Estimating the Regional Welfare Impact of Tariff Changes: Application to the United States

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Abstract

We propose an empirical method to estimate the regional welfare impact of changes in import tariffs and apply this method to the United States. Using a translog expenditure function and state-level data, the impact of a change in tariffs on prices and purchases from other states and foreign countries is obtained. Tariff revenue is assumed to be distributed on a per-capita basis, so states with greater production will experience a welfare gain from tariffs on those products (due to rising producer surplus) while those with little production will lose (due to falling consumer surplus). Over 2002-17, we find that 28 states benefitted from reduced tariffs, with national gains of $5.8 billion or $50 per household annually. These national gains were eliminated by the tariff increases over 2017-2019 with national losses of $57 per household and rising to $103 per household over 2017-2022, but 25 states still gained. These estimates of the national losses from tariff increases are much lower than found in other studies for the 2017-19 period, due to this study incorporating *product exclusions* that reduced the tariffs on certain products, and also due to differences in the methods of calculation.

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1. Introduction

The work of Autor, Dorn and Hanson (ADH, 2013, 2016) and Acemoglu et. al. (2016) highlighted the different impacts of changes in trade policy on regions in the United States. These papers focused on China's entry to the World Trade Organization in 2001 as the trade policy shock (the "China shock"), and they documented the impact on employment as well as wages in U.S. commuting zones. They showed that regions differed greatly in their response to the China shock, with long-lasting outcomes (ADH, 2022). Since their work, a growing number of studies have studied the impact of the China shock and other change in trade policy on U.S. regions, often by using quantitative models (e.g. Caliendo, Dvorkin and Fernando, 2019). These models have confirmed the differential impact across regions from the China shock, and in some case, have also confirmed the magnitude of the employment responses found by ADH.[1]

It can be expected that quantitative models including U.S. regions can be applied to other changes in trade policy, even if the changes are not as dramatic as the China shock. The empirical methodology used by ADH relied heavily on the national changes in U.S. imports from China in each sector. Their shift-share analysis converted those changes in Chinese imports at the national level into changes at the regional level by using the initial shares of employment in each industry within the region: regions with more initial employment in, say, steel production, would be expected to experience a greater drop in employment due to increased imports of steel from China. A similar approach can be taken for a change in sectoral tariffs, where the change in national tariffs can be imputed to regions using their initial share of those industries (see Blanchard, Bown and Chor, 2022, and Autor, Beck, Dorn and Hanson, 2024). It would be

[1] Rodríguez-Clare, Ulate and Vásquez (2022) found that the employment impact arising from the China shock in a quantitative model matches the impact found in ADH only if rigid wages are incorporated into the quantitative model, as well as differing elasticities of labor response across regions and occupations. See also the review by Caliendo and Parro (2022).

preferable, however, to have a dataset that directly measures the sectoral imports from each foreign country to each U.S. region, rather than relying on a shift-share analysis. In addition, rather than looking at the outcome for employment or wages, it would be desirable to measure the impact on consumers, producers, and overall welfare for each region.

The goal of this paper is to propose a relatively simple empirical framework to measure the regional welfare impact of changes in U.S. tariffs. We rely on a U.S. state-level dataset obtained from the Freight Analysis Framework (FAF), which distinguishes imports and exports by eight foreign regions (with China included within Southeast Asia) and shipments from 50 states for 42 industries. This dataset can be used to compute apparent consumption for each sector in each region, so that the share of apparent consumption in each region relative to local purchases and imports from every other region is obtained. This dataset is merged with U.S. import tariffs and disaggregate state-level imports at the 6-digit Harmonized System level, as we discuss in section 2. Importantly, we use the *applied tariffs* calculated as annual duties collected divided by the value of trade. This approach differs from other studies of the impact of U.S. tariffs, such as Amiti et al. (2019a, b) and Fajgelbaum et al. (2020a, b), who examine the impact of the Section 201/232/301 tariff increases enacted by the Trump administration during 2018-2019, including the bilateral tariff war with China. These authors use *statutory* tariffs that are significantly higher than the applied tariffs because the applied tariffs include *product exclusions* that were in effect for certain products from mid-2018.

To apply these data, in section 3 we model the sectoral purchases of each U.S. state from other states and foreign countries. Tariff revenue is assumed to be distributed on a per-capita basis, as would occur if the tariff revenue is spent on public goods so that every person receives equal benefits. In this case, states with greater production will experience a welfare gain from tariffs on those products (due to rising producer surplus) while those with little production will lose (due to falling consumer surplus). In other words, the welfare impact of tariffs differs across states due to their production structures. At the *national level,* there is a deadweight loss from tariffs since consumption and production occur at prices higher than the international prices. But at the state level, this logic must be modified. A state with more supply, for example, will gain more in producer surplus from the tariff increase and its *per-capita portion* of tariff revenue may exceed the revenue that its own imports (which might be zero) are generating. This state can gain from tariffs whereas other states that have little or no supply will lose from tariffs.

The rest of our model is outlined in section 4-6. With 42 disaggregate goods, many states will not be buying or selling to other states or to the rest of the world, so there are many zeros in the dataset. It is important, therefore, to adopt a framework for import demand that naturally allows for zeros in trade. For this purpose we adopt a translog model of demand in each sector. Rather than explaining the *log* of expenditure shares, as in a CES model, we will be explaining the *level* of expenditure shares, and these can be zero whenever the price is too high for consumers to purchase it, i.e. above its reservation price.[2]

Our empirical results are discussed in sections 7-8, beginning with the estimation of translog parameters and then moving to the state-level welfare results. Over 2002-2017, we find that 28 states benefitted from reduced tariffs under various free trade areas, with national gains of $5.8 billion or $50 per household annually. The increase in tariffs over 2017-19 reversed these gains, with a national welfare loss of $7.1 billion or $57 per household, but 25 states still gained. Extending the analysis to 2017-2022, the national welfare loss due to tariff increases is nearly

[2] In a constant elasticity of substitution (CES) model the reservation price of a good in infinite, which is why zeros in trade do not naturally arise unless fixed costs of trade are incorporated. The translog system is tractable even when some goods have a price above their reservation prices, so that the available product varieties are changing over time (Feenstra, 2003; Feenstra and Weinstein, 2017).

twice as large: $13.0 billion or $103 per household, but again, 25 states still gain.

The national welfare losses that we compute are notably lower than in Amiti et al. (2019a, b) and Fajgelbaum et al. (2020a, b), and in section 9 we examine reasons for this outcome. We begin with aggregation bias, since we work at the 6-digit HS level (which is the finest available for state-level data), whereas those authors use 10-digit HS data. We find that this bias would not increase our welfare costs by more than about $10 per household. In contrast, the use of *end-of-year statutory* tariffs by them has a very large impact on the welfare costs that they calculate. These statutory tariffs are significantly higher than the applied tariffs due to product exclusions. Cox (2023) studies these product exclusions for the steel industry and they were used widely for imports from China, too. In addition to product exclusions, we argue that our method of calculating the cost of tariffs, which relies on a Tornqvist index that is consistent with the translog, gives lower costs than from evaluating the tariff increases at the initial level of imports (before the tariff increase), as done by Fajgelbaum et al. (2020a, b), which is similar to a Laspeyres index of the tariffs. We show how our calculation for 2017-2019 would increase by using the statutory tariffs, by using a Laspeyres index, and by using strong substitution away from those tariffs as in Amiti et al. (2019b). In this way, we are able to explain our low estimates of the welfare cost as compared to the higher estimates obtained by those authors. Further conclusions are given in section 10 and additional material is gathered in the Appendix.

2. FAF and Tariff Data

FAF Dataset

The Freight Analysis Framework (FAF version 5) has estimates of freight flows into and out of U.S. states and metropolitan areas. It is disaggregated into eight modes of transport (though we do not make use of that disaggregation) and 42 sector codes including all types of agricultural goods, raw materials, and manufactured goods, according to the Standard Classification of Transported Goods (SCTG) framework. These 42 sectors are listed in Table 1, where it is seen that certain sectors like building stones, natural stones, and gravel (sectors 10-12), coal (14) and crude petroleum (16) are quite narrow and homogeneous, where other sectors like machinery (34) and electronics and office equipment (34) are very broad and differentiated. The FAF dataset is produced by the Bureau of Transportation Statistics, which relies on data from several sources: the Commodity Flow Survey that details transportation flows within the United States but with less coverage that the FAF; the U.S. import and export data from U.S. Census; and additional data from agriculture, mineral extraction and other sectors. The import and export data from Census are aggregated into eight broad regions when being merged with the FAF dataset.[3]

We will denote the FAF sectors by $n = 1,\ldots,N$ where $N = 42$, with U.S. states denoted by $i, j = 1,\ldots,50$ and foreign regions by $i, j = 51,\ldots,R$, where $R = 58$. Also denote the value of shipments from state j to state i in sector n and year t by Y_{ijt}^{n}, for $i, j =1,\ldots,50$. The years of our sample are 2002, 2007, 2012, and annual data from 2017-2022. We denote the value of imports – inclusive of import duties – from foreign country j to state i by M_{ijt}^{n}. Then apparent consumption E_{it}^{n} in state i is the sum of domestic shipments plus imports:

$$E_{it}^{n} = \sum_{j=1}^{50} Y_{ijt}^{n} + \sum_{j=51}^{R} M_{ijt}^{n}.$$

To measure domestic and import shares, we divide domestic shipments and imports from each foreign country by domestic consumption to obtain: $s_{ijt}^{n} = \frac{Y_{ijt}^{n}}{E_{it}^{n}}$,for $j = 1,\ldots,50$ and $s_{ijt}^{n} = M_{ijt}^{n}/E_{it}^{n}$,for $j = 51,\ldots,R$.

[3] The FAF dataset is downloaded from https://www.bts.gov/faf, and we use values expressed in constant 2017 dollars. We likewise express imports from the U.S. Census in 2017 dollars.

Table 1: Standard Classification of Transported Goods (SCTG) sectors

Sector	Description	Expenditure Share (percent) 2022	Sector	Description	Expenditure Share (percent) 2022
1	Live animals/fish	1.11%	22	Fertilizers	0.48%
2	Cereal grains	1.30	23	Chemical prods.	2.26
3	Other ag prods.	2.03	24	Plastics/rubber	4.09
4	Animal feed	1.07	25	Logs	0.08
5	Meat/seafood	2.17	26	Wood prods.	1.66
6	Milled grain prods.	1.15	27	Newsprint/paper	0.71
7	Other foodstuffs	3.78	28	Paper articles	0.81
8	Alcoholic beverages	1.45	29	Printed prods.	0.71
9	Tobacco prods.	0.39	30	Textiles/leather	3.06
10	Building stone	0.04	31	Nonmetal min. prods.	1.37
11	Natural sands	0.06	32	Base metals	3.06
12	Gravel	0.12	33	Articles-base metal	2.48
13	Nonmetallic minerals	0.13	34	Machinery	5.37
14	Metallic ores	0.15	35	Electronics	8.13
15	Coal	0.12	36	Motorized vehicles	6.76
16	Crude petroleum	2.41	37	Transport equip.	0.88
17	Gasoline	5.58	38	Precision instruments	2.03
18	Fuel oils	5.06	39	Furniture	1.62
19	Coal-n.e.c.	5.29	40	Misc. mfg. prods.	4.24
20	Basic chemicals	1.64	41	Waste/scrap	0.38
21	Pharmaceuticals	6.48	42	Mixed freight	8.31

Source: https://www.bts.gov/faf

Import Tariffs

The FAF dataset does not include tariffs, so we merged it with U.S. state-level trade and tariff data from Census (https://usatrade.census.gov/). The finest level of trade detail at the state level is the 6-digit Harmonized System (HS6) level, denoted by h for countries c, so that the HS6 *ad valorem* tariffs are τ_{ct}^{h}. In Table 2 we provide summary statistics for the tariff data. In column (1) we show national duties paid divided by the national customs value for all U.S. imports. There is a fall in this national tariff from 2002 to 2007, which reflects new free trade agreements (FTA) with countries including Chile, Singapore, Australia, Morocco, Bahrain, and the

Dominican Republic-Central America FTA. National average tariffs are quite stable from 2007 to 2017 and then begin to rise with the tariff policies pursued under President Trump's administration. The tariff of 2.8% in 2022 is twice that of 1.4% in 2017, but both of these are small since only about one-third of U.S. imports are subject to any tariff duties.

For comparison, in column (2) of Table 2 we report the total duties paid divided by the total *dutiable value* of all U.S. imports. These tariffs are more substantial, ranging from a low of 4.2% in 2012 to a high of 8.9% in 2020-21, and reflect *all* import tariffs applied by the United States, including but not limited to: the Section 201 tariffs initiated in 2018 on solar panels and washing machines, the Section 232 and steel and aluminum; and the Section 301 tariffs on many imports from China. In the remainder of Table 2 we focus on all U.S. tariffs on imports from China, which include the Section 301 tariffs and the subsequent 2018-19 bilateral tariff war. In columns (3) and (4), we take the *simple average* of the tariffs on China over all HS6 products. In column (3), the tariffs are computed as import duties (possibly zero) divided by the *customs-value* of imports from China, while in column (4), the tariffs equal the import duties divided by the *dutiable-value* of imports from China, which may be less than the customs value.

