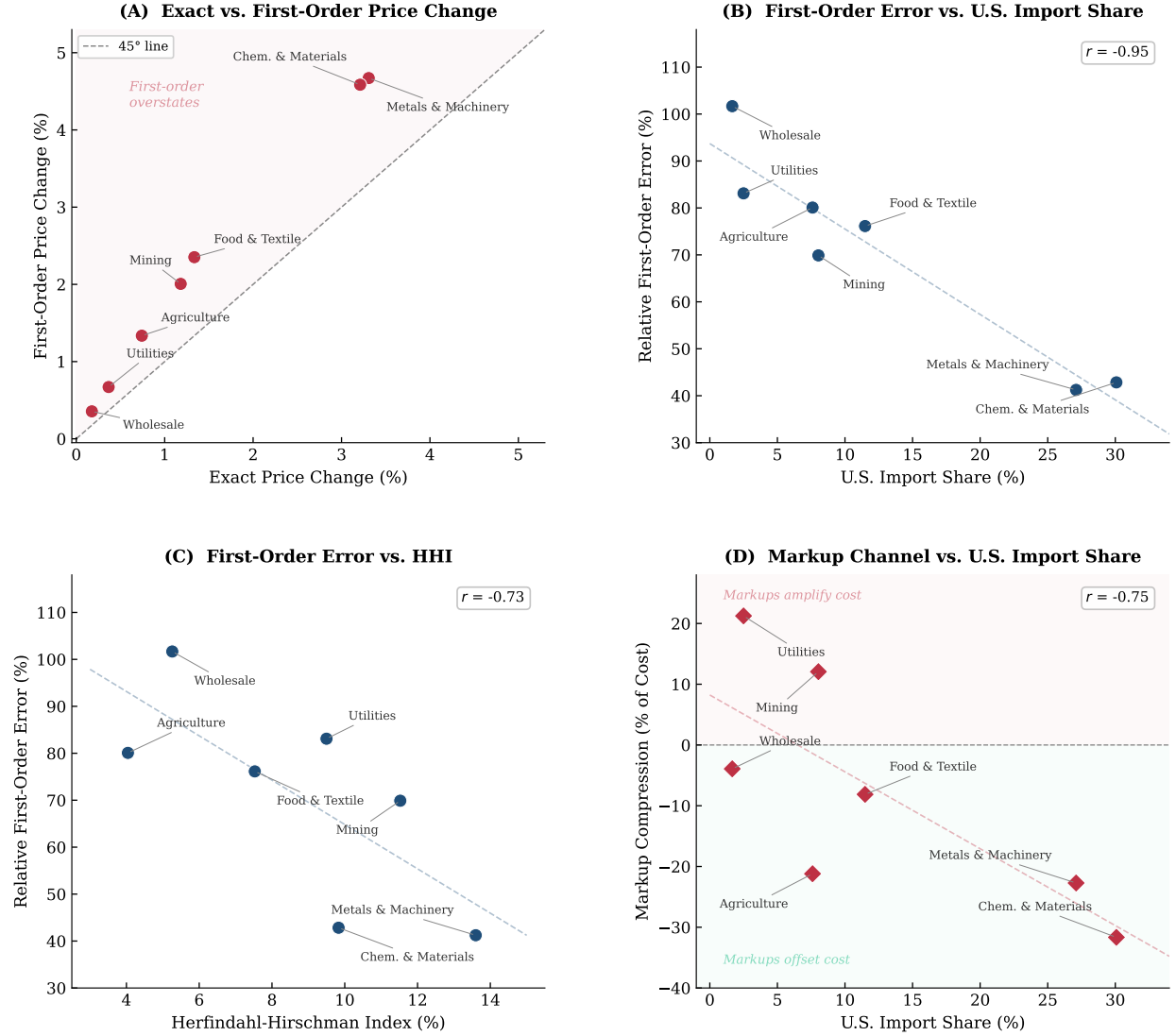


Figure 1: Sectoral Heterogeneity in Price Decomposition under a 25% Tariff  
*Note:* Results are estimated at the three-digit NAICS level and aggregated to two-digit groups. Panel (A) plots the exact sectoral price change against its first-order approximation; all points lie above the 45-degree line. Panel (B) plots the relative first-order error against U.S. import share. Panel (C) plots the same error against the sectoral Herfindahl-Hirschman Index. Panel (D) shows the markup contribution as a percentage of cost pass-through against U.S. import share; negative values indicate markup compression and positive values indicate markup amplification.  $r$  denotes the Pearson correlation coefficient.

statement grows with the size of the sectoral price effect—driven by U.S. import share—from 0.18 percentage points in Wholesale Trade to 1.4 percentage points in Chemical & Materials Manufacturing. In Chemical & Materials, for example, cost pass-through alone predicts a price increase of 6.71%, markup compression subtracts 2.12 percentage points, and within-industry reallocation subtracts a further 1.38 percentage points, yielding an exact effect of

3.21%. The first-order prediction of 4.59% overstates by 43%.

Panel (B) reveals that the *relative* error moves in the opposite direction: it exceeds 100% in Wholesale Trade (1.7% U.S. share) but falls to roughly 40% in the two largest manufacturing sectors (27–30% U.S. share). The correlation between U.S. import share and relative error is  $-0.95$ .

To see why, note that to second order the within-industry reallocation effect is proportional to the within-industry *variance* of firm-level log price changes (equation (2.8)). In a sector where U.S. imports account for only 1.7% of expenditure, nearly all varieties are unaffected, so the *mean* price change is small. But the few tariff-affected varieties experience large price increases, generating substantial *variance* relative to the mean. The reallocation effect, which scales with variance, therefore dominates the first-order term, which scales with the mean—producing a large relative error.

Conversely, in Chemical & Materials Manufacturing, U.S. firms account for 30% of the market. A substantial share of varieties faces the tariff, so the mean shock is large, and the variance-to-mean ratio is correspondingly smaller. The first-order approximation captures most of the price effect, and the relative error falls to 43%.

Panel (C) shows that sector-level concentration (HHI) also predicts the approximation error, though less tightly ( $r = -0.73$ ). Higher concentration is associated with smaller relative errors. The intuition is that more concentrated sectors tend to have fewer, larger firms—and when firms are large, individual price changes have smaller deviations from the share-weighted mean, reducing the variance that drives reallocation. The weaker fit reflects the fact that HHI measures *overall* concentration, whereas the approximation error depends specifically on the *tariff-induced* dispersion of price changes. Two sectors with identical HHI can generate very different reallocation effects if one has a high U.S. import share and the other does not.

Panel (D) uncovers a qualitative difference across sectors in the markup channel. For each sector, we ask: for every percentage point of cost increase, how much do markups absorb (or

amplify)? We measure this as the ratio  $\bar{\mu}_i^{(1)}/\bar{c}_i^{(1)}$ —the average markup change relative to the average cost change. Negative values mean markups absorb part of the cost shock; positive values mean markups amplify it.

In the three manufacturing sectors—where U.S. firms hold 11–30% of the market—markup compression offsets 8–32% of the cost shock at the two-digit level.<sup>8</sup> The mechanism is straightforward: as the tariff raises U.S. firms’ costs, they lose market share, face more elastic residual demand, and reduce their markups. The effect is largest in Chemical & Materials (−32%) and Metals & Machinery (−23%), where U.S. firms’ pre-tariff shares are high enough that their loss of market share substantially increases their perceived elasticities.