Columns (3) and (4) differ because there are a number of consumer products (such as laptops, computer monitors and some toys) that did not have tariffs on imports from China and therefore have zero dutiable value. The value of these imports with zero tariffs can be inferred from column (5), where we report the 2017 customs value of Chinese imports for which duties are collected. The total value of Chinese imports in 2017 was $504 billion, and in that year, column (5) shows that $238 billion – or just under one-half – were subject to duties. In 2019 that fraction rose to about three-quarters ($384/504 = 76%) under tariffs enacted by the Trump administration, and in 2022 that fraction was more than four-fifths (414/504 = 82%).

Table 2: Summary of U.S. Tariffs from Census: All Imports and from China

	All U.S. Imports		U.S. Imports from China				
	Total Duty/ Customs value, (percent)	Total Duty/ Dutiable value (percent)	Average of HS6 Duty/ Customs value (percent)		Average of HS6 Duty/ Dutiable value (percent)		2017 China Imports with $\tau_{c,t}^{h} > 0$ in (4), ($ billion)
	(1)	(2)	(3a)	(3b)	(4a)	(4b)	(5)
2002	1.7%	4.9%	3.9%		5.9%		Na
2007	1.3	4.4	3.6		6.1		Na
2012	1.3	4.2	3.5		6.0		Na
2017	1.4	4.7	3.5		6.0		$237.6
2018	1.8	5.6	6.1	7.0	10.2	10.6	368.6
2019	2.7	7.8	16.2	17.5	18.7	19.2	384.3
2020	2.8	8.9	20.0	21.7	22.3	22.8	419.3
2021	3.0	8.9	20.7	22.2	22.3	22.8	432.2
2022	2.8	8.2	20.3	22.0	22.1	22.7	413.5

Notes: Columns (3b) and (4b) replace any HS6 tariffs that fall from 2017 by their 2017 levels.

We have arranged columns (3) and (4) so that they can be readily compared with the summary tariffs in Fajgelbaum et al. (2020a, b). Combining the 2018-19 tariffs on China, Fajgelbaum et al. (2020b, Table 1) report an average U.S. tariff of 26.4% in 2019 as compared to 4.1% in 2017, for a *22.3 percentage point increase in average tariffs*. Their sample are 10-digit HS imports from China that experienced an increase in tariffs due to the trade war. This differs from columns (3a) and (4a) in Table 2 which includes *all* Chinese imports. We approximate their approach in in columns (3b) and (4b) by replacing any HS6 tariffs that fall from 2017 by their 2017 levels. We then find from column (3b) that the average tariffs are 17.5% in 2019 and 3.5% in 2017, *for a 14 percentage point increase in average tariffs* and similarly in column (4b). In comparison, the increase in average tariffs over 2017-19 used by Fajgelbaum et al. (22.3 percent) is *8.3 percentage points greater – or more than 50% higher* – than what we show in Table 2.

There are two reasons to find lower tariff increases in our HS6 data from Census, and a third possible reason. The first reason is that the 2018 and 2019 tariffs used by Fajgelbaum et al.

(2020a, b) in their summary statistics and welfare calculations reflect the *end-of-year* statutory tariffs, whereas the applied tariffs from Census reflect tariff increases occurring within each year. In 2018, for example, we find an average China tariff measured by Duty/Dutiable value of 10.6% in Table 2, column 4(b), whereas Fajgelbaum et al. (2020a, p. 9) report 15.5%, which is the same 50% difference that we found just above when examining 2017-2019. The Census tariffs are constructed from "calculated duty" that is reported monthly, so when summed over the year the calculated duty reflects the tariff increases within the year. In contrast, Fajgelbaum et al. (2020a, b) and Amiti et al. (2019b) use *end-of-year* tariffs to measure the welfare cost.[4]

Second, these authors use *statutory tariffs* during 2018-19 reported by the U.S. International Trade Commission (USITC).[5] According to Fajgelbaum et al. (2020a, p. 7), these tariffs were "swiftly implemented within three weeks following a press release for the Office of the U.S. Trade Representative" (USTR). The tariffs, however, are subject to a process whereby U.S. importers can appeal to the USTR to obtain a "product exclusion". Such product exclusions in the steel industry were highlighted by Cox (2023), for example, and they were widely granted to offset the tariffs on China, too.[6] These exclusions are *not reflected* in the statutory tariffs published by the USITC, because the USTR grants these exclusions after a review process (but retroactively). For example, nearly six months after the first wave of Section 301 tariffs against China were effective on July 6, 2018, the USTR announced:

[4] Amiti et al. (2019a) calculated the monthly welfare cost of the tariffs in 2018, but when extending their results to 2019 in Amiti et al. (2019b), they focus on the end-of-year statutory tariffs. Fajgelbaum et al. (2020a) make use of the monthly tariffs in their estimation of the tariff passthrough, but not in their calculation of the welfare costs.

[5] See: https://hts.usitc.gov/.

[6] All special tariffs, including those implemented by the Trump administration, are described in Chapter 99 of the Harmonized Tariff System (HTS), available at https://hts.usitc.gov/. The 2024 Chapter 99 document is 630 pages, of which 178 pages describe exclusions granted at some time on the Section 301 tariffs applied to imports from China.

> On Dec. 21, 2018, the Office of the U.S. Trade Representative submitted for publication a Federal Register Notice to modify the Harmonized Tariff Schedule in order to grant nearly 1,000 product exclusion requests from tariffs that went into effect on July 6 on approximately $34 billion worth of imports from China. … The product exclusions announced in this notice will apply as of the July 6, 2018 effective date of the $34 billion action, and will extend for one year after the publication of this notice.[7]

There were similar product exclusions announced after each wave of Section 301 tariffs, reported in Chapter 99 of the Harmonized Tariff System (HTS, see note 6) as well as in the Federal Register. The tariff data from Census based on "calculated duties" reflects these exclusions, as we illustrate with a detailed example below.

A third possible reason why our applied tariffs are lower that the statutory tariffs is that either Census underestimates the "calculated duty", or that our use of HS6 data (which is the finest level available at the state level) leads to some downward bias due to aggregation. We examine the first issue in Appendix A and find that it is not significant for U.S. imports from China. The second issue is examined in section 9, where we conclude that there may be some downward bias due to aggregation, but that it is small.

To further understand the product exclusions, we provide an example in Table 3 for U.S. imports from China in just one HS6 code (841869), Refrigerating or Freezing Equipment. In 2017, all seven HS10 codes within this 6-digit code had zero tariffs. Fajgelbaum et al. (2020a, b) use a statutory tariff on all these HS10 categories of 25% starting in July 2018, so their "scaled" tariff for 2018 (i.e. scaled by the number of months it is effective) is 0.125 with a maximum tariff of 0.25 at the end of the year, and both the "scaled" and maximum tariffs for 2019 are 0.25. By a simple search of Chapter 99 of the Harmonized Tariff System (HTS) for the

[7] Source: https://ustr.gov/about-us/policy-offices/press-office/press-releases/2018/december/ustr-grants-first-round-product.

Table 3: Details of Trade for U.S. Imports from China, HS6 841869, Refrigerating or Freezing Equipment

	Customs Value ($mill)	Dutiable Value ($ mill)	Calculated Duty ($ mill)	Duty/ Customs value	Duty/ Dutiable value	Product Exclusion
	(1)	(2)	(3)	(4)	(5)	(6)
2017						
Seven HS 10-digit categories	455.5	0.0	0.0	0.0	na	
2018						
1. Icemaking Machines	111.0	16.8	4.2	0.04	0.25	**Yes**
2. Drinking Water Coolers	123.6	2.7	0.65	0.01	0.24	**Yes**
3. Soda and beer dispensing	14.6	6.6	1.6	**0.11**[a]	0.25	
4. Centrifugal Liquid Chilling	4.9	1.9	.39	**0.08**[a]	0.21	
5. Reciprocating Liquid Chilling	1.1	.35	.08	**0.08**[a]	0.24	
6. Absorption Liquid Chilling	4.1	.89	.22	0.05	0.25	**Yes**
7. Refrig/freezing equip, nes	138.1	20.5	5.1	0.04	0.25	**Yes**
Total	**397.3**	**49.6**	**12.3**	**0.031**	**0.248**	
2019						
1. Icemaking Machines	86.4	12.2	3.0	0.04	0.25	**Yes**
2. Drinking Water Coolers	143.4	0.14	.03	0.00	0.25	**Yes**
3. Soda and beer dispensing	6.5	6.5	1.6	0.25	0.25	
4. Centrifugal Liquid Chilling	1.6	1.6	.28	**0.17**[b]	**0.17**[b]	
5. Reciprocating Liquid Chilling	.44	.44	.11	0.24	0.24	
6. Absorption Liquid Chilling	4.1	2.1	.53	0.13	0.25	**Yes**
7. Refrig/freezing equip, nes	98.1	54.1	13.5	0.14	0.25	**Yes**
Total	**340.5**	**77.2**	**19.1**	**0.056**	**0.248**	
2022						
1. Icemaking Machines	214.1	214.0	52.5	0.24	0.25	
2. Drinking Water Coolers	130.8	130.8	32.4	0.25	0.25	
3. Soda and beer dispensing	14.9	14.9	3.7	0.25	0.25	
4. Centrifugal Liquid Chilling	1.3	1.3	.32	0.24	0.24	
5. Reciprocating Liquid Chilling	4.2	4.2	1.0	0.25	0.25	
6. Absorption Liquid Chilling	11.0	11.0	2.0	**0.19**[b]	**0.19**[b]	
7. Refrig/freezing equip, nes	165.4	165.4	41.3	0.25	0.25	
Total	**541.8**	**541.7**	**133.3**	**0.246**	**0.246**	

Notes: The seven rows for each year are the HS10 products within this HS6 category. Fajgelbaum et al. (2020a, b) use a statutory tariff in all HS10 products of 0.25 starting in July 2018, so their "scaled" tariff for 2018 is 0.125 with a max tariff of 0.25 at the end of the year, and both the "scaled and max tariffs for 2019 are 0.25.

a. These applied tariffs are similar to the "scaled" tariff of 0.125.
b. These applied tariffs differ from the statutory tariff of 0.25, even though there was no product exclusion that we could identify from HTS Chapter 99 on these HS10 items.

HS6 code 841869, we can identify four HS10 categories within it that had product exclusions starting in 2018 and 2019, which are marked in Table 3 as the first two and last two HS10 products. In these four products, the Duty/Dutiable value shown in Table 3 for 2018, 2019 and 2022 are all close to 0.25, but in 2018 and 2019 there is a much lower tariff obtained for Duty/Customs value. In other words, *the product exclusions on these four HS10 codes creates a portion of the HS10 value that is not subject to any duty, so that the dutiable value is lower.*

Specifically, in 2018 (2019), about $400 ($340) million was imported in this HS6 category, but only $50 ($77) million was a dutiable value subject to the statutory tariff. We will be using Duty/Customs value calculated at the HS6 level to measure tariffs, and it is clear from Table 3 that this measure is *very much lower* than the Duty/Dutiable value at the HS6 level, which is in turn slightly lower than the statutory tariff (0.25 effective July 2018) in 2018 and 2019. By 2022, however, the product exclusions are no longer in effect and then Duty/Customs value at the HS6 level equals Duty/Dutiable value.

Two other conclusions can be gleaned from Table 3. First, in 2018 we show in bold the middle three HS10 codes that are *not* subject to product exclusions and have Duty/Customs value in the range of 0.08-0.11. That is not too different from the “scaled” tariff of 0.125 reported by Fajgelbaum et al. (2020a, b) for 2018, which illustrates that the Census value for calculated duties reflects the time period that a tariff is in effect, even if the tariff changes within the year. Tariffs on China continued rise during 2018, so that is why Duty/Customs value for 2018 in Table 3 is particularly low (0.031), but higher in 2019 (0.056), and much higher in 2022 (0.246) when we do not find any evidence of product exclusions for this HS6 code.

Second, we also show in bold one HS10 product in each of 2019 and 2022 that have applied tariffs *lower than* their statutory rate, i.e. 0.17 and 0.19, respectively, rather than 0.25, but without any product exclusion that we can find in HTS Chapter 99. We have no explanation for the lower tariffs on those two products. Very little of those products are imported in either year, so these lower tariffs have a minimal impact on the average HS6 tariff. But to the extent that this situation arises in other HS codes, it creates a further reason for Duty/Customs value and also Duty/Dutiable value to be less than the statutory tariffs.

Sectoral Tariffs and Passthrough to Unit-Values

At times we will need to aggregate the HS tariffs to the FAF sector level, as we do in this section to investigate the pass-through of tariffs to import and domestic unit-values in the FAF data. For each FAF sector *n* and foreign region *j*, let us denote the HS6 goods *h* and foreign countries *c* that supply to the United States in year *t* by the set $(h, c) \in H_{jt}^n$, with the number of HS-country pairs denoted by $\left|H_{jt}^n\right|$. Then we consider two aggregations of U.S. tariffs into FAF sectors and regions,

$$\tau_{jt}^n \equiv \sum_{(h,c)\in H_{jt}^n} \frac{\tau_{ct}^h}{\left|H_{jt}^n\right|}, \quad j = 51, \dots, 58, \tag{1}$$

$$\tau 2_{jt}^n \equiv \frac{\sum_{(h,c)\in H_{jt}^n} \widetilde{M}_{ct}^h \tau_{ct}^h}{\sum_{(h,c)\in H_{jt}^n} \widetilde{M}_{ct}^h} = \sum_{(h,c)\in H_{jt}^n} \left(\frac{\widetilde{M}_{ct}^h}{\widetilde{M}_{jt}^n}\right) \tau_{ct}^h\,, \tag{2}$$

where $\widetilde{M}_{ct}^h = M_{ct}^h/(1 + \tau_{ct}^h)$ is the *net-of-duty* U.S. customs value of the HS6 good *h* from foreign county *c*, so that $\widetilde{M}_{jt}^n = \sum_{(h,c)\in H_{jt}^n} \widetilde{M}_{ct}^h$ in the denominator of (2) is the net-of-duty U.S. imports in FAF sector *n* and region *j*. The first definition of the sectoral tariff in (1) is the *simple average* of the HS tariffs within it. The second definition is the sectoral tariff duties $\sum_{(h,c)\in H_{ij}^n} \widetilde{M}_{ct}^h \tau_{ct}^h$ collected in that sector divided by the total customs value imports, which is equivalently written in (2) as the *import weighted average* of the HS tariffs. These weights create some noise in the tariff shown in definition (2), because changes in the import weights will change $\tau2_{jt}^{n}$ even if there is no change in the HS tariffs τ_{ct}^{h}.

From the FAF data, the sectoral unit-values are obtained by dividing the shipment value by the quantity (in tons). We denote this unit value by UV_{ijt}^{n} for states $i = 1,\ldots,50$ and state or foreign regions $j = 1,\ldots,58$. Focusing initially on the *import* unit-values, we run the fixed-effects regression:

$$\ln UV_{ijt}^{n} = \delta_{t}^{*} + \delta_{ij}^{n} + \beta \ln(1 + \tau_{jt}^{n}) + u_{ijt}^{n}, \;\; i = 1, \ldots, 50, \;\; j = 51, \ldots, 58,$$

where δ_{t}^{*} and δ_{ij}^{n} are year and state-region-sector fixed effects, and β is a pass-through coefficient from tariffs to import prices. As mentioned earlier, the years of our sample are 2002, 2007, 2012, and annual data from 2017-2022, and we experiment with the data from 2002-2022 and 2007-2022 in this regression.

We run four variations of this regression, as shown in Table 4. First using the full 2002-2022 sample, we use either the simple average sector tariff, τ_{jt}^{n}, or the import-weighted average, $\tau2_{jt}^{n}$. The results in columns (1) and (2) show that we obtain a pass-through coefficient β of 0.778 using the simple average versus 0.198 (and insignificant) using the weighted average. The lower coefficient using the weighted average tariff matches our expectation that measurement error arising from the weights reduces the coefficient, but the magnitude of reduction is more than we might normally expect. One reason for this outcome is that the measurement error does not satisfy the classical assumption that it is uncorrelated with other variables in the regression. Instead, the measurement error from using import weights is endogenous to the magnitude of HS tariff changes, because a large change in the tariff would shift the HS import weight by more.

The period 2002-2007 includes numerous tariff decreases from FTAs, so we experiment with dropping 2002. The results in columns (3) and (4) of Table 4 show that both pass-through

Table 4: Passthrough of Sectoral Tariffs

Dependent variable: Unit-values of imports	**2002-2022 period**		**2007-2022 period**	
	(1)	(2)	(3)	(4)
	Simple avg. Tariff	Import-weighted avg. Tariff	Simple avg. Tariff	Import-weighted avg. Tariff
ln(1+ τ_{jt}^{n})	0.778***	0.198	0.990***	0.546***
	(0.245)	(0.169)	(0.241)	(0.170)
Observations	115,916	115,916	101,932	101,932
R-squared	0.795	0.795	0.811	0.811
year FE	Y	Y	Y	Y
state-country-sector FE	Y	Y	Y	Y

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.10

coefficients increase over 2007-2022, and we now obtain a pass-through of 0.990 using the simple average versus 0.546 (and significant) using the weighted average. The former is within one standard error of the estimate 0.778 obtained over the entire period and shows that pass-through when using the simple average tariff is very close to unity, i.e. on average, the United States can be treated as a small country. That finding is in accordance with the studies of tariffs enacted under the Trump administration (Amiti, et al., 2019a, Fajgelbaum et al., 2020), which typically find pass-through of unity at the disaggregate HS level.[8]

For these reasons, we will treat the United States as a small country for the rest of the paper so the pass-through coefficient is $\beta = 1$. For the import-weighted average tariff, the pass-through of 0.546 in column (4) is much higher than in column (2), but it still suffers from downward bias from measurement error. We therefore do not use $\tau 2_{jt}^{n}$ for most of the remainder of the paper, except when we compute tariff revenue, for which $\tau 2_{jt}^{n}$ is well-suited because it can be multiplied by the customs value of imports to obtain tariff revenue.

[8] Amiti et al. (2020) find less than complete pass-through, however, for tariffs in the steel industry.

We are also interested in the change in domestic unit-values that are caused by changes in tariffs. Denote the set of foreign countries selling to state *i* in sector *n* and year *t* by J_{it}^{n*}, and the number of these countries by R_{it}^{n*}. Then define the average tariff facing state *i* by: [9]

$$\ln T_{it}^{n} \equiv \frac{1}{R_{it}^{n*}} \sum_{k \in J_{it}^{n*}} \ln(1 + \tau_{kt}^{n}), \; i = 1, \ldots, 50.$$

To infer the impact of tariffs changes on domestic prices, we run the simple regression:

$$\ln UV_{ijt}^{n} = \delta_t + \delta_{ij}^{n} + \beta_1 \ln T_{it}^{n} + \beta_2 \ln T_{jt}^{n} + u_{ijt}^{n}, \;\; i, j = 1, \ldots, 50, \qquad (3)$$

where δ_t and δ_{ij}^{n} are year and state-region-sector fixed effects, and β_1 and β_2 are pass-through coefficients from tariffs to domestic prices. The coefficient β_1 measures how the changes in tariffs in a destination state affect the local prices, while β_2 measures how the changes in tariffs in an origin state affect the prices charged for sales to other states. Estimating (3) over 2002-2022, the coefficients (standard errors) obtained are $\hat{\beta}_1 = 0.50\ (0.31)$ and $\hat{\beta}_2 = 1.72\ (0.33)$. So one-half of the average tariff in a state is reflected in the local unit-value, while there is a magnified impact of the tariff in an origin state on the unit-value charged to the destinations. These estimates will be used to calculate how tariffs impact the prices for *intra-state* trade.

3. Welfare in each U.S. State

We now develop a general expression for the change in welfare for each U.S. state due to tariff changes, consisting of the change in consumer and producer welfare and tariff revenue. This state-level expression differs from the conventional *national* deadweight loss because we will assume that tariff revenue is distributed on a *per-capita basis* to each U.S. state. States

[9] Note that there are some states *i* where product *n* is sold locally or purchased from other states, but there are no foreign imports. In that case, $J_{it}^{n*} = \emptyset$ so T_{it}^{n} cannot be computed, but we would still like to include a value for this variable in the regression. In these cases we set T_{it}^{n} equal to the maximum value of $(1 + \tau_{jt}^{n})$ over all foreign countries *j*.

that have more local production of the protected industry will gain more than other regions from a tariff increase, since the produce surplus in that region grows more. A tariff will raise domestic production, which reduces *national* imports and tariff revenue for that reason, leading to an efficiency loss for the country. But at the *regional level,* states with greater domestic production can still gain despite this efficiency loss, as we will illustrate.

Consumer Surplus

In year t and for each sector, a U.S. state faces the R-dimensional price vector $\boldsymbol{p}_{it}^{n}$, consisting of the prices p_{ijt}^{n} from each source region $j = 1,\ldots,R$. In state i, *total expenditure* across all sectors to achieve utility of U_{it}

$$E_{it} = E_i[e_i^1(\boldsymbol{p}_{it}^1), \ldots, e_i^N(\boldsymbol{p}_{it}^N), U_{it}], \quad i = 1,\ldots,50.$$

Within the expenditure function E_i, we are assuming that the sectoral price vectors $\boldsymbol{p}_{it}^{n}$ can be aggregated into the sub-expenditure functions $e_i^n(\boldsymbol{p}_{it}^n)$, which act like *sectoral prices*. The derivative of the expenditure function with respect to a sectoral price equals the sectoral quantity Q_{it}^n, where $E_{it}^n \equiv Q_{it}^n e_i^n(\boldsymbol{p}_{it}^n)$ is the sectoral expenditure by state i in year t. We interpret sectoral expenditure E_{it}^n as *apparent consumption* in that sector-state-year, while total expenditure $E_{it} = \sum_n E_{it}^n$ is *total apparent consumption on tradable goods* in that state-year.

Suppose that the price vectors $\boldsymbol{p}_{it}^{n}$ change from period t-1 to t due to exogenous changes in tariffs and endogenous changes in the supply prices from each U.S. state. We do not allow for any endogenous changes in the foreign prices (net of the tariff), since we are treating the United States as a *small country* as discussed in section 2. The changes in tariffs and endogenous state prices will change the sectoral prices $e_i^n(\boldsymbol{p}_{it}^n)$, and the *compensating variation* is the change in total expenditure to obtain a *fixed* level of total utility U_{it-1}:

$$CV_{it} = \sum_{n=1}^{N} \int_{e_{it-1}^n}^{e_{it}^n} \frac{\partial E_i}{\partial \ln e_{i\tau}^n} d \ln e_{i\tau}^n = \sum_{n=1}^{N} \int_{e_{it-1}^n}^{e_{it}^n} E_{i\tau}^n \; d \ln e_{i\tau}^n ,$$

where the state-sectoral expenditure $E_{i\tau}^n$ depends on the arguments $(e_{i\tau}^1, \ldots, e_{i\tau}^N, U_{it-1})$ and the sectoral prices $e_{i\tau}^n = e_i^n(\boldsymbol{p}_{i\tau}^n)$, as $\boldsymbol{p}_{i\tau}^n$ varies from $\boldsymbol{p}_{it-1}^n$ to $\boldsymbol{p}_{it}^n$. CV_{it} is the change in expenditure that would be needed to compensate the consumer for the change in prices, holding utility fixed at U_{it-1}, or the *compensating variation*.

From the mean value theorem, the compensating variation is alternatively written as

$$CV_{it} = \sum_{n=1}^{N} \bar{E}_i^n \left(\ln e_{it}^n - \ln e_{it-1}^n\right),$$

for some average expenditure $\bar{E}_i^n$ between E_{it-1}^n and a hypothetical expenditure E_{it}^n allowing for period $t-1$ utility in period $t.$ We do not attempt to evaluate that hypothetical expenditure, and instead use observed expenditures in both periods and take their harmonic mean to obtain $\bar{E}_i^n$:

$$\bar{E}_i^n = \left[\frac{1}{2}\left(\frac{1}{E_{it}^n} + \frac{1}{E_{it-1}^n}\right)\right]^{-1}.$$

What we are calling CV_{it}, then, is a measure of the annual welfare change with mean expenditure in-between that of the two periods (we explain later why we use a harmonic mean), and not a true compensating variation.

We will be using a translog sectoral expenditure function, introduced in the next section, which means that the change in a sectoral price is a Tornqvist index of the change in prices $\ln p_{ijt}^n$ from the states and foreign countries $j = 51, \ldots, R$ selling to state *i*:

$$\ln e_{it}^n - \ln e_{it-1}^n = \tfrac{1}{2}\textstyle\sum_{j=1}^{R}(s_{ijt}^n + s_{ijt-1}^n)(\ln p_{ijt}^n - \ln p_{ijt-1}^n) \,. \qquad (4)$$

Substituting (4) into the above equations, we obtain CV_{it} as a Tornqvist index of prices changes induced by tariff changes, times the average level of expenditure in each sector $\bar{E}_i^n$:

$$CV_{it} = \sum_{n=1}^{N} \frac{\bar{E}_i^n}{2} \sum_{j=1}^{R} (s_{ijt}^n + s_{ijt-1}^n)(\ln p_{ijt}^n - \ln p_{ijt-1}^n).$$

Notice that in this formula we are allowing the change in shares from s_{ijt-1}^n to s_{ijt}^n to capture the impact of tariffs on expenditures from each state or foreign countries. In other words, we are using the observed expenditure shares to capture the reduction in consumption of imported goods, as reflected in the drop from q_0^{US} to q_1^{US} in Figure 1, for the United States as a whole. This expression summarizes the *change in consumer surplus* from a change in tariffs, or the area *a*+*b*+*c*+*d* in Figure 1, representing the change in consumer surplus with U.S. demand D^{US} and supply S^{US} and an *ad valorem* tariff of τ. In this diagram, the loss in consumer surplus is offset by the gains in produce surplus *a* plus tariff revenue of *c*, to result in a net loss due to the tariff of *b*+*d*. In the next section we will be more precise about the consumer surplus loss in our model by adopting a translog function form for the sectoral prices e_{it}^n. In the rest of this section we discuss producer surplus and the distribution of tariff revenue across states.