In Mining and Utilities, however, markups *amplify* the cost shock by 12% and 21%, respectively. The reversal arises from a second, opposing force: when U.S. firms lose market share, domestic incumbents *gain* share, face less elastic demand, and raise their markups. Because U.S. imports are small in these sectors (8% and 2.5%) and concentration is relatively high (HHI of 11.5% and 9.5%, respectively), the tariff barely dents the incumbents’ dominant positions—instead, the small increase in domestic share is enough to push their markups higher. The net effect on the sector’s average markup is positive: the markup increases by incumbents outweigh the markup decreases by U.S. firms.

The correlation between U.S. import share and the markup channel is −0.75: the more exposed a sector is to the tariff, the more likely it is that U.S. firms’ markup compression dominates. In sectors with low U.S. exposure, the incumbents’ markup amplification prevails. This sign reversal illustrates a broader point from the decomposition: the sign of the markup component  $\bar{\mu}_i^{(1)}$  is not pinned down a priori. Whether endogenous markups dampen or amplify the aggregate price effect is an empirical question that depends on the distribution of market power across affected and unaffected firms.

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<sup>8</sup>At the three-digit level, most manufacturing subsectors exhibit markup compression, but Computer & Electronic Products (NAICS 334) is an exception: its positive markup contribution (+1.08%) reflects domestic incumbents gaining market power as U.S. firms retreat. See Appendix F.

## 4.4 Endogenous Markups and Robustness

Table 4 examines the sensitivity of our results to alternative specification choices. We consider a near-monopolistic-competition limit with many equal-sized firms and a variation in the set of shocked sectors.

Table 4: Endogenous Markups and Robustness: Alternative Specifications

| Specification                      | Price change (%)  |           | Reallocation bias |          |
|------------------------------------|-------------------|-----------|-------------------|----------|
|                                    | Exact $\hat{p}_t$ | 1st order | Basis pts         | Relative |
| Baseline (5 firms, 7 sectors)      | 0.66              | 1.00      | +33.4             | +50.5%   |
| Many firms ( $\approx$ mon. comp.) | 0.69              | 1.32      | +63.8             | +93.2%   |
| Fewer sectors (5 sectors)          | 0.63              | 0.93      | +30.3             | +48.0%   |

*Note:* Estimation at the three-digit NAICS level, aggregated. Baseline: 5 U.S. firms per three-digit industry, with heterogeneous sizes from the ITA U.S. Exporter Database, 7 tariff-affected two-digit groups, 25% tariff. “Many firms ( $\approx$  mon. comp.)”: the aggregate U.S. import value in each sector is split equally across enough firms that each U.S. firm’s share is small; markups remain close to  $\sigma/(\sigma - 1)$ , leaving little scope for markup adjustments. “Fewer sectors”: 5 two-digit groups only (drops Utilities and Wholesale). *Reallocation bias* is the gap between the first-order prediction and the exact  $\hat{p}_t$ : the price movement first-order methods miss by holding market shares fixed.

The results highlight the quantitative importance of endogenous markups. The “many firms” specification splits U.S. import value equally across enough firms per sector that each U.S. firm’s share is small, so markups stay close to the monopolistic-competition benchmark  $\sigma/(\sigma - 1)$  and have limited scope to compress. The exact price effect rises only modestly from 0.66% to 0.69%, but with the markup channel largely shut down, the reallocation bias rises from 50.5% to 93.2%—nearly doubling—confirming that endogenous markup adjustments are central to approximation accuracy, not a minor refinement.

Reducing the set of tariff-affected sectors from 7 to 5—dropping Utilities and Wholesale Trade—lowers the exact price effect modestly from 0.66% to 0.63%, with the reallocation bias remaining severe at 48.0%. Across all specifications, first-order methods overstate the true price effect by 48–93%, with the monopolistic-competition limit providing an upper bound on the bias when markup adjustments are absent.

Appendix F presents the full three-digit NAICS decomposition for all 32 tariff-affected

industries, revealing substantial within-group heterogeneity: relative first-order errors range from 23% in Petroleum/Coal Manufacturing to over 140% in low-exposure agricultural and wholesale subsectors.

## 5 Conclusion

This paper shows that assessing the aggregate price effects of tariffs requires accounting for expenditure reallocation across firms and endogenous markup adjustments. Simple fixed-share calculations miss both forces: consumers substitute away from tariff-affected varieties, and firms adjust markups in response to changes in costs and market shares. Under CES demand, expenditure reallocation always reduces the aggregate price effect relative to first-order predictions. We further show that the magnitude of this reduction can be decomposed into cost variance, markup variance, and their covariance, revealing whether markup adjustments absorb or amplify cost shocks.

Applying this framework to Canadian retaliatory tariffs on U.S. imports, we find that first-order calculations substantially overstate the aggregate price effect of a 25% tariff. Within-industry substitution and markup compression both contribute meaningfully to this reduction, and the discrepancy grows sharply with tariff size: at a 50% tariff, a first-order calculation more than doubles the true price effect. Under oligopolistic competition, markups typically act as a shock absorber. Tariff-affected firms compress their markups, reducing price dispersion and dampening the reallocation effect by more than half relative to a constant-markup benchmark. The direction of the markup channel, however, varies across sectors. It dampens the cost shock in high-U.S.-exposure manufacturing sectors, but amplifies it in low-exposure sectors with concentrated domestic incumbents, such as Mining and Utilities, where the market share lost by U.S. firms flows toward already-large domestic firms whose markups rise.

The policy implication is direct. Approaches that abstract from market-share reallocation

or endogenous markup adjustment can substantially overstate the price effects of large tariffs. For tariffs of 25% or more, such as those imposed in 2025, the overstatement is large enough to affect welfare calculations and the perceived trade-off between retaliation and domestic price stability. Accurate measurement of aggregate price effects therefore requires accounting for both reallocation and markup compression.

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## A Exact Decomposition of Aggregate Price Changes

This appendix derives an exact decomposition of changes in the aggregate nested CES price index. We begin with a decomposition of industry-level price changes and then embed this within a decomposition of the change in the aggregate price index.

**Within industry.** Recall that the sectoral price index in industry  $i$  at time  $t$  is the CES aggregate

$$P_{it} = \left( \sum_f \sum_o P_{foit}^{1-\sigma} \right)^{\frac{1}{1-\sigma}}, \quad (\text{A.1})$$

where  $P_{foit}$  is the price of the variety produced by firm  $f$  from origin country  $o$  in industry  $i$  at time  $t$  and  $\sigma > 1$  is the elasticity of substitution. The market share of each variety is given by

$$\omega_{foit} = \frac{P_{foit}^{1-\sigma}}{P_{it}^{1-\sigma}}. \quad (\text{A.2})$$

Note that, by definition,  $\sum_f \sum_o \omega_{foit} = 1$ .