Producer Surplus

We assume that the production function in state *j* that produces in sector *n* is

$$y_{jt}^n = f_{jt}^n(L_{jt}^n, K_j^n),$$

where y_{jt}^n is output, L_{jt}^n is employment, and K_j^n is sector-specific capital that we assume does not change over the time period being considered. We also assume that the wage *w* for labor does not change, so our analysis is partial equilibrium in this sense. Further, we separate production for local use or sale to other U.S. states versus production for foreign export and assume that $f_{jt}^n(L_{jt}^n, K_j^n)$ applies only to *production for sale in the United States*. This assumption is made because we do not know in general how the U.S. tariffs will change the prices for U.S. goods

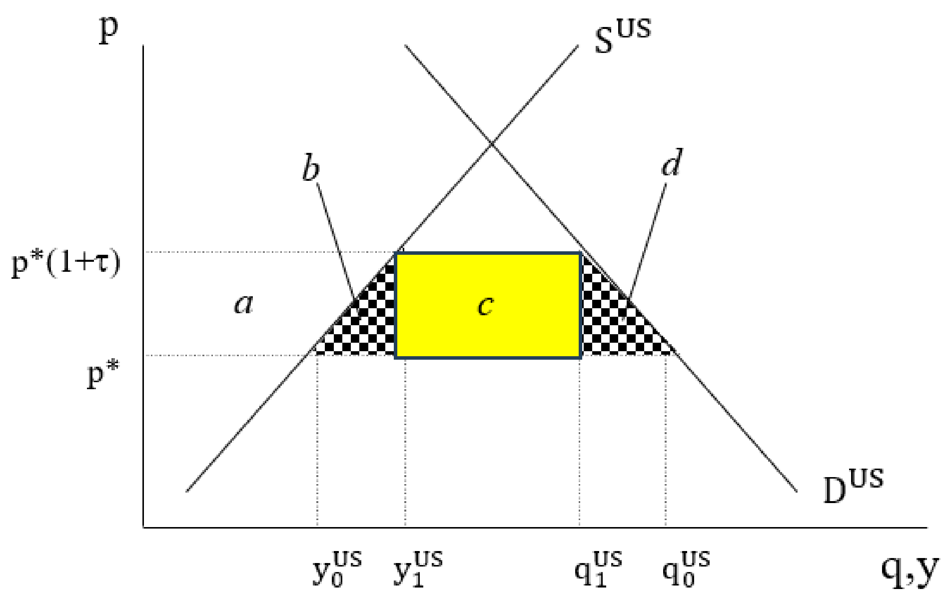


Figure 1: Tariffs in a Small Country

sold abroad (due to retaliation or general equilibrium effects). So our analysis is also partial equilibrium by ignoring the export market for U.S. firms.

We let y_{ijt}^n denote the output that state *j* sends to state *i*, so that total output sent to U.S. states is $y_{jt}^n = \sum_{i=1}^{50} y_{ijt}^n$. We assume iceberg trade costs, so $d_{ij}^n \geq 1$ units must be shipped from state *j* in order for one unit to arrive in state *i,* with $d_{ii}^n = 1$. Then for the competitive industry in state *j* to sell locally and to other states *i*, those prices must satisfy

$$p_{ijt}^n = d_{ij}^n p_{jjt}^n \text{ when } y_{ijt}^n, y_{jjt}^n > 0, \quad i, j = 1,\ldots,50.$$

When this arbitrage condition in holds, then firms in state *j* t are indifferent between selling locally or to state *i*: the prices earned (net of iceberg costs) will be the same. Using the arbitrage condition, we can express the profit maximization problem for the industry in state *j* by hypothetically supposing that all its output is sold locally at the price p_{jjt}^n:

$$\Pi_{jt}^n = \max_{L_{jt}^n \geq 0} \{p_{jjt}^n f_{jt}^n(L_{jt}^n, K_j^n) - w_{jt}^n L_{jt}^n\},$$

where $y_{jt}^n = f_{jt}^n(L_{jt}^n, K_j^n)$ is the sector *n* output of state *j* in year *t*.

This expression for profits is the return to the fixed factor in the industry, or producer surplus, which can be summed across sectors to obtain $\Pi_{jt} = \sum_{n=1}^{N} \Pi_{jt}^n$. The derivative of industry profits Π_{jt}^n with respect to the local price p_{jjt}^n equals total output y_{jt}^n, and the total *value* of production is $Y_{jt}^n = p_{jjt}^n y_{jt}^n$. We suppose that the local prices p_{jjt}^n change endogenously due to tariffs. Then the change in producer surplus is

$$\Delta\Pi_{jt} = \sum_{n=1}^{N} \int_{p_{jjt-1}^n}^{p_{jjt}^n} \frac{\partial \Pi_{jt}^n}{\partial \ln p_{jj\tau}^n} \partial \ln p_{jj\tau}^n = \sum_{n=1}^{N} \int_{p_{jjt-1}^n}^{p_{jjt}^n} Y_{j\tau}^n \ \partial \ln p_{jj\tau}^n \, .$$

From the mean value theorem, this expression is alternatively written as

$$\Delta\Pi_{jt} = \sum_{n=1}^{N} \bar{Y}_j^n \left(\ln p_{jjt}^n - \ln p_{jjt-1}^n\right). \tag{5}$$

where $\bar{Y}_i^n$ are average shipments evaluated at some local prices between p_{jjt-1}^n and p_{jjt}^n.

Expression (5) summarizes the *change in producer surplus* from a change in tariffs, like the area *a* in Figure 1, representing the change in producer surplus including sales to state *j* and exports to all other states. The price arbitrage condition ensures that prices to all purchasing states change by the same log amount:

$$\ln p_{ijt}^n - \ln p_{ijt-1}^n = \ln p_{jjt}^n - \ln p_{jjt-1}^n \text{ when } y_{ij\tau}^n, y_{jj\tau}^n > 0 \text{ for } \tau = t-1, t.$$

We let $I_j^n \subseteq \{1, \dots, 50\}$ denote the set of states *i* that state *j* sells to in *both periods*, and we assume that if this set is not empty then $j \in I_j^n$; i.e. if the state sells to any other state, then it sells to itself. It follows that for all $i \in I_j^n$ we can replace the price change $\left(\ln p_{jjt}^n - \ln p_{jjt-1}^n\right)$

in (5) with $\left(\ln p_{ijt}^{n} - \ln p_{ijt-1}^{n}\right)$. We show below how supply to each state is determined by demand conditions there, and we denote an average supply over periods $t-1$ and t by $\bar{Y}_{ij}^{n}$. These are summed to obtain $\bar{Y}_{j}^{n} = \sum_{i=1}^{50} \bar{Y}_{ij}^{n}$ which we use in (5).

This still leaves destination states $k \notin I_j^n$ that state *j* is supplying to in only one period: when it does not supply, the price must be below that implied by the arbitrage condition. Rather than use such a low price, we should instead use the *reservation price for producers, i.e. when they are just indifferent between supplying or not.* In this case, the change in price from the reservation price to that in the supplying period would still satisfy the arbitrage condition, so we calculate that price change as a simple average of the changes in other prices:

$$\overline{\Delta \ln p_{\circ j}^{n}} \equiv \sum_{i \in I_j^n} \frac{1}{R_j^n} \left(\Delta \ln p_{ijt}^{n}\right), \quad \text{for } j = 1,\ldots,50,$$

where R_j^n is the number of states in the set I_j^n and we use the "dot" notation to indicate which subscript is being summed over.[10] We use this expression to replace the price change in (5) whenever the destination state is $k \notin I_j^n$. This includes states *k* that state *j* does not sell to in both periods, so that $\bar{Y}_{kj}^{n} = 0$ and the price change multiplying $\bar{Y}_{kj}^{n}$ in (5) is irrelevant.

With these conventions, we rewrite producer surplus from (5) as

$$\Delta \Pi_{jt} = \sum_{n=1}^{N} \sum_{i \in I_j^n} \bar{Y}_{ij}^{n} \Delta \ln p_{ijt}^{n} + \sum_{n=1}^{N} \overline{\Delta \ln p_{\circ j}^{n}} \sum_{k \notin I_j^n} \bar{Y}_{ik}^{n}. \qquad (6)$$

Firms are indifferent about which state to supply to when the arbitrage condition holds, so the amount sent to each state is determined from demand conditions there:

[10] Note that this calculation of a reservation price fails when there is no state *i* that state *j* sells to in both periods, so that $I_j^n = \emptyset$. This outcome occurs, for example, when a state fully exits or enters a particular industry. We find that such exit occurs between 2002 and 2017 for some states in the coal industry, and less commonly in metallic ores. We do not attempt to impute the producer surplus loss in such cases.

$$Y_{ijt}^{n} = E_{it}^{n} s_{ijt}^{n} \text{ and } Y_{ijt-1}^{n} = E_{it-1}^{n} s_{ijt-1}^{n}.$$

As mentioned above, we will choose $\bar{E}_i^n$ as the harmonic mean of expenditure in the two periods. Further, suppose that we choose as $\bar{Y}_{ij}^n$ is a share-weighted harmonic mean of the outputs,

$$\bar{Y}_{ij}^{n} = \left[\frac{s_{ijt}^{n}}{\left(s_{ijt}^{n} + s_{ijt-1}^{n}\right)} \frac{1}{Y_{it}^{n}} + \frac{s_{ijt-1}^{n}}{\left(s_{ijt}^{n} + s_{ijt-1}^{n}\right)} \frac{1}{Y_{it-1}^{n}}\right]^{-1}.$$

Then it can be readily show that

$$\bar{Y}_{ij}^{n} = \frac{\bar{E}_i^n}{2} (s_{ijt}^{n} + s_{ijt-1}^{n})$$

In other words, the average value of output $\bar{Y}_{ij}^n$ sold from state *j* to state *i* is related to average expenditure $\bar{E}_i^n$ in that state by it by the average expenditure shares $\frac{1}{2}(s_{ijt}^{n} + s_{ijt-1}^{n})$ for purchases from state *j*. This sensible relationship simplifies our expressions and is why we choose harmonic means for $\bar{E}_i^n$ and $\bar{Y}_{ij}^n$.

Tariff Revenue

The government collects budget revenue from tariffs of B_t^n in sector *n* and total revenue of $B_t = \sum_{n=1}^{N} B_t^n$ when summed across sectors. We assume that this revenue is distributed to states on a per-capita basis, much like would occur if the tariff proceeds are spent on public goods. Then the overall change in welfare from a change in tariffs is

$$\Delta W_{it} = -CV_{it} + \Delta\Pi_{it} + \left(\frac{\bar{L}_i}{\bar{L}_{US}}\right) \Delta B_t, \tag{7}$$

where $\bar{L}_i$ is the average population of state *i* and $\bar{L}_{US} = \sum_{1=1}^{50} \bar{L}_i$ the average population of the United States over *t*-1 and *t*. Note that because the compensating variation CV_{it} is a consumer cost, we add a minus sign in (7) to convert it to the welfare impact.

With tariff-revenue is distributed on a per-capita basis to states (and not on the basis of the tariff revenue that is collected for imports into each state), there can be large differences across states in their gains or losses due to changes in tariffs. To illustrate this, let us assume for simplicity that all 50 states have the same population and demand, but differ in their supply. When there is an *ad valorem* import tariff of τ added, then a state with no production will face the consumer surplus loss that is 1/50 of the national loss, or (*a*+*b*+*c*+*d*)/50 in Figure 2(a). The state receives 1/50 of the national tariff revenue, or *c*/50, so its net less is the dark shaded area (*a*+*b*+*d*)/50, which exceeds 1/50 of the national loss *b*+*d*.

On the other hand, consider a state that under free trade would have supply just equal to demand, with $y_0 = q_0^{US}/50,$ but under the tariff its supply rises so that it begins to export to other states, $y_1 > q_1^{US}/50$ as shown in Figure 2(b). For this state, the loss in consumer surplus is still (*a*+*b*+*c*+*d*)/50 but that is covered the rise in producer surplus which *exceeds* the consumer loss by the area *e*, representing it's gain from selling to other states. This state, like all the others, still receives tariff revenue of *c*/50, so its net gain due to the tariff is *e* + *c*/50. States that export to other states at the free trade price would gain even more from the tariff. This simple graphical exercise shows that the per-capita distribution of tariff revenue makes a profound difference to the state-level gains and losses when states also differ in their productive capacity.

As a further exercise (not illustrated), suppose that the state shown in Figure 2(b) has a more elastic supply curve, with supply still equal to demand at the free trade price. Then the area e would expand and *ceteris paribus* the state would gain more. But other things are not constant, because the more elastic state supply would lead to a more elastic national supply curve S^{us} and would therefore reduce imports and national tariff revenue. That would reduce the revenue *c*/50 sent to each state. In can be reasoned that the state with more elastic supply would still gain, but the more elastic supply response there would be imposing a *pecuniary externality* on the other states by reducing their 1/50 share of national tariff revenue.

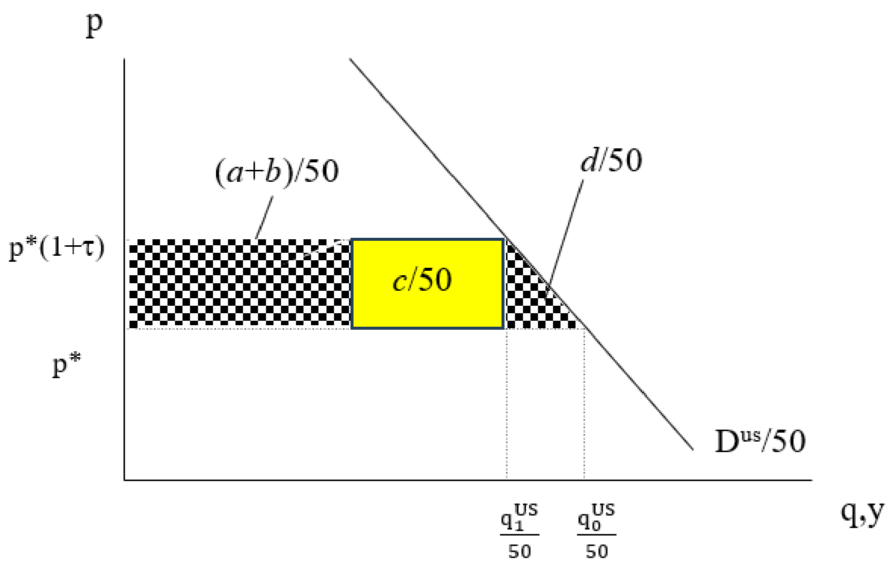


Figure 2(a): Tariffs in States with No Production

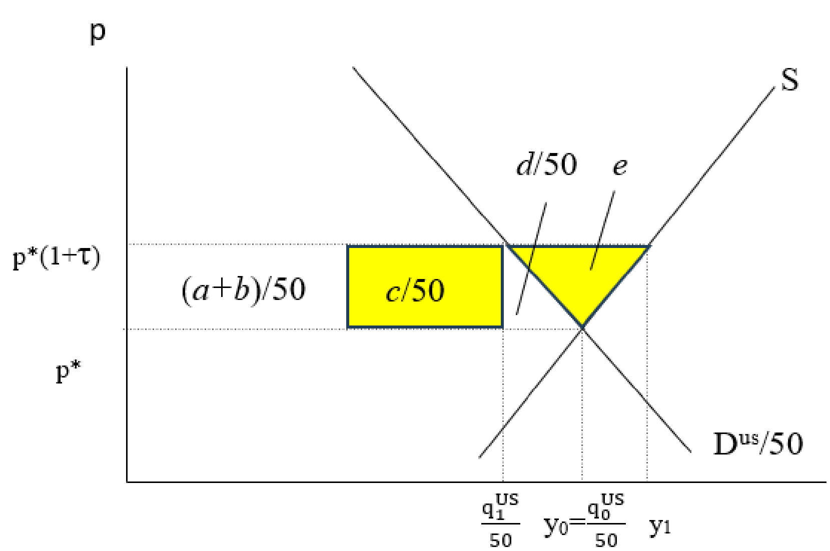


Figure 2(b): Tariffs in States with Production

4. Translog Sectoral Prices and Trade Between Regions

For the sectoral prices $e_{it}^n = e_i^n(\boldsymbol{p}_{it}^n)$, we use a translog function (Diewert, 1976, p. 139) which is defined over the prices that U.S. state *i* pays for purchases locally and from all other states and foreign countries. Then the translog sectoral price is

$$\ln e_{it}^n = \alpha_0^n + \sum_{j=1}^R \alpha_{ij}^n \ln p_{ijt}^n + \frac{1}{2}\sum_{j=1}^R \sum_{k=1}^R \gamma_{jk}^n \ln p_{ijt}^n \ln p_{ikt}^n, \text{ with } \gamma_{jk}^n = \gamma_{kj}^n, \quad (8)$$

where p_{ijt}^n denote the price paid in state *i* to purchase the good from region *j* in year *t.* We allow the parameters α_{ij}^n to differ according to the state, as some states will have greater demand for certain products (e.g. more steel purchased in Michigan). For simplicity we have assumed that the substitution parameters γ_{jk}^n are the same across states *i,* however. To ensure that the expenditure function is homogenous of degree one, we add the restrictions that:

$$\sum_{j=1}^R \alpha_{ij}^n = 1 \quad \text{and} \quad \sum_{j=1}^R \alpha_{ik}^n = 0, \; k \neq j.$$

We further require that all goods enter "symmetrically" into the parameters γ_{jk}^n by imposing the restrictions that:

$$\gamma_{jj}^n = -\frac{\gamma^n(R-1)}{R} < 0, \quad \gamma_{jk}^n = \frac{\gamma^n}{R} > 0 \;, \text{ for } j \neq k \text{ with } j, k = 1,\ldots,R. \quad (9)$$

It is readily confirmed that the restrictions in (9) satisfy $\sum_{k=1}^R \gamma_{jk}^n = 0$.

The share of its expenditure that state *i* purchases from region *j*, or s_{ijt}^n, is computed by differentiating (8) with respect to $\ln p_{ijt}^n$ and using the symmetry restrictions in (9):

$$s_{ijt}^n = \alpha_{ij}^n - \gamma^n\left(\ln p_{ijt}^n - \overline{\ln P_{it}^n}\right), \quad \text{with} \quad \overline{\ln P_{it}^n} \equiv \sum_{j=1}^R \frac{1}{R} \ln p_{ijt}^n. \quad (10)$$

Notice that the term $\overline{\ln P_{it}}$ refers to the average over the prices from *all source regions* in period *t*, including countries that are not selling to region *i*, in which case the appropriate price to use in the expenditure function is the *reservation price*, where demand is zero We can solve for the reservation price of the countries not selling by setting the share equation in (10) equal to zero. Specifically, for each U.S. state *i,* if it does not purchase from region *j* then $s_{ijt}^{n} = 0$ and we solve for that reservation prices from (10) as.

$$\ln p_{ijt}^{n} = \frac{\alpha_{ij}^{n}}{\gamma^{n}} - \overline{\ln P_{it}^{n}}, \text{ when } s_{ijt}^{n} = 0. \quad (11)$$

For clarity, we define $J_{it}^{n} \subseteq \{1, \dots, R\}$ as the domestic states plus foreign countries that sell to the U.S. state *i* in year *t*. Then the reservation prices in (11) apply for all regions $j \notin J_{it}^{n}$. We also need to eliminate the reservation prices within the overall average $\overline{\ln P_{it}^{n}}$, however. That is done by writing this average using (11) as

$$\overline{\ln P_{it}^{n}} \equiv \sum_{j=1}^{R} \frac{1}{R} \ln p_{ijt}^{n} = \frac{1}{R}\left[\sum_{j \in J_{it}^{n}} \ln p_{ijt}^{n} + \sum_{j \notin J_{it}^{n}} \left(\frac{\alpha_{ij}^{n}}{\gamma^{n}} + \overline{\ln P_{it}^{n}}\right)\right].$$

Denote the number of regions included in $J_{it}^{n} \subseteq \{1, \dots, R\}$ by $R_{it}^{n} = R - \sum_{j \notin J_{it}^{n}} 1$. Then multiplying both sides of the above equation by R and combining terms involving $\overline{\ln P_{it}^{n}}$, we can readily solve for $\overline{\ln P_{it}^{n}}$ as:

$$\overline{\ln P_{it}^{n}} = \frac{1}{R_{it}^{n}}\left(\sum_{j \in J_{it}^{n}} \ln p_{ijt}^{n} + \sum_{j \notin J_{it}^{n}} \frac{\alpha_{ij}^{n}}{\gamma^{n}}\right) = \overline{\ln p_{\iota \circ t}^{n}} + \frac{\overline{\alpha_{\iota t}^{n}}}{\gamma^{n}},$$

where: $\overline{\ln p_{\iota \circ t}^{n}} \equiv \frac{1}{R_{it}^{n}} \sum_{j \in J_{it}^{n}} \ln p_{ijt}^{n}$, and $\bar{\alpha}_{it}^{n} \equiv \frac{1}{R_{it}^{n}} \sum_{j \notin J_{it}^{n}} \alpha_{ij}^{n} = \frac{1}{R_{it}^{n}}\left(1 - \sum_{j \in J_{it}^{n}} \alpha_{ij}^{n}\right)$.

Notice that $\overline{\ln p_{\iota \circ t}^{n}}$ defined above, as distinct from $\overline{\ln P_{it}^{n}}$, is the average of log prices over the countries *actually selling* to region *i*. The expression $\bar{\alpha}_{it}^{n}$ is inversely related to the range of selling countries: as the set J_{it} expands, then the summation $\sum_{j \in J_{it}^{n}} \alpha_{ij}^{n}$ rises and R_{it} also rises, so that $\overline{\alpha_{\iota t}^{n}}$ falls for both reasons. We can substitute these two terms back into the share equation (10) to obtain:

$$s_{ijt}^{n} = \alpha_{ij}^{n} + \bar{\alpha}_{it}^{n} - \gamma^{n}(\ln p_{ijt}^{n} - \overline{\ln p_{\iota \circ t}^{n}}). \quad (12)$$

In order to obtain the sector parameters γ^n, we follow the approach of Feenstra and Weinstein (2017). We add an error term to the share equation:

$$s_{ijt}^n = \alpha_{ij}^n + \bar{\alpha}_{it}^n - \gamma^n\left(\ln p_{ijt}^n - \overline{\ln p_{\iota\circ t}^n}\right) + \varepsilon_{ijt}^n, \text{ with } j \in J_{it}^n. \tag{13}$$

Differencing this equation over time and with respect to a benchmark country *k*, we obtain:

$$\Delta s_{ijt}^n - \Delta s_{ikt}^n = -\gamma^n\left(\Delta \ln p_{ijt}^n - \Delta \ln p_{ikt}^n\right) + \Delta\varepsilon_{ijt}^n - \Delta\varepsilon_{ikt}^n. \tag{14}$$

This demand equation is combined with a supply equation from each region to each state, and as in Feenstra (1994) and Feenstra and Weinstein (2017), the identifying assumption is that the errors in demand and supply are uncorrelated. The prices from each region are measured by their unit-values. In Appendix B we outline this procedure to estimate the sector parameters γ^n.

5. Consumer Costs of Tariffs in each U.S. State

For the translog sectoral price e_{it}^n in (8), it is well-known (Diewert, 1976) that the ratio of these translog functions can be measured by the Tornqvist index as shown in (4). When a good is not sold from a location *j* to state *i* in year *t*, then the price p_{ijt} appearing in (4) equals the reservation price*,* while the share s_{ijt}^n equals zero. We have already defined the regions $j \in J_{it}^n$ as the states and foreign countries *j* selling to state *i* in year *t*, and likewise for the regions $j \in J_{it-1}^n$ in year $t - 1$. Let us denote the set of regions selling to state *i* in *both years* – or the "common set" – as $J_i^n \equiv J_{it}^n \cap J_{it-1}^n$, and denote the number of these regions by R_i^n. We can solve for the prices of goods from all regions $j \notin J_i^n$ that that are not in the common set by inverting the share equation (12):

$$\ln p_{ijt}^n = \frac{1}{\gamma^n}\left(\alpha_{ij}^n + \bar{\alpha}_{it}^n - s_{ijt}^n\right) + \overline{\ln p_{\iota\circ t}^n}, \quad j \notin J_i^n. \tag{15}$$

We can substitute this solution for price back into the Tornqvist index (4) to obtain an expression for the change in the sectoral price in each sector:

$$\Delta\ln e_{it}^{n} = \ln e_{it}^{n} - \ln e_{it-1}^{n}$$

$$= \sum_{j\in J_i^n} \frac{1}{2}(s_{ijt}^{n} + s_{ijt-1}^{n})(\ln p_{ijt}^{n} - \ln p_{ijt-1}^{n}) + \sum_{j\notin J_i^n} \frac{1}{2}(s_{ijt}^{n} + s_{ijt-1}^{n})(\ln p_{ijt}^{n} - \ln p_{ijt-1}^{n})$$

$$= \sum_{j\in J_i^n} \frac{1}{2}(s_{ijt}^{n} + s_{ijt-1}^{n})(\ln p_{ijt}^{n} - \ln p_{ijt-1}^{n})$$

$$+ \sum_{j\notin J_i^n} \frac{1}{2}\left(s_{ijt}^{n} + s_{ijt-1}^{n}\right)\left[\frac{1}{\gamma^n}\left(\bar{\alpha}_{it}^{n} - s_{ijt}^{n}\right) + \overline{\ln p_{\iota\circ t}^{n}} - \frac{1}{\gamma^n}\left(\bar{\alpha}_{it-1}^{n} - s_{ijt-1}^{n}\right) - \overline{\ln p_{\iota\circ t-1}^{n}}\right]. \quad (16)$$

For welfare analysis, we need to infer the changes in these prices – which are measured by unit-values in the FAF dataset – that are *caused by* changes in tariffs. These regressions we run in section 2. We are only interested in the component of prices changes that are caused by the tariffs, so ignoring the fixed effects, the prices for $j \in J_i^n$ used in (16) are measured by

$$\Delta \ln \hat{p}_{ijt}^{n} = \hat{\beta}_1 \Delta \ln T_{it}^{n} + \hat{\beta}_2 \Delta \ln T_{jt}^{n} \quad \text{for } j \in J_i^n,\ i, j = 1, \ldots, 50, \quad (17)$$

$$\Delta\ln \hat{p}_{ijt}^{n} = \Delta\ln(1 + \tau_{jt}^{n}) \quad \text{for } j \in J_i^n,\ i = 1, \ldots, 50,\ j = 51, \ldots, 58. \quad (18)$$

where we use the estimated coefficients $\hat{\beta}_1 = 0.50$ and $\hat{\beta}_2 = 1.72$ in (17), and we treat the United States as a small country in (18) by using unity as the pass-through from change in tariffs to changes in the import prices.