Define log price changes from period  $t-1$  to period  $t$  at the sector and firm levels as

$$\hat{p}_{it} = \ln P_{it} - \ln P_{it-1}$$

and

$$\hat{p}_{foit} = \ln P_{foit} - \ln P_{foit-1},$$

respectively. Similarly, define the log change in firm-level market shares as

$$\hat{\omega}_{foit} = \ln \omega_{foit} - \ln \omega_{foit-1}.$$

Taking logs of equation (A.2) and first-differencing yields

$$\hat{\omega}_{foit} = (1 - \sigma)(\hat{p}_{foit} - \hat{p}_{it}). \quad (\text{A.3})$$

Multiplying each side of this equation by the base-period weight  $\omega_{foit-1}$ , summing across all varieties sold in the industry, and rearranging yields the exact identity

$$\hat{p}_{it} = \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit} + \frac{1}{\sigma - 1} \sum_f \sum_o \omega_{foit-1} \hat{\omega}_{foit}. \quad (\text{A.4})$$

The within-industry reallocation term for sector  $i$ ,  $\sum_f \sum_o \omega_{foit-1} \hat{\omega}_{foit}$ , measures the gap (scaled by the factor  $\sigma - 1$ ) between the sector's true log price change,  $\hat{p}_{it}$ , and the fixed-share weighted average of firm log price changes,  $\sum_f \sum_o \omega_{foit-1} \hat{p}_{foit}$ .

**Across industries.** We aggregate across industries to compute the change in the final consumption price index. The economy-wide price index is the CES aggregator over industry-level price indices with elasticity of substitution  $\rho > 1$ :

$$P_t = \left( \sum_i P_{it}^{1-\rho} \right)^{\frac{1}{1-\rho}}.$$

The corresponding industry-level expenditure shares are

$$s_{it} \equiv \frac{P_{it}^{1-\rho}}{P_t^{1-\rho}},$$

where  $\sum_i s_{it} = 1$  and log changes in the aggregate price index and industry-level expenditure shares are  $\hat{p}_t = \ln P_t - \ln P_{t-1}$  and  $\hat{s}_{it} = \ln s_{it} - \ln s_{i,t-1}$ , respectively. By analogy with equation (A.3), we have

$$\hat{s}_{it} = (1 - \rho)(\hat{p}_{it} - \hat{p}_t). \quad (\text{A.5})$$

Summing equation (A.5) across industries weighting by base-period weights (and using  $\sum_i s_{i,t-1} = 1$ ) provides the exact industry-level decomposition of aggregate price changes:

$$\hat{p}_t = \sum_i s_{i,t-1} \hat{p}_{it} + \frac{1}{\rho - 1} \sum_i s_{i,t-1} \hat{s}_{it}. \quad (\text{A.6})$$

The across-industry reallocation effect,  $\sum_i s_{i,t-1} \hat{s}_{it}$ , is the gap (scaled by the factor  $\rho - 1$ ) between the true aggregate log price change,  $\hat{p}_t$ , and the fixed-share mean log sectoral price change,  $\sum_i s_{i,t-1} \hat{p}_{it}$ .

### Aggregate price changes in terms of within- and across-industry reallocations.

Combining the within-industry identity (A.4) with the across-industry identity (A.6) yields the exact linear-in-share-change decomposition of the change in the aggregate price index into first-order effects, which include direct cost pass-through and markup adjustments, within-industry reallocation effects, and across-industry reallocation effects:

$$\begin{aligned} \hat{p}_t = & \sum_i s_{i,t-1} \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit} \\ & + \sum_i s_{i,t-1} \frac{1}{\sigma - 1} \sum_f \sum_o \omega_{foit-1} \hat{\omega}_{foit} + \frac{1}{\rho - 1} \sum_i s_{i,t-1} \hat{s}_{it}. \end{aligned} \quad (\text{A.7})$$

## B Approximation of Sectoral Price Index Changes

We derive a second-order log-linearization of changes in the sectoral price index in equation (A.1). Let  $X_{it} \equiv \sum_f \sum_o P_{foit}^{1-\sigma}$  so that  $\ln P_{it} = \frac{1}{1-\sigma} \ln X_{it}$ . Using  $P_{foit} = P_{foit-1} e^{\hat{p}_{foit}}$  and denoting base-period weights  $\omega_{foit-1} = \frac{P_{foit-1}^{1-\sigma}}{X_{it-1}}$ , we have

$$\begin{aligned} \frac{X_{it}}{X_{it-1}} &= \sum_f \sum_o \omega_{foit-1} e^{(1-\sigma)\hat{p}_{foit}} \\ &\approx 1 + (1-\sigma) \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit} + \frac{(1-\sigma)^2}{2} \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit}^2, \end{aligned}$$

where we used  $e^x \approx 1 + x + \frac{x^2}{2}$  and  $\sum_f \sum_o \omega_{foit-1} = 1$ . Taking logs and expanding  $\ln(1+u) \approx u - \frac{u^2}{2}$  with  $u = (1 - \sigma) \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit} + \frac{(1-\sigma)^2}{2} \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit}^2$  gives

$$\begin{aligned} \hat{p}_{it} &= \frac{1}{1-\sigma} \left[ (1-\sigma) \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit} + \frac{(1-\sigma)^2}{2} \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit}^2 \right. \\ &\quad \left. - \frac{(1-\sigma)^2}{2} \left( \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit} \right)^2 \right] + \mathcal{O}(\|\hat{p}\|^3) \\ &= \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit} + \frac{1-\sigma}{2} \left[ \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit}^2 - \left( \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit} \right)^2 \right] + \mathcal{O}(\|\hat{p}\|^3) \end{aligned}$$

Using the variance identity,

$$\sum_f \sum_o \omega_{foit-1} \hat{p}_{foit}^2 - \left( \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit} \right)^2 = \sum_f \sum_o \omega_{foit-1} \left( \hat{p}_{foit} - \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit} \right)^2,$$

and noting that replacing  $\sum_f \sum_o \omega_{foit-1} \hat{p}_{foit}$  by  $\hat{p}_{it}$ , the exact industry-level price change, inside the right-hand-side quadratic introduces only an  $\mathcal{O}(\|\hat{p}\|^3)$  error, we obtain the second-order log-linearization

$$\hat{p}_{it} = \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit} - \frac{\sigma-1}{2} \sum_f \sum_o \omega_{foit-1} (\hat{p}_{foit} - \hat{p}_{it})^2 + \mathcal{O}(\|\hat{p}\|^3). \quad (\text{B.1})$$

Defining the within-industry mean price change that is equivalent to the fixed-share first-order approximation of the industry-level price change as

$$\bar{p}_{it}^{(1)} \equiv \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit}, \quad (\text{B.2})$$

the industry-level price change approximation can be written as

$$\hat{p}_{it} = \bar{p}_{it}^{(1)} - \frac{\sigma-1}{2} \text{Var}_\omega(\hat{p}_{it}) + \mathcal{O}(\|\hat{p}\|^3), \quad (\text{B.3})$$

where  $\text{Var}_\omega(\hat{p}_{it})$  is the within-industry variance of price changes about the first-order approx-

imation of the industry-level price change given by

$$\text{Var}_\omega(\hat{p}_{it}) \equiv \sum_f \sum_o \omega_{foit-1} \left( \hat{p}_{foit} - \bar{p}_{it}^{(1)} \right)^2. \quad (\text{B.4})$$

**Alternative representation in terms of market share changes.** Squaring equation (A.3) and substituting  $(\hat{p}_{foit} - \hat{p}_{it})^2 = \frac{\hat{\omega}_{foit}^2}{(1-\sigma)^2}$  into equation (B.1) implies the second-order approximation of industry-level price changes can be written in terms of squared changes in market shares:

$$\hat{p}_{it} = \bar{p}_{it}^{(1)} - \frac{1}{2(\sigma-1)} \sum_f \sum_o \omega_{foit-1} \hat{\omega}_{foit}^2 + \mathcal{O}(\|\hat{p}\|^3). \quad (\text{B.5})$$

Since  $\sigma > 1$  and  $\omega_{foit-1} > 0$ , the second term in this approximation must be non-positive.

Because  $\sum_f \sum_o \omega_{foit} = 1$ , expanding  $\omega_{foit} = \omega_{foit-1} e^{\hat{\omega}_{foit}}$  to second order allows this share-sum constraint to be re-expressed as

$$\sum_f \sum_o \omega_{foit-1} \hat{\omega}_{foit} = -\frac{1}{2} \sum_f \sum_o \omega_{foit-1} \hat{\omega}_{foit}^2 + \mathcal{O}(\|\hat{\omega}\|^3). \quad (\text{B.6})$$

Using the share-sum constraint (B.6) shows that equations (A.4) and (B.5) coincide up to second order, while equations (B.3) and (B.5) are equivalent second-order approximations, since

$$\sum_f \sum_o \omega_{foit-1} \hat{\omega}_{foit} = -\frac{\sigma-1}{2} \text{Var}_\omega(\hat{p}_{it}) + \mathcal{O}(\|\hat{p}\|^3).$$

The log change in the industry-level price index in equations (A.4), (B.3), and (B.5) equals a weighted average of individual-variety log price changes (the first-order effect) plus a second-order correction term. The reallocation effect is non-positive and equals zero only when all firms in the industry change their prices by the same proportion (i.e., there is no within-industry dispersion). Its magnitude increases with the dispersion of firm-level price changes and the elasticity of substitution,  $\sigma$ .

## C Approximation of Aggregate Price Index Change

Applying the steps used in Appendix B to the industry level, we derive a second-order approximation of the aggregate price change. Define  $Y_t = \sum_i P_{it}^{1-\rho}$  so that  $\ln P_t = \frac{1}{1-\rho} \ln Y_t$  and  $s_{i,t-1} = \frac{P_{i,t-1}^{1-\rho}}{Y_{t-1}}$  and let  $P_{it} = P_{i,t-1} e^{\hat{p}_{it}}$ . Then,

$$\frac{Y_t}{Y_{t-1}} = \sum_i s_{i,t-1} e^{(1-\rho)\hat{p}_{it}} \approx 1 + (1-\rho) \sum_i s_{i,t-1} \hat{p}_{it} + \frac{(1-\rho)^2}{2} \sum_i s_{i,t-1} \hat{p}_{it}^2,$$

where we used  $e^x \approx 1 + x + \frac{x^2}{2}$  and  $\sum_i s_{i,t-1} = 1$ . Let  $m_1 \equiv \sum_i s_{i,t-1} \hat{p}_{it}$  and  $m_2 \equiv \sum_i s_{i,t-1} \hat{p}_{it}^2$ . Using  $\ln(1+u) \approx u - \frac{u^2}{2}$  with  $u = (1-\rho)m_1 + \frac{(1-\rho)^2}{2}m_2$  (so that  $u^2 = (1-\rho)^2 m_1^2 + \mathcal{O}(\|\hat{p}\|^3)$ ),

$$\begin{aligned} \hat{p}_t &= \frac{1}{1-\rho} \left[ (1-\rho)m_1 + \frac{(1-\rho)^2}{2}m_2 - \frac{(1-\rho)^2}{2}m_1^2 \right] + \mathcal{O}(\|\hat{p}\|^3) \\ &= m_1 + \frac{1-\rho}{2} [m_2 - m_1^2] + \mathcal{O}(\|\hat{p}\|^3) \\ &= \sum_i s_{i,t-1} \hat{p}_{it} - \frac{\rho-1}{2} \sum_i s_{i,t-1} \left( \hat{p}_{it} - \sum_j s_{j,t-1} \hat{p}_{jt} \right)^2 + \mathcal{O}(\|\hat{p}\|^3), \end{aligned} \quad (\text{C.1})$$

where the last equality applies the variance identity

$$\sum_i s_{i,t-1} \hat{p}_{it}^2 - \left( \sum_i s_{i,t-1} \hat{p}_{it} \right)^2 = \sum_i s_{i,t-1} \left( \hat{p}_{it} - \sum_j s_{j,t-1} \hat{p}_{jt} \right)^2.$$

Up to third-order terms, the weighted mean  $\sum_j s_{j,t-1} \hat{p}_{jt}$  inside the quadratic in equation (C.1) can be replaced by  $\hat{p}_t$  itself. Thus, equivalently to second order,

$$\hat{p}_t = \sum_i s_{i,t-1} \hat{p}_{it} - \frac{\rho-1}{2} \sum_i s_{i,t-1} (\hat{p}_{it} - \hat{p}_t)^2 + \mathcal{O}(\|\hat{p}\|^3). \quad (\text{C.2})$$

Using equation (A.5) gives the share-change representation,

$$\hat{p}_t = \sum_i s_{i,t-1} \hat{p}_{it} - \frac{1}{2(\rho-1)} \sum_i s_{i,t-1} \hat{s}_{it}^2 + \mathcal{O}(\|\hat{p}\|^3).$$

**Aggregate index in terms of firm-level price and share changes.** The first-order approximation of the change in the aggregate price index, which we denote by  $\bar{p}_t^{(1)}$ , is equal to the fixed-share across-industry mean change in the industry-level price indices that, to first order, are themselves a function of within-industry firm-level price changes given by equation (B.2). Therefore:

$$\begin{aligned}\bar{p}_t^{(1)} &\equiv \sum_i s_{i,t-1} \bar{p}_{it}^{(1)} \\ &= \sum_i s_{i,t-1} \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit}.\end{aligned}\tag{C.3}$$

Assuming a common within-industry elasticity  $\sigma > 1$  in every sector, substituting the second-order within-industry approximation (B.3) into equation (C.2), and evaluating quadratic terms at first order yields

$$\begin{aligned}\hat{p}_t &= \sum_i s_{i,t-1} \bar{p}_{it}^{(1)} - \sum_i s_{i,t-1} \frac{\sigma-1}{2} \sum_f \sum_o \omega_{foit-1} \left( \hat{p}_{foit} - \bar{p}_{it}^{(1)} \right)^2 \\ &\quad - \frac{\rho-1}{2} \sum_i s_{i,t-1} \left( \bar{p}_{it}^{(1)} - \sum_j s_{j,t-1} \bar{p}_{jt}^{(1)} \right)^2 + \mathcal{O}(\|\hat{p}\|^3).\end{aligned}\tag{C.4}$$

Define the across-industry variance of the industry-level price changes about the aggregate price change at first order as

$$\text{Var}_s(\bar{p}_t^{(1)}) \equiv \sum_i s_{i,t-1} \left( \bar{p}_{it}^{(1)} - \bar{p}_t^{(1)} \right)^2.$$