We also need to solve for the terms in (16) involving the change in $\bar{\alpha}_{it}^{n}$. Differencing the terms in (13) and then averaging over the common regions J_i^n we obtain:

$$\frac{\Delta\bar{\alpha}_{it}^{n}}{\gamma^n} + \Delta\,\overline{\ln p_{\iota\circ t}^{n}} = \sum_{j\in J_i^n} \frac{1}{R_i^n}\left(\frac{\Delta s_{ijt}^{n}}{\gamma^n} + \Delta \ln p_{ijt}^{n}\right) - \sum_{j\in J_i^n} \frac{1}{\gamma^n R_i^n}\left(\Delta\varepsilon_{ijt}^{n}\right).$$

We will assume that the final term above – the average of the errors – equals zero in expected value, so we impose that the average is zero in the above equation to estimate $\Delta\bar{\alpha}_{it}^{n}$. We replace $\Delta \ln p_{ijt}^{n}$ above with the predicted price changes $\Delta\ln \hat{p}_{ijt}^{n}$ from (17), and we define the simple average (over the common regions) of the change in the predicted prices and shares as[11]

$$\overline{\Delta\ln \hat{p}_{i\circ}^{n}} = \sum_{j\in J_i^n} \frac{1}{R_i^n}\left(\Delta\ln \hat{p}_{ijt}^{n}\right) \text{ and } \overline{\Delta s_{it}^{n}} = \sum_{j\in J_i^n} \frac{1}{R_i^n}\left(\Delta s_{ijt}^{n}\right). \tag{19}$$

Substituting the above equations back into (16), we arrive at the expression for the sectoral price change that we shall measure:

$$\Delta\ln e_{it}^{n} = -V_{it}^{n} + \sum_{j\in J_i^n} \tfrac{1}{2}(s_{ijt}^{n} + s_{ijt-1}^{n})\,\Delta\ln \hat{p}_{ijt}^{n} + \overline{\Delta\ln \hat{p}_{i\circ}^{n}} \sum_{k\notin J_i^n} \tfrac{1}{2}(s_{ikt}^{n}+s_{ikt-1}^{n}) \tag{20}$$

where

$$V_{it}^{n} \equiv \frac{1}{2\gamma^n}\sum_{k\notin J_i^n}[(s_{ikt}^{n})^2 - (s_{ikt-1}^{n})^2] - \left(\frac{\overline{\Delta s_{it}^{n}}}{\gamma^n}\right)\sum_{k\notin J_i^n} \tfrac{1}{2}(s_{ikt}^{n}+s_{ikt-1}^{n}). \tag{21}$$

The term V_{it}^{n} reflects product variety and will be discussed below. The second term on the right of (20) is a Tornqvist index defined over all domestic and import prices for the common set of regions. This term reflects the consumer cost of the tariff: it is the change in consumer surplus as captured by the area *a*+*b*+*c*+*d* in Figure 1. The third term captures an average price change for regions selling in only one period, which appears because that average price change is a component of the reservation price change in (15).

Turning to the variety term, the first expression on the right of (21) introduces the

[11] Note that there is a subtle difference in notation between $\Delta \overline{\ln p_{i\circ t}^{n}}$ and $\overline{\Delta\ln \hat{p}_{i\circ}^{n}}$. The former is defined as the difference in the average prices, where the average is over the sets J_{it}^{n} of all supplying regions in each period; whereas the latter is defined as the difference in predicted prices, where now the average is over the common set $j \in J_i^n$ of selling regions in both periods. The latter should be distinguished from $\overline{\Delta\ln p_{\circ j}^{n}}$, which is the average price change over states $i \in I_j^n$ buying from j in both periods.

squared shares coming new or disappearing regions selling to state i: $\sum_{k\notin J_i^n}(s_{ikt}^n)^2$ is the Herfindahl index of the shares of the selling states. If sales are more concentrated among fewer selling states, then the Herfindahl index rises and the cost of living falls, indicating a welfare gain. Feenstra and Weinstein (2017) argue that a Herfindahl index of the shares arises under translog preference due to "crowding" in product space. Unlike in the CES case, where the elasticity of substitution between products does not change, under translog the elasticity of demand and substitution increases as more product varieties are added. This result is seen by computing the elasticity of import demand by differentiating the log share in (12), $s_{ijt}^n = p_{ijt}^n q_{ijt}^n / E_{it}^n$, with respect to its price (holding $\overline{\ln p_{\iota\circ t}^n}$ and sectoral expenditure E_{it}^n fixed for simplicity):

$$\frac{d\ln s_{ijt}^n}{d\ln p_{ijt}^n} = 1 + \frac{d\ln q_{ijt}^n}{d\ln p_{ijt}^n} = -\frac{\gamma^n}{s_{ijt}^n} \Rightarrow \eta_{ijt}^n \equiv -\frac{d\ln q_{ijt}^n}{d\ln p_{ijt}^n} = \left(1 + \frac{\gamma^n}{s_{ijt}^n}\right). \qquad (22)$$

We see that as the number of regions supplying to state i rises, so that the shares s_{ijt}^n fall, then the demand elasticity in absolute value – or η_{ijt}^n – also rises, which indicates greater substitution between goods. For this reason, when more regions sell to a state and the Herfindahl index of shares falls, then there is a loss in welfare due to "crowding" in product space.

The fact that translog preference incorporate "crowding" offsets but does not eliminate the gains from variety. These gains come when more regions sell to a state and are captured by the second expression on the right of (21). To understand this term, suppose that the number of regions that a state purchases from rises. That would lead to a fall in shares from those regions already selling in period $t-1$, so that $\overline{\Delta s_{it}^n} = \sum_{j\in J_i^n} \frac{1}{R_i^n}\left(\Delta s_{ijt}^n\right) < 0$. In that case the second term subtracted in (21) is negative, contributing to $V_{it}^n > 0$ and a reduction in sectoral prices in (20), which is a welfare gain. This gain is due to increased variety, i.e. importing new varieties from new state or new foreign countries. Notice that by using the elasticities in (22), this second term can be rewritten as

$$\left(\frac{\overline{\Delta s_{it}^n}}{\gamma^n}\right)\sum_{k\notin J_i^n}\tfrac{1}{2}(s_{ikt}^n+s_{ikt-1}^n)=\frac{\overline{\Delta s_{it}^n}}{2}\left[\frac{1}{(\eta_{ikt}^n-1)}+\frac{1}{(\eta_{ikt-1}^n-1)}\right].$$

This expression is quite similar to the welfare effect of variety change in the CES case from Feenstra (1994), except that in the CES case the demand elasticity is constant.

6. Total Change in Welfare

Our analysis in the last section has focused on the change in the sectoral price e_{ijt}^n in each sector. We now use the results from section 2 to sum across industries and obtain the change in consumer welfare, producer surplus, and overall state welfare when we also add tariff revenue, which is distributed on a per-capita basis to the U.S. states.

Recall that $J_{it}^{*n}\subseteq\{51,\ldots,R\}$ is the set of *foreign regions* selling to state i in sector n in year t, and let $J_i^{*n}\equiv J_{it-1}^{*n}\cap J_{it-1}^{*n}$ denote the *foreign regions selling in both* $t-1$ and t. The *states* selling in both years are then $J_i^n\backslash J_i^{*n}$. We substitute (20) into $CV_{it}=\sum_{n=1}^{N}\bar{E}_i^n\,\Delta\ln e_{it}^n$ to obtain the compensating variation by state:

$$CV_{it}=-V_{it}+CV_{it}^M+CV_{it}^D+\sum_{n=1}^{N}\overline{\Delta\ln\hat{p}_{i\circ}^n}\sum_{j\notin J_i^n}\frac{\bar{E}_i^n}{2}(s_{ijt}^n+s_{ijt-1}^n),\qquad(23)$$

with:

$$V_{it}=\sum_{n=1}^{N}\bar{E}_i^n\,V_{it}^n,$$

$$CV_{it}^M=\sum_{n=1}^{N}\bar{E}_i^n\sum_{j\in J_i^{*n}}\tfrac{1}{2}(s_{ijt}^n+s_{ijt-1}^n)\,\Delta\ln\hat{p}_{ijt}^n,$$

$$CV_{it}^D=\sum_{n=1}^{N}\bar{E}_i^n\sum_{j\in J_i^n\backslash J_i^{*n}}\tfrac{1}{2}(s_{ijt}^n+s_{ijt-1}^n)\,\Delta\ln\hat{p}_{ijt}^n.$$

Notice that we are separating the Tornqvist index of price changes into those arising from changing import tariffs, CV_{it}^{M}, and those arising from the induced change in domestic unit-values from FAF data, CV_{it}^{D}. The import term can be measured with greater accuracy by using the HS6 trade values by foreign country and associated tariffs. Specifically, rather than relying on the FAF data for imports by sector and foreign regions, we will instead measure

$$CV_{it}^{M} = \bar{M}_i \sum_{(h,c)\in H_i^n} \tfrac{1}{2}(s_{ict}^{h} + s_{ict-1}^{h})\,\Delta\ln(1+\tau_{ct}^{h}), \tag{24}$$

where $\bar{M}_i = \left[\frac{1}{2}\left(\frac{1}{M_{it}} + \frac{1}{M_{it-1}}\right)\right]^{-1}$ is the harmonic mean of state *i* total imports over $t-1$ and t, H_i^n are the common HS6-country codes between $t-1$ and t, and $s_{ict}^{h} = M_{ict}^{h}/M_{it}$ is the share of total imports coming from the HS6-country pair (h,c) in year *t*.

For producer surplus, we use (6) and $\bar{Y}_{ij}^{n} = \frac{\bar{E}_i^n}{2}(s_{ijt}^{n} + s_{ijt-1}^{n})$, along with the predicted price changes replacing actual price changes as in (17), to obtain:

$$\Delta\Pi_{jt} = \underbrace{\sum_{n=1}^{N}\sum_{i\in I_j^n}\frac{\bar{E}_i^n}{2}(s_{ijt}^{n} + s_{ijt-1}^{n})\Delta\ln\hat{p}_{ijt}^{n}}_{\Delta PS_{jt}^{D}} + \sum_{n=1}^{N}\overline{\Delta\ln\hat{p}_{\circ j}^{n}}\sum_{k\notin I_j^n}\frac{\bar{E}_k^n}{2}(s_{kjt}^{n} + s_{kjt-1}^{n}), \tag{25}$$

where as defined earlier, $\overline{\Delta\ln\hat{p}_{\circ j}^{n}} \equiv \sum_{i\in I_j^n}\frac{1}{R_j^n}\left(\Delta\ln\hat{p}_{ijt}^{n}\right)$ reflects average price changes for sellers from state *j*. This expression is incorporated into the second term on the right of (25), multiplied by the shares for states k that state j sells to in only one period. These shares are small, so producer surplus primarily reflects ΔPS_{jt}^{D} defined above, which is the average change in unit-values on domestic shipments arising from tariff changes.

State welfare is $\Delta\Pi_{jt} - CV_{it} + (\bar{L}_i/\bar{L}_{US})\Delta B_t$, which includes the per-capita share of tariff revenue. Summing across states to obtain national welfare, the term $\sum_{i=1}^{50}\Delta PS_i^{D}$ will cancel with

$-\sum_{i=1}^{50} CV_i^D$, because the producer surplus gain from selling in one state at higher prices is a consumer surplus loss to that state. The change in national welfare is then

$$\Delta W_t = \Delta B_t - \sum_{i=1}^{50} CV_{it}^M + \sum_{i=1}^{50} V_{it} \tag{26}$$

$$- \sum_{n=1}^{N} \sum_{i=1}^{50} \left[\overline{\Delta \ln \hat{p}_{i\circ}^n} \sum_{j \notin J_i^n} \frac{\bar{E}_i^n}{2} (s_{ijt}^n + s_{ijt-1}^n) - \overline{\Delta \ln \hat{p}_{\circ i}^n} \sum_{k \notin I_j^n} \frac{\bar{E}_k^n}{2} (s_{kit}^n + s_{kit-1}^n) \right].$$

The final term above in brackets depends on differences between the average change in the prices for buyers and sellers, but only within FAF sectors that do not have purchases or sales in both periods. This term is small in practice, so the change in national welfare primarily reflects three terms: the change in tariff revenue, minus CV_{it}^M summed across states to obtain the familiar triangle *b*+*d* in Figure 1, and the variety term V_{it} summed across states.

The variety term reflects the entry and exit of foreign exporting countries. If the United States enters into a free trade agreement (FTA) with a foreign country, for example, we might expect that it begins to export some new products to the United States: this would be an example of Viner's "trade creation" if the product had previously been produced in the United States, or "trade diversion" if the product had previously been exported by another (lower cost) foreign country. In the former case, there is a new foreign country *j* with $s_{ijt}^n > 0$ and $s_{ijt-1}^n = 0$, then V_{it}^n in (21) is positive provided that $\overline{\Delta s_{it}^n} < 0$, meaning that expenditure is reduced on the regions selling to state *i* in both periods.

On the other hand, in the "trade diversion" case there the new foreign country *j* replaces another foreign country *k* (not in the FTA) that formerly exported that product to the United States. Suppose that the share of the new exporter equals that of the disappearing foreign country

k, so $s^n_{ijt} = s^n_{ikt-1} > 0$ with $s^n_{ijt-1} = s^n_{ikt} = 0$. In this case the first term on the right of (21) is zero when summed over countries j and k, and the second term is also zero if there is no change in expenditure on other countries so that $\overline{\Delta s^n_{\iota t}} = 0$. It follows that (21) is zero and there will be welfare loss from switching from a country outside to inside the FTA because of the drop in tariff revenue. To summarize, the term V^n_{it} combined with tariff revenue neatly captures the trade creation and trade diversion effects of Viner.