Then, using equations (B.4) and (C.3), the aggregate price change at first order can be written as

$$\hat{p}_t = \underbrace{\bar{p}_t^{(1)}}_{\text{first-order component}} - \underbrace{\sum_i s_{i,t-1} \frac{\sigma-1}{2} \text{Var}_\omega(\hat{p}_{it})}_{\text{within-industry dispersion}} - \underbrace{\frac{\rho-1}{2} \text{Var}_s(\bar{p}_t^{(1)})}_{\text{across-industry dispersion}} + \mathcal{O}(\|\hat{p}\|^3).\tag{C.5}$$

Using  $\hat{\omega}_{foit} = (1 - \sigma)(\hat{p}_{foit} - \hat{p}_{it})$  and  $\hat{s}_{it} = (1 - \rho)(\hat{p}_{it} - \hat{p}_t)$ , replacing  $\hat{p}_{it}$  and  $\hat{p}_t$  by their first-order counterparts, and substituting for the quadratic terms in equation (C.4) (which only affects  $\mathcal{O}(\|\hat{p}\|^3)$  terms), we obtain the squared-share-change representation to second order

$$\begin{aligned}\hat{p}_t &= \sum_i s_{i,t-1} \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit} \\ &\quad - \sum_i s_{i,t-1} \frac{1}{2(\sigma - 1)} \sum_f \sum_o \omega_{foit-1} \hat{\omega}_{foit}^2 \\ &\quad - \frac{1}{2(\rho - 1)} \sum_i s_{i,t-1} \hat{s}_{it}^2 + \mathcal{O}(\|\hat{p}\|^3).\end{aligned}\tag{C.6}$$

From  $\sum_i s_{it} = 1$  and a second-order expansion, the industry-level share-sum constraint is

$$\sum_i s_{i,t-1} \hat{s}_{it} = -\frac{1}{2} \sum_i s_{i,t-1} \hat{s}_{it}^2 + \mathcal{O}(\|\hat{s}\|^3).\tag{C.7}$$

Equations (C.4), (C.5), and (C.6) are equivalent second-order approximations, since

$$\sum_i s_{i,t-1} \hat{s}_{it} = -\frac{\rho - 1}{2} \text{Var}_s(\bar{p}_t^{(1)}) + \mathcal{O}(\|\hat{p}\|^3),$$

while the linear-in-share-change form in equation (A.7) is an exact identity under CES and matches them up to second order.

Analogously with the within-industry reallocation term, the across-industry reallocation term is non-positive and equal to zero only when all industry-level prices change by the same proportion. Moreover, its magnitude is increasing in the dispersion of industry-level price changes and with the strength of across-industry substitution,  $\rho$ . As a result, the first-order approximation,  $\bar{p}_t^{(1)}$ , overestimates the aggregate price response (to second order). The extent to which the first-order approximation overstates the aggregate price change depends on the dispersion in firm-level price changes and the strength of substitution within and across sectors.

## D Decomposition into Markup and Cost Components

Each firm's price equals its markup times marginal cost:

$$P_{f_{oit}} = \mu_{f_{oit}} \cdot C_{f_{oit}}$$

where  $\mu_{f_{oit}}$  is the markup and  $C_{f_{oit}}$  is the marginal cost. Taking logs and differencing yields the exact decomposition

$$\hat{p}_{f_{oit}} = \hat{\mu}_{f_{oit}} + \hat{c}_{f_{oit}}, \quad (\text{D.1})$$

where  $\hat{\mu}_{f_{oit}} \equiv \ln \mu_{f_{oit}} - \ln \mu_{f_{oit-1}}$  and  $\hat{c}_{f_{oit}} \equiv \ln C_{f_{oit}} - \ln C_{f_{oit-1}}$ .

We decompose sectoral and aggregate price changes into markup and cost components without defining exact aggregate markup- or cost-change indices.

**Decomposition of sectoral price changes.** Substituting equation (D.1) into equation (B.1) and defining market-share weighted averages

$$\bar{\mu}_{it}^{(1)} \equiv \sum_f \sum_o \omega_{f_{oit-1}} \hat{\mu}_{f_{oit}}$$

and

$$\bar{c}_{it}^{(1)} \equiv \sum_f \sum_o \omega_{f_{oit-1}} \hat{c}_{f_{oit}}$$

yields

$$\hat{p}_{it} = \bar{\mu}_{it}^{(1)} + \bar{c}_{it}^{(1)} - \frac{\sigma - 1}{2} \sum_f \sum_o \omega_{f_{oit-1}} (\hat{p}_{f_{oit}} - \hat{p}_{it})^2 + \mathcal{O}(\|\hat{p}\|^3). \quad (\text{D.2})$$

Netting out the sum of the market-share weighted average markup and marginal cost  $(\bar{\mu}_{it}^{(1)} + \bar{c}_{it}^{(1)})$  from equation (D.1) gives

$$\hat{p}_{f_{oit}} - (\bar{\mu}_{it}^{(1)} + \bar{c}_{it}^{(1)}) = (\hat{\mu}_{f_{oit}} - \bar{\mu}_{it}^{(1)}) + (\hat{c}_{f_{oit}} - \bar{c}_{it}^{(1)}). \quad (\text{D.3})$$

To second-order accuracy, replacing  $\hat{p}_{it}$  inside the quadratic term in equation (D.2) with its first-order approximation  $\bar{p}_{it}^{(1)} \equiv \bar{\mu}_{it}^{(1)} + \bar{c}_{it}^{(1)}$  (the error is  $\mathcal{O}(\|\hat{p}\|^3)$ ) and substituting in equation (D.3) implies that

$$\hat{p}_{it} = \bar{\mu}_{it}^{(1)} + \bar{c}_{it}^{(1)} - \frac{\sigma - 1}{2} \sum_f \sum_o \omega_{foit-1} \left( (\hat{\mu}_{foit} - \bar{\mu}_{it}^{(1)}) + (\hat{c}_{foit} - \bar{c}_{it}^{(1)}) \right)^2 + \mathcal{O}(\|\hat{p}\|^3). \quad (\text{D.4})$$

Define the variance of firm-level markups and marginal costs about their industry-level market-share weighted averages as

$$\text{Var}_\omega(\hat{\mu}_{it}) \equiv \sum_f \sum_o \omega_{foit-1} (\hat{\mu}_{foit} - \bar{\mu}_{it}^{(1)})^2$$

and

$$\text{Var}_\omega(\hat{c}_{it}) \equiv \sum_f \sum_o \omega_{foit-1} (\hat{c}_{foit} - \bar{c}_{it}^{(1)})^2,$$

respectively, and the corresponding covariance of these centered measures as

$$\text{Cov}_\omega(\hat{\mu}_{it}, \hat{c}_{it}) \equiv \sum_f \sum_o \omega_{foit-1} (\hat{\mu}_{foit} - \bar{\mu}_{it}^{(1)}) (\hat{c}_{foit} - \bar{c}_{it}^{(1)}).$$

Expanding the quadratic term in equation (D.4), the sectoral price change is

$$\hat{p}_{it} = \bar{\mu}_{it}^{(1)} + \bar{c}_{it}^{(1)} - \frac{\sigma - 1}{2} \left[ \text{Var}_\omega(\hat{\mu}_{it}) + \text{Var}_\omega(\hat{c}_{it}) + 2\text{Cov}_\omega(\hat{\mu}_{it}, \hat{c}_{it}) \right] + \mathcal{O}(\|\hat{p}\|^3). \quad (\text{D.5})$$