Estimating Tariff Revenue

Our final task is to estimate the change in tariff ΔB_t that occurs from the change in tariffs, and not because of growth in the economy or any other changes that can influence the data for tariff revenue. To achieve this, we treat state-sector expenditure as constant at $\bar{E}^n_i$. We will also use the change in shares $\Delta \hat{s}^n_{ijt}$ that are predicted from the import share equation. Because these shares are measured at tariff-inclusive prices, the predicted net-of-duty customs value of imports into state *i* from foreign region *j* is $\widehat{M}^n_{ijt} \equiv \bar{E}^n_i \hat{s}^n_{ijt}/(1 + \tau 2^n_{jt})$. It follows that the change in national tariff revenue when using these predicted imports is

$$\Delta \hat{B}_t = \sum_{n=1}^{N} \sum_{i=1}^{50} \sum_{j=51}^{58} \Delta\left(\tau 2^n_{jt} \widehat{M}^n_{ijt}\right) = \sum_{n=1}^{N} \sum_{i=1}^{50} \sum_{j=51}^{58} \bar{E}^n_i \Delta\left(\tau 2^n_{jt} \hat{s}^n_{ijt}/(1 + \tau 2^n_{jt})\right). \qquad (27)$$

To obtain the predicted shares, we re-derive the import share equation as in (13) but use only the observations $j \in J^n_i$ that are available in both periods $t-1$ and t, to obtain:

$$\hat{s}^n_{ijt} = \hat{\alpha}^n_{ij} + \overline{\hat{\alpha}^n_{\iota}} - \hat{\gamma}^n\left(\ln \hat{p}^n_{ijt} - \overline{\ln \hat{p}^n_{\iota \circ t}}\right), \text{ with } j \in J^n_i, \qquad (28)$$

where $\overline{\hat{\alpha}^n_{\iota}} = \frac{1}{R^n_i} \sum_{j \notin J^n_i} \hat{\alpha}^n_{ij}$ and $\overline{\ln \hat{p}^n_{\iota \circ t}} = \frac{1}{R^n_i} \sum_{j \in J^n_i} \ln \hat{p}^n_{ij}$. We have not yet estimated the taste parameters $\hat{\alpha}^n_{ij}$, but we can choose these so that $\frac{1}{2}\left(\hat{s}^n_{ijt} + \hat{s}^n_{ijt-1}\right) = \frac{1}{2}\left(s^n_{ijt} + s^n_{ijt-1}\right)$. Also,

$\Delta\hat{s}_{ijt}^{n} = -\hat{\gamma}^{n}\left(\Delta \ln \hat{p}_{ijt}^{n} - \overline{\Delta \ln \hat{p}_{\iota\circ t}^{n}}\right)$ from (28). Then we use the identity $\Delta(x_t y_t) \equiv$ $(\Delta x_t)\frac{1}{2}(y_{t-1} + y_t) + \frac{1}{2}(x_{t-1} + x_t)\Delta y_t$ to write:

$$\Delta\left(\tau 2_{jt}^{n}\hat{s}_{ijt}^{n}/(1+\tau 2_{jt}^{n})\right) \equiv \left(\Delta\frac{\tau 2_{jt}^{n}}{1+\tau 2_{jt}^{n}}\right)\frac{1}{2}(s_{ijt}^{n} + s_{ijt-1}^{n}) + \frac{1}{2}\left(\frac{\tau 2_{jt-1}^{n}}{1+\tau 2_{jt-1}^{n}} + \frac{\tau 2_{jt}^{n}}{1+\tau 2_{jt}^{n}}\right)\Delta\hat{s}_{ijt}^{n}$$
$$= \left(\Delta\frac{\tau 2_{jt}^{n}}{1+\tau 2_{jt}^{n}}\right)\frac{1}{2}(s_{ijt}^{n} + s_{ijt-1}^{n}) - \frac{1}{2}\left(\frac{\tau 2_{jt-1}^{n}}{1+\tau 2_{jt-1}^{n}} + \frac{\tau 2_{jt}^{n}}{1+\tau 2_{jt}^{n}}\right)\hat{\gamma}^{n}\left(\Delta\ln \hat{p}_{ijt}^{n} - \overline{\Delta\ln \hat{p}_{\iota\circ}^{n}}\right),$$

where the predicted change in import price $\Delta\ln \hat{p}_{ijt}^{n}$ is obtained from the tariff change as in (18), while $\overline{\Delta\ln \hat{p}_{\iota\circ}^{n}}$ uses the predicted import and domestic price changes as in (19).[12] It is convenient to divide out $(s_{ijt}^{n} + s_{ijt-1}^{n})$ on the right and rewrite this expression using the estimated import elasticities:

$$\Delta\left(\tau 2_{jt}^{n}\hat{s}_{ijt}^{n}/(1+\tau 2_{jt}^{n})\right) = \frac{1}{2}(s_{ijt}^{n} + s_{ijt-1}^{n})$$
$$\times\left[\left(\Delta\frac{\tau 2_{jt}^{n}}{1+\tau 2_{jt}^{n}}\right) - \frac{1}{2}\left(\frac{\tau 2_{jt-1}^{n}}{1+\tau 2_{jt-1}^{n}} + \frac{\tau 2_{jt}^{n}}{1+\tau 2_{jt}^{n}}\right)\left\{\frac{1}{2}\left[\frac{1}{(\hat{\eta}_{ikt}^{n}-1)} + \frac{1}{(\hat{\eta}_{ikt-1}^{n}-1)}\right]\right\}^{-1}\left(\Delta\ln \hat{p}_{ijt}^{n} - \overline{\Delta\ln \hat{p}_{\iota\circ}^{n}}\right)\right]. \quad (29)$$

The expression in curly brackets $\{\ldots\}^{-1}$ in (29) is the harmonic mean of the sector import elasticities (minus one) over the two periods. As these elasticities rise, there is more substitution away from imports as tariffs increase. The import elasticities in (22) depend on their shares, and as we discuss in the next section, the elasticities range from a minimum of about 1.1 up to very large values as the shares go towards zero. We have experimented with using a lower-bound for the import elasticities in (29), such as 2, 3, 4, 5, and we find that the rise in tariff revenue as

[12] Our derivation has assumed that $j \in J_i^n$ so that the foreign country is selling in both periods $t-1$ and t. When that is not the case, we do not attempt to predict the import share but use the observed $s_{ijt-1}^{n} > 0$ or $s_{ijt}^{n} > 0$ to compute tariff revenue, with the share in the other period equal to zero. In addition, for the eight sectors where the estimate of γ^n was the upper bound of 5 from the grid search, we simply use the observed shares in both periods.

tariffs increase is reduced by only a small amount. A greater impact on tariff revenue occurs when alternative tariffs are used to compute the final term in (29), i.e. to compute the rise in prices $\Delta \ln \hat{p}_{ijt}^{n} = \Delta \ln(1 + \tau_j^n)$ from each region j, depending on whether we use applied or statutory tariffs for τ_j^n. We will find that the greater rise in statutory tariffs leads to much more substitution away from those imports and a smaller increase in tariff revenue.

7. Estimation Results

Translog Parameters and Elasticities

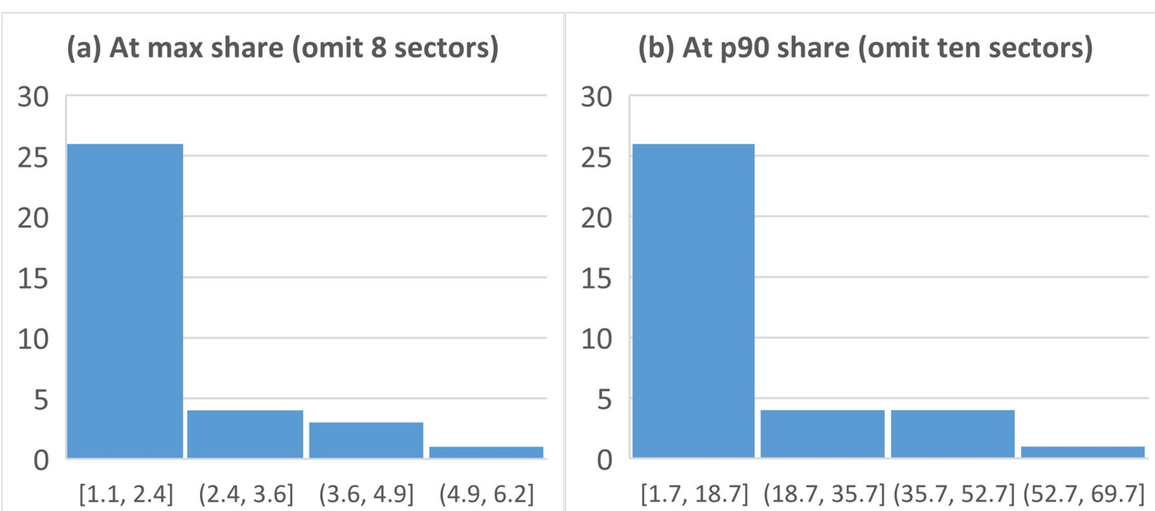
The translog expenditure function is estimated separately for the 42 sectors, using the method of Feenstra and Weinstein (2017). The cross-sectional variation in expenditure shares and unit-values comes from the 58 regions available in the FAF dataset, and the time-series variation comes from taking difference over the periods 2002-2007, 2007-2012, and 2012-2017, and then one-year differences from 2017-2022. Recall that the FAF dataset has a number of sectors that are homogeneous products, and that showed up in the initial estimation results, where 17 sectors did not converge to a value for γ^n. In these cases, we implement a grid-search to obtain the minimum sum of squared residuals, considering values of γ^n in the interval (0,5] at increments of 0.01. Of the 17 non-converged sectors, 3 sectors arrive at intermediate values of γ^n and the other 14 sectors – of one-third of the total – have a minimum sum of squared residuals at the upper-bound of $\hat{\gamma}^n = 5$.[13] This high value is enough to ensure that the elasticity in (22) exceeds 11 provided that the share from an individual region is less than one-half, which is typically the case. In other words, the upper bound of $\hat{\gamma}^n = 5$ corresponds to a homogeneous good. Of the 14 sectors obtaining this value, however, some of them consist of goods that we would consider to be differentiated.

[13] See Appendix Table B1, column (1).

To obtain an interior estimate of γ^n for more sectors, we implemented a second estimation, where we replaced the unit-value of imports by the average tariff in that sector. In this case, more sectors converge to an interior value and that is particularly true for the sectors that we consider to be composed of differentiated goods. On the other hand, for the sectors that we consider to be homogeneous goods, we did not use the value of γ^n from the second estimation even if an interior value in (0,5] was obtained. By this procedure, we end up with 8 homogeneous good sectors at the boundary value of $\hat{\gamma}^n = 5$, with the remaining 34 sectors treated as differentiated goods with interior values $0 < \hat{\gamma}^n < 1.47$.

Using the translog estimates, the elasticities of sectoral demand can be calculated as in (22), and these depend on the demand shares. Omitting the eight industries where we use $\hat{\gamma}^n = 5$, we have 34 sectors and eight foreign regions. Focusing on those imports, we show in Figure 3(a) a simple histogram of the demand elasticities at the *highest* share of imports over the eight foreign regions and all years, which results in the lowest elasticities. In 26 of the sectors the

Figure 3: Import Elasticities



import elasticity ranges between 1.1 and 2.4, while in the remaining 8 sectors the import elasticity varies up to 6.2. If we instead consider the import share at the 90th percentile, as in Figure 3(b), then in 26 of the industries the elasticity is between 1.7 and 18.7, and it is even higher for ten other sectors (including the 8 sectors for which we set $\hat{\gamma}^n = 5$).

8. State-Level Welfare Changes

2002-2017 Period

We begin with the period 2002-2017, which was generally a time of U.S. tariff reductions because of free trade agreements (FTAs) with various countries, including: Chile (in 2004), Singapore (2004), Australia (2005), Morocco (2006), Bahrain (2006), and the Dominican Republic-Central America FTA (2006-2009), Oman (2009), Peru (2009), Korea (2012), Colombia (2012), and Panama (2012). Period $t-1$ in our equations is treated as 2002 and period t is 2017, so we are examining the long difference between these two years. Examining this early period will provide a useful contrast with the period after 2017, when U.S. tariffs began to rise.

In row 1 of Table 5, we provide the sum of the states' estimates for the variety gain V_t, the consumer surplus change from import prices $-CV_t^M$, the consumer surplus change from domestic prices $-CV_t^D$, and the total change in consumer surplus $-CV_t$, which is approximately equal to the sum of these (but differs according to the last term shown in (23)). Total consumer surplus rises by \$48.7 billion due to declining prices, or \$416 per household (in constant \$2017), and all states experience this gain as illustrated in Figure 4. Much of the gain (\$38.4 billion) is due to declining domestic prices within $-CV_t^D$ that follow from the tariff reductions according to our estimate of (3) with $\hat{\beta}_1 = 0.50$ and $\hat{\beta}_2 = 1.72$. The direct gains from tariff reductions are shown by the variety term (\$7 billion) and the reduction in import prices $-CV_t^M$ (\$3 billion).

The reduction in domestic prices that follow from tariff reductions leads to a fall in producer surplus in the selling states. Adding up across states as shown in Table 6 (row 1), we obtain the change in producer surplus ΔPS_t^D of –38.4 billion, which is just equal to that domestic component of the consumer surplus gain $-CV_t^D$ when summed across states, in Table 5 (row 1). All states but one experience a decline in producer surplus, as illustrated in Figure 5. The single state with rising producer surplus is Michigan, and that is due to a rising tariff within the FAF sector Motorized Vehicles.

In Table 6 (row 1) we also report the estimated change in tariff revenue $\Delta\hat{B}_t$ resulting from the tariff reductions, which is –4.2 billion. Summing the appropriate terms from Tables 5 and 6 as in (26) we obtain the net change in national welfare of \$5.8 billion or \$50 per household with 28 states experiencing welfare gains: these are the states with *less production* in the sectors with falling tariffs.[14] The changes in state welfare are illustrated in Figure 6. The states with the greatest gains in welfare per household are in the Southwest and some of the Rocky Mountain states, with mixed results for the Midwest, Southeast, Northeast, and Pacific regions. On the other hand, Montana, North Dakota, Iowa, and Arkansas lose the most in welfare per household. In each of these states, it turns out that the gain from lower import prices, $-CV_{it}^M$, is very small and *less than* the loss from reduced tariff revenue. Even though these are low population states, the loss from reduced *per capita* tariff revenue exceeds that loss if it was calculated with the *actual* state imports, which is why these states lose from tariff reductions.