Equivalently, substituting equation (D.1) into equation (A.4) gives the linear-in-share-changes decomposition of the sectoral price change as

$$\hat{p}_{it} = \bar{\mu}_{it}^{(1)} + \bar{c}_{it}^{(1)} + \frac{1}{\sigma - 1} \sum_f \sum_o \omega_{foit-1} \hat{\omega}_{foit}.$$

The first-order terms in equation (D.5) are market-share weighted markup and cost changes. The second-order terms include: the markup change variance reflecting the disper-

sion of firm markup changes, the cost change variance reflecting the dispersion of firm cost changes, and the covariance of the markup and cost changes. The sign of this covariance term captures firms' pricing behavior; a negative covariance is consistent with incomplete pass-through of cost changes (i.e., firms that face larger cost increases tend to compress markups by more), while a positive covariance indicates that markups are pro-cyclical (i.e., firms raise markups by more when costs rise by a larger amount).

**Aggregate decomposition.** Building on the within-sector analysis, define the across-sector expenditure-share weighted-average markup and cost changes as

$$\bar{\mu}_t^{(1)} \equiv \sum_i s_{i,t-1} \bar{\mu}_{it}^{(1)}$$

and

$$\bar{c}_t^{(1)} \equiv \sum_i s_{i,t-1} \bar{c}_{it}^{(1)},$$

respectively. From equations (B.2), (C.3), and (D.1), we have that  $\bar{p}_t^{(1)} = \bar{\mu}_t^{(1)} + \bar{c}_t^{(1)}$ .

Substituting equation (D.1) and the sectoral decomposition  $\bar{p}_{it}^{(1)} \equiv \bar{\mu}_{it}^{(1)} + \bar{c}_{it}^{(1)}$  into the aggregate price change approximation in equation (C.4) implies that

$$\begin{aligned} \hat{p}_t = & \bar{\mu}_t^{(1)} + \bar{c}_t^{(1)} - \sum_i s_{i,t-1} \frac{\sigma - 1}{2} \sum_f \sum_o \omega_{foit-1} \left( (\hat{\mu}_{foit} - \bar{\mu}_{it}^{(1)}) + (\hat{c}_{foit} - \bar{c}_{it}^{(1)}) \right)^2 \\ & - \frac{\rho - 1}{2} \sum_i s_{i,t-1} \left( (\bar{\mu}_{it}^{(1)} - \bar{\mu}_t^{(1)}) + (\bar{c}_{it}^{(1)} - \bar{c}_t^{(1)}) \right)^2 + \mathcal{O}(\|\hat{p}\|^3). \end{aligned}$$

As with the within-sector decomposition, define the variance of industry-level markups and marginal costs relative to their aggregate expenditure-share weighted averages as

$$\text{Var}_s(\bar{\mu}_t^{(1)}) \equiv \sum_i s_{i,t-1} (\bar{\mu}_{it}^{(1)} - \bar{\mu}_t^{(1)})^2$$

and

$$\text{Var}_s(\bar{c}_t^{(1)}) \equiv \sum_i s_{i,t-1} (\bar{c}_{it}^{(1)} - \bar{c}_t^{(1)})^2,$$

respectively, and the covariance of the relative change in sectoral markups and costs as

$$\text{Cov}_s(\bar{\mu}_t^{(1)}, \bar{c}_t^{(1)}) \equiv \sum_i s_{i,t-1} (\bar{\mu}_{it}^{(1)} - \bar{\mu}_t^{(1)}) (\bar{c}_{it}^{(1)} - \bar{c}_t^{(1)}).$$

Then, we can write the aggregate price change approximation to second order as

$$\begin{aligned} \hat{p}_t \approx & \underbrace{\bar{\mu}_t^{(1)} + \bar{c}_t^{(1)}}_{\text{first-order}} \\ & \underbrace{- \frac{\sigma - 1}{2} \sum_i s_{i,t-1} \left[ \text{Var}_\omega(\hat{\mu}_{it}) + \text{Var}_\omega(\hat{c}_{it}) + 2\text{Cov}_\omega(\hat{\mu}_{it}, \hat{c}_{it}) \right]}_{\text{within-industry}} \\ & \underbrace{- \frac{\rho - 1}{2} \left[ \text{Var}_s(\bar{\mu}_t^{(1)}) + \text{Var}_s(\bar{c}_t^{(1)}) + 2\text{Cov}_s(\bar{\mu}_t^{(1)}, \bar{c}_t^{(1)}) \right]}_{\text{across-industry}} \end{aligned}$$

The aggregate price change decomposes into: (i) first-order weighted-average markup and cost changes across all firms; (ii) within-industry second-order terms (described above) that are weighted by industry-level expenditure shares; and (iii) across-industry second-order terms. These across-industry terms are analogous to the within-industry terms and include the variances of industry-level markup and cost changes and their covariance. All terms in the approximation are computable from firm-level data given a specified model of firms' price-setting behavior.

## E Third-Order Approximation

The second-order variance-covariance decomposition (D.5) can exhibit non-negligible approximation errors in models with endogenous markups. We derive a third-order approximation that can substantially improve accuracy without sacrificing economic interpretability of the

approximation components.

**Sectoral decomposition.** Expanding changes in the sectoral CES price index in equation (A.1) to third order yields

$$\hat{p}_{it} = \sum_f \sum_o \omega_{foit-1} \hat{p}_{foit} - \frac{\sigma-1}{2} \text{Var}_\omega(\hat{p}_{it}) + \frac{(\sigma-1)^2}{6} \text{Skew}_\omega(\hat{p}_{it}) + \mathcal{O}(\|\hat{p}\|^4),$$

where  $\text{Skew}_\omega(\hat{p}_{it}) \equiv \sum_f \sum_o \omega_{foit-1} (\hat{p}_{foit} - \bar{p}_{it}^{(1)})^3$  is the weighted third central moment (the skewness of firm-level price changes).

Using  $\hat{p}_{foit} = \hat{\mu}_{foit} + \hat{c}_{foit}$  and the multinomial expansion  $(a+b)^3 = a^3 + 3a^2b + 3ab^2 + b^3$ , the skewness term can be written as

$$\text{Skew}_\omega(\hat{p}_{it}) = \text{Skew}_\omega(\hat{\mu}_{it}) + 3 \text{CoSkew}_\omega(\hat{\mu}_{it}^2, \hat{c}_{it}) + 3 \text{CoSkew}_\omega(\hat{\mu}_{it}, \hat{c}_{it}^2) + \text{Skew}_\omega(\hat{c}_{it}),$$

where we define the following *co-skewness* terms:

$$\begin{aligned} \text{CoSkew}_\omega(\hat{\mu}_{it}^2, \hat{c}_{it}) &\equiv \sum_f \sum_o \omega_{foit-1} (\hat{\mu}_{foit} - \bar{\mu}_{it}^{(1)})^2 (\hat{c}_{foit} - \bar{c}_{it}^{(1)}) \\ \text{CoSkew}_\omega(\hat{\mu}_{it}, \hat{c}_{it}^2) &\equiv \sum_f \sum_o \omega_{foit-1} (\hat{\mu}_{foit} - \bar{\mu}_{it}^{(1)}) (\hat{c}_{foit} - \bar{c}_{it}^{(1)})^2. \end{aligned}$$

Therefore, we can write the third-order approximation of the change in a sector's price index as

$$\begin{aligned} \hat{p}_{it} &\approx \underbrace{\bar{\mu}_{it}^{(1)} + \bar{c}_{it}^{(1)}}_{\text{first-order}} \\ &\quad - \underbrace{\frac{\sigma-1}{2} \left[ \text{Var}_\omega(\hat{\mu}_{it}) + \text{Var}_\omega(\hat{c}_{it}) + 2\text{Cov}_\omega(\hat{\mu}_{it}, \hat{c}_{it}) \right]}_{\text{second-order (variance-covariance)}} \\ &\quad + \underbrace{\frac{(\sigma-1)^2}{6} \left[ \text{Skew}_\omega(\hat{\mu}_{it}) + 3\text{CoSkew}_\omega(\hat{\mu}_{it}^2, \hat{c}_{it}) + 3\text{CoSkew}_\omega(\hat{\mu}_{it}, \hat{c}_{it}^2) + \text{Skew}_\omega(\hat{c}_{it}) \right]}_{\text{third-order (skewness, co-skewness)}} \quad (\text{E.1}) \end{aligned}$$

The  $\text{Skew}_\omega(\hat{c}_{it})$  term in equation (E.1) captures asymmetry in cost shocks. Positive skewness naturally arises in the context of an import tariff that impacts only a subset of firms in an industry. This positive third-order adjustment can potentially be offset by the  $\text{Skew}_\omega(\hat{\mu}_{it})$  term, which captures the asymmetry in markup adjustments across firms within a sector, whenever the skewness of markup adjustments is negative. This could arise in a situation where firms with relatively large initial market shares experience large markup *decreases* (e.g., large U.S. firms losing market power after a tariff). The  $\text{CoSkew}_\omega(\hat{\mu}_{it}^2, \hat{c}_{it})$  term captures how cost changes correlate with extreme markup deviations, while  $\text{CoSkew}_\omega(\hat{\mu}_{it}, \hat{c}_{it}^2)$  captures how markup changes correlate with extreme cost deviations.

The coefficient  $(\sigma - 1)^2/6$  on the third-order term implies that skewness effects are amplified in markets with high substitutability (large  $\sigma$ ).

**Aggregate decomposition.** As with the second-order approximation, the third-order approximation at the aggregate level includes both within-industry and across-industry terms. In addition, an aggregate decomposition at third order includes mixed cross-level  $\mathcal{O}(\|\hat{p}\|^3)$  terms that arise from evaluating the across-industry variance at sector prices that themselves contain within-industry second-order corrections. In our application, across-industry reallocation terms are close to zero in magnitude (see Table 2). Therefore, we omit these cross-level terms from the following formula characterizing the third-order aggregate price-

change decomposition:

$$\begin{aligned}
\hat{p}_t \approx & \underbrace{\bar{\mu}_t^{(1)} + \bar{c}_t^{(1)}}_{\text{first-order}} \\
& - \underbrace{\frac{\sigma-1}{2} \sum_i s_{i,t-1} \left[ \text{Var}_\omega(\hat{\mu}_{it}) + \text{Var}_\omega(\hat{c}_{it}) + 2\text{Cov}_\omega(\hat{\mu}_{it}, \hat{c}_{it}) \right]}_{\text{within-industry second-order}} \\
& + \underbrace{\frac{(\sigma-1)^2}{6} \sum_i s_{i,t-1} \left[ \text{Skew}_\omega(\hat{\mu}_{it}) + 3\text{CoSkew}_\omega(\hat{\mu}_{it}^2, \hat{c}_{it}) \right.}{\text{within-industry third-order}} \\
& \quad \left. + 3\text{CoSkew}_\omega(\hat{\mu}_{it}, \hat{c}_{it}^2) + \text{Skew}_\omega(\hat{c}_{it}) \right]}_{\text{within-industry third-order}} \\
& - \underbrace{\frac{\rho-1}{2} \left[ \text{Var}_s(\bar{\mu}_t^{(1)}) + \text{Var}_s(\bar{c}_t^{(1)}) + 2\text{Cov}_s(\bar{\mu}_t^{(1)}, \bar{c}_t^{(1)}) \right]}_{\text{across-industry second-order}} \\
& + \underbrace{\frac{(\rho-1)^2}{6} \left[ \text{Skew}_s(\bar{\mu}_t^{(1)}) + 3\text{CoSkew}_s((\bar{\mu}_t^{(1)})^2, \bar{c}_t^{(1)}) \right.}{\text{across-industry third-order}} \\
& \quad \left. + 3\text{CoSkew}_s(\bar{\mu}_t^{(1)}, (\bar{c}_t^{(1)})^2) + \text{Skew}_s(\bar{c}_t^{(1)}) \right]}_{\text{across-industry third-order}},
\end{aligned}$$

where the across-industry skewness and co-skewness terms are defined analogously to the corresponding within-industry terms using industry-level averages  $\bar{\mu}_{it}^{(1)}$  and  $\bar{c}_{it}^{(1)}$  with sector weights  $s_{i,t-1}$ . That is,

$$\text{Skew}_s(\bar{\mu}_t^{(1)}) \equiv \sum_i s_{i,t-1} (\bar{\mu}_{it}^{(1)} - \bar{\mu}_t^{(1)})^3$$

and

$$\text{CoSkew}_s((\bar{\mu}_t^{(1)})^2, \bar{c}_t^{(1)}) \equiv \sum_i s_{i,t-1} (\bar{\mu}_{it}^{(1)} - \bar{\mu}_t^{(1)})^2 (\bar{c}_{it}^{(1)} - \bar{c}_t^{(1)}),$$

while  $\text{Skew}_s(\bar{c}_t^{(1)})$  and  $\text{CoSkew}_s(\bar{\mu}_t^{(1)}, (\bar{c}_t^{(1)})^2)$  are defined similarly. The coefficient  $(\rho-1)^2/6$  is typically much smaller than  $(\sigma-1)^2/6$  because  $\rho < \sigma$ , so across-industry third-order effects are generally negligible relative to within-industry effects.

## F Three-Digit NAICS Sectoral Decomposition

The main text aggregates results to the two-digit NAICS level. This appendix presents the full three-digit decomposition for all 32 tariff-affected industries under the baseline 25% tariff specification. Table F.1 reports each sector’s U.S. import share, exact and first-order price changes, relative first-order error, and the first-order markup and cost components.

Several patterns emerge at the three-digit level that complement the two-digit results in Section 4.3.

**Within-group heterogeneity.** The two-digit aggregates mask wide variation within broad NAICS groups. Within Chemical & Materials Manufacturing (32), first-order relative errors range from 23% in Petroleum/Coal (324), where U.S. imports account for 51% of the market, to 102% in Wood Products (321), where U.S. share is only 8%. Similarly, within Metals & Machinery (33), errors range from 32% in Computer/Electronic Products (334) to 81% in Fabricated Metals (332) and Furniture (337). The key driver is U.S. import share: the correlation between U.S. share and relative first-order error is  $r = -0.79$  across all 32 industries ( $r = -0.72$  with HHI).