[14] The net amount of state production can be assessed from the term $\Delta PS_{it}^D - CV_{it}^D$, which sums to zero across all states in the nation. With tariffs falling we tend to have $\Delta PS_{it}^D < 0$, but this term is positive if the state gains in consumer surplus from intra-state imports. Assigning unity to the states that gain and zero otherwise, there is a correlation of 0.4 between the states that gain from intra-state trade and the states that gain in overall welfare: of the 23 states gaining from intra-state trade, 10 more gain when imports and tariff revenue are added, while 5 states no longer gain because of the drop in tariff revenue or a negative variety effect which overwhelm the gains from intra-state trade and imports.

Table 5: U.S. National Consumer Surplus Change

Period and HS6 tariffs used:	V_t ($ bill)	$-CV_t^D$ ($ bill)	$-CV_t^M$ ($ bill)	$-CV_t$ ($ bill)	$-CV_t/HH_{US}$ ($)	States with $-CV_{it} > 0$
2002-2017						
1. $\frac{Duty}{Customs\ value}$	7.0	38.4	3.1	48.8	417	50
2017-2019						
2. $\frac{Duty}{Customs\ value}$	-0.3	-177.1	-35.0	-212.5	-1,698	0
3. and $t_{2019} \geq t_{2017}$	-0.3	-177.1	-36.1	-213.6	-1,706	0
2017-2022						
4. $\frac{Duty}{Customs\ value}$	-0.5	-221.1	-43.6	-265.3	-2,104	0
5. and $t_{2022} \geq t_{2017}$	-0.5	-221.1	-45.0	-266.6	-2,115	0

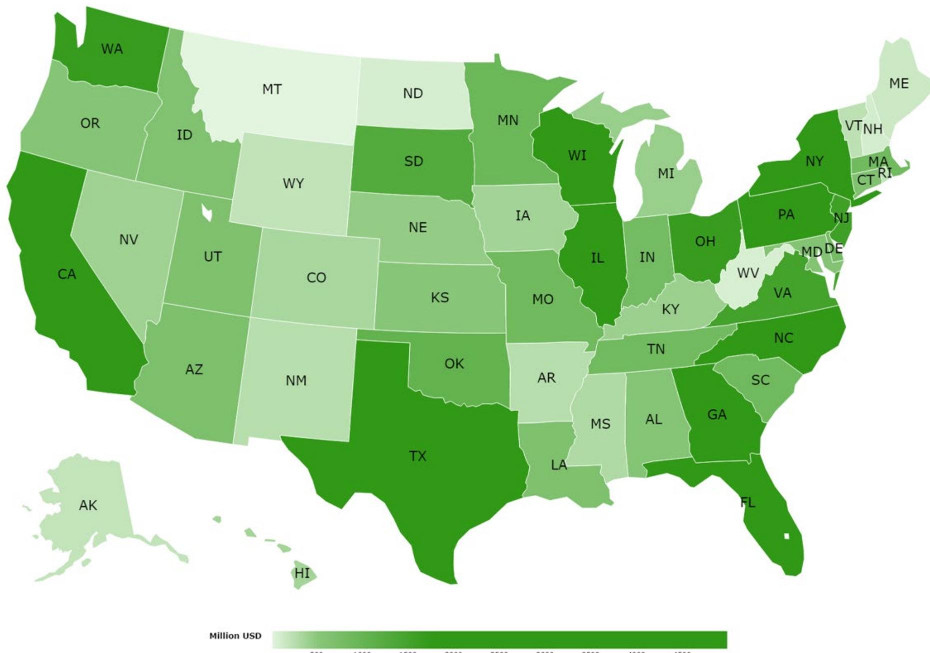
Table 6: US National Producer Surplus and Welfare Change

Period and HS6 tariffs used:	ΔPS_t^D ($ bill)	States with $\Delta PS_{it}^D > 0$	$\Delta\hat{B}_t$ ($ bill)	ΔW_t ($ bill)	$\Delta W_t/HH_{US}$ ($)	States with $\Delta W_{it} > 0$
2002-2017						
1. $\frac{Duty}{Customs\ value}$	-38.4	1	-4.2	5.8	50	28
2017-2019						
2. $\frac{Duty}{Customs\ value}$	177.1	50	29.2	-6.2	-50	25
3. and $t_{2019} \geq t_{2017}$	177.1	50	29.7	-7.1	-57	25
2017-2022						
4. $\frac{Duty}{Customs\ value}$	221.1	50	32.5	-11.7	-93	28
5. and $t_{2022} \geq t_{2017}$	221.1	50	32.6	-13.0	-103	25

Notes to Tables 5 and 6: Each column except those labeled as "States with…" show the national total as a difference from 2017, in $2017. Rows 1, 2 and 4 uses Duties/Customs value at the HS6 level to measure tariffs. Rows 3 and 5 replace any HS6 tariff that falls from 2017 by its 2017 value. The total changes in consumer surplus, $-CV_t$, producer surplus, ΔPS_t^D, tariff revenue, $\Delta\hat{B}_t$, and welfare, ΔW_t, are shown by (23) and (25)–(27), and HH_{US} is the number of households in the United States.

Figure 4: State Consumer Surplus Changes, 2002-2017

(a) Total consumer surplus change



(b) Per household consumer surplus change

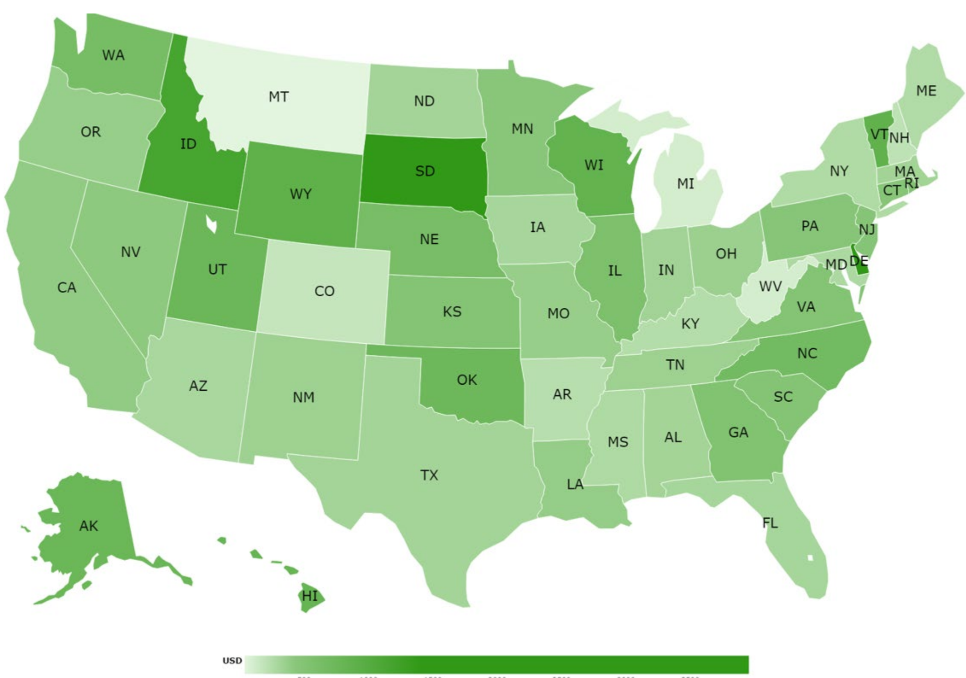
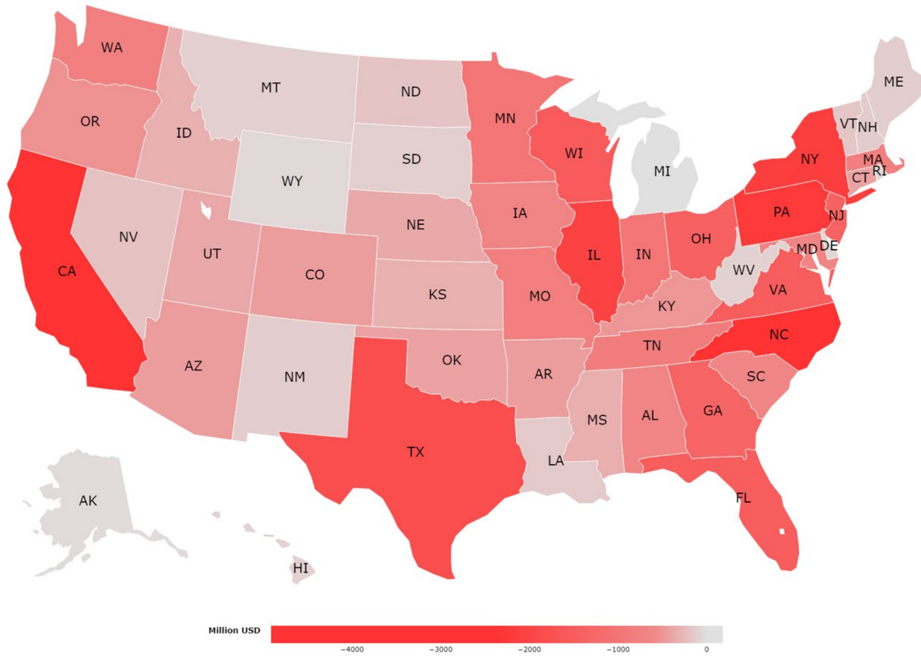


Figure 5: State Producer Surplus Changes, 2002-2017

(a) Total producer surplus change



(b) Per household producer surplus change

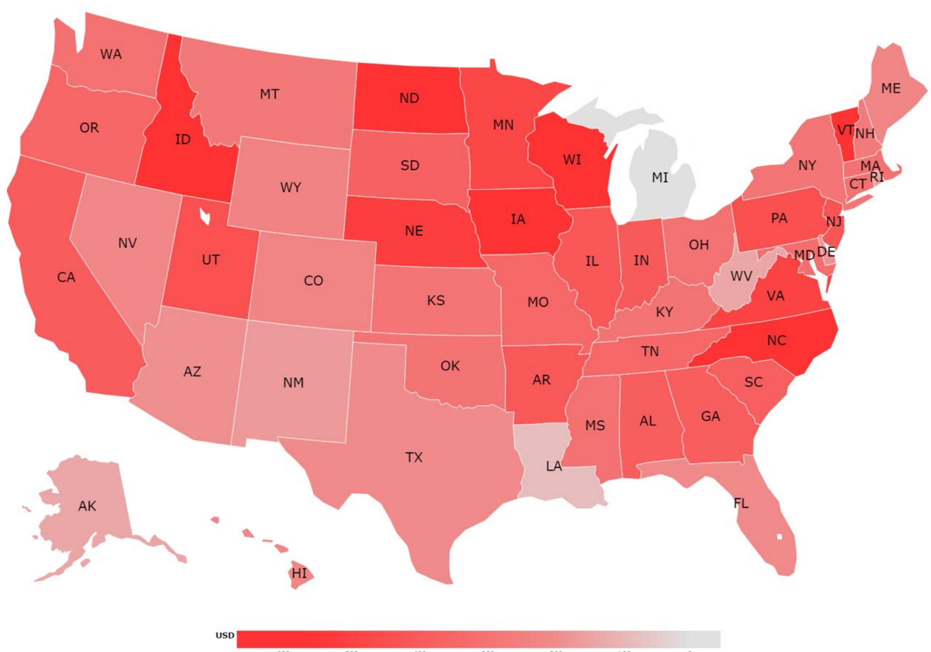
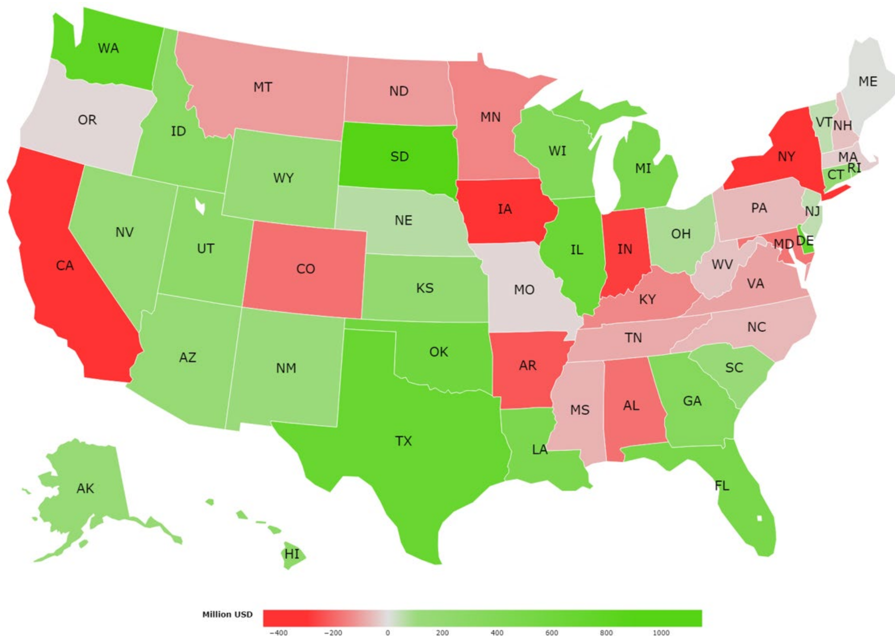