**Markup compression varies by exposure.** The mean markup contribution  $\bar{\mu}^{(1)}$  is most negative in high-U.S.-share manufacturing sectors:  $-4.34\%$  in Petroleum/Coal (324),  $-2.85\%$  in Chemicals (325),  $-2.78\%$  in Transportation Equipment (336), and  $-2.21\%$  in Paper (322). These sectors have substantial U.S. presence, so the tariff triggers large market share shifts and correspondingly large markup compression. In contrast, Mining (21) and Utilities (22) show *positive* markup contributions ( $+0.12\%$  to  $+0.24\%$ ): in these sectors, the tariff shifts demand toward domestic incumbents whose market power increases, amplifying rather than dampening the cost shock. The correlation between U.S. share and  $\bar{\mu}^{(1)}$  is  $r = -0.85$ .

Table F.1: Sectoral Price Decomposition: Three-Digit NAICS Industries

| NAICS                                              | Industry              | U.S. Share | Price Change (%) |           | Rel. Err. | First-Order Decomp. (%) |                   |
|----------------------------------------------------|-----------------------|------------|------------------|-----------|-----------|-------------------------|-------------------|
|                                                    |                       | (%)        | Exact            | 1st Order |           | (%)                     | $\bar{\mu}^{(1)}$ |
| <i>Agriculture (11)</i>                            |                       |            |                  |           |           |                         |                   |
| 111                                                | Crop Production       | 25.0       | 2.40             | 4.15      | +73.0     | −1.43                   | 5.59              |
| 112                                                | Animal Production     | 0.1        | 0.01             | 0.02      | +140.6    | 0.00                    | 0.02              |
| 113                                                | Forestry/Logging      | 3.7        | 0.39             | 0.82      | +113.2    | 0.01                    | 0.82              |
| 114                                                | Fishing/Hunting       | 0.1        | 0.01             | 0.03      | +140.5    | 0.00                    | 0.03              |
| 115                                                | Support Activities    | 0.6        | 0.07             | 0.14      | +109.6    | 0.02                    | 0.13              |
| <i>Mining (21)</i>                                 |                       |            |                  |           |           |                         |                   |
| 211                                                | Oil/Gas Extraction    | 8.9        | 1.32             | 2.23      | +68.8     | 0.24                    | 1.98              |
| 212                                                | Mining (excl. O&G)    | 7.8        | 1.12             | 1.94      | +73.2     | 0.21                    | 1.74              |
| <i>Utilities (22)</i>                              |                       |            |                  |           |           |                         |                   |
| 221                                                | Utilities             | 2.5        | 0.37             | 0.67      | +83.1     | 0.12                    | 0.55              |
| <i>Food &amp; Textile Manufacturing (31)</i>       |                       |            |                  |           |           |                         |                   |
| 311                                                | Food Mfg              | 12.1       | 1.25             | 2.36      | +89.5     | −0.34                   | 2.70              |
| 312                                                | Beverage/Tobacco      | 11.6       | 1.51             | 2.52      | +67.1     | −0.06                   | 2.58              |
| 313                                                | Textile Mills         | 33.4       | 4.58             | 6.59      | +43.9     | −0.85                   | 7.44              |
| 314                                                | Textile Products      | 20.4       | 3.43             | 4.60      | +34.1     | 0.05                    | 4.55              |
| 316                                                | Leather Products      | 2.9        | 0.83             | 1.16      | +39.8     | 0.53                    | 0.63              |
| <i>Chemical &amp; Materials Manufacturing (32)</i> |                       |            |                  |           |           |                         |                   |
| 321                                                | Wood Products         | 7.7        | 0.82             | 1.66      | +101.9    | −0.04                   | 1.70              |
| 322                                                | Paper Mfg             | 30.6       | 3.12             | 4.61      | +48.0     | −2.21                   | 6.82              |
| 323                                                | Printing              | 14.9       | 1.44             | 2.71      | +88.5     | −0.62                   | 3.33              |
| 324                                                | Petroleum/Coal        | 51.4       | 5.79             | 7.14      | +23.2     | −4.34                   | 11.48             |
| 325                                                | Chemical Mfg          | 37.6       | 4.03             | 5.55      | +37.5     | −2.85                   | 8.39              |
| 326                                                | Plastics/Rubber       | 24.3       | 2.45             | 4.01      | +63.9     | −1.41                   | 5.42              |
| 327                                                | Non-Metallic Mineral  | 15.2       | 1.58             | 2.74      | +74.1     | −0.64                   | 3.38              |
| <i>Metals &amp; Machinery Manufacturing (33)</i>   |                       |            |                  |           |           |                         |                   |
| 331                                                | Primary Metals        | 26.0       | 3.56             | 5.29      | +48.8     | −0.51                   | 5.80              |
| 332                                                | Fabricated Metals     | 17.9       | 1.82             | 3.30      | +80.8     | −0.70                   | 3.99              |
| 333                                                | Machinery Mfg         | 35.3       | 4.23             | 5.90      | +39.6     | −1.98                   | 7.88              |
| 334                                                | Computer/Electronic   | 15.5       | 3.44             | 4.53      | +31.5     | 1.08                    | 3.45              |
| 335                                                | Electrical Equipment  | 25.7       | 3.56             | 5.06      | +42.2     | −0.67                   | 5.73              |
| 336                                                | Transportation Equip. | 33.1       | 3.45             | 4.61      | +33.6     | −2.78                   | 7.38              |
| 337                                                | Furniture Mfg         | 10.4       | 1.19             | 2.15      | +80.8     | −0.18                   | 2.33              |
| 339                                                | Misc. Manufacturing   | 20.6       | 2.78             | 4.23      | +52.1     | −0.36                   | 4.58              |
| <i>Wholesale Trade (41)</i>                        |                       |            |                  |           |           |                         |                   |
| 414                                                | Personal/Household    | <0.1       | <0.01            | <0.01     | +140.9    | 0.00                    | <0.01             |
| 415                                                | Motor Vehicle Wh.     | 9.1        | 0.96             | 1.90      | +98.5     | −0.13                   | 2.03              |
| 417                                                | Machinery/Equipment   | 0.4        | 0.04             | 0.08      | +132.9    | 0.00                    | 0.08              |
| 418                                                | Building Materials    | 5.9        | 0.64             | 1.31      | +103.4    | −0.01                   | 1.32              |

*Note:* Baseline specification: 25% tariff on U.S. imports, 5 U.S. firms per three-digit industry. Rel. Err. = (1st Order/Exact - 1)  $\times$  100%.  $\bar{\mu}^{(1)}$  and  $\bar{c}^{(1)}$  are share-weighted mean log changes in markups and costs, respectively.

**Low-exposure sectors dominate relative errors.** The largest relative errors (> 100%) occur in sectors with negligible U.S. presence: Animal Production (112), Fishing (114), and

Personal/Household Wholesale (414) all exceed 140%. In these sectors, the absolute price effect is tiny (below 0.03%), but the first-order approximation roughly doubles the true effect. While economically small in absolute terms, these errors illustrate the fundamental point: the first-order bias is a *relative* phenomenon driven by the variance-to-mean ratio of firm-level price changes, not by the level of the price change itself.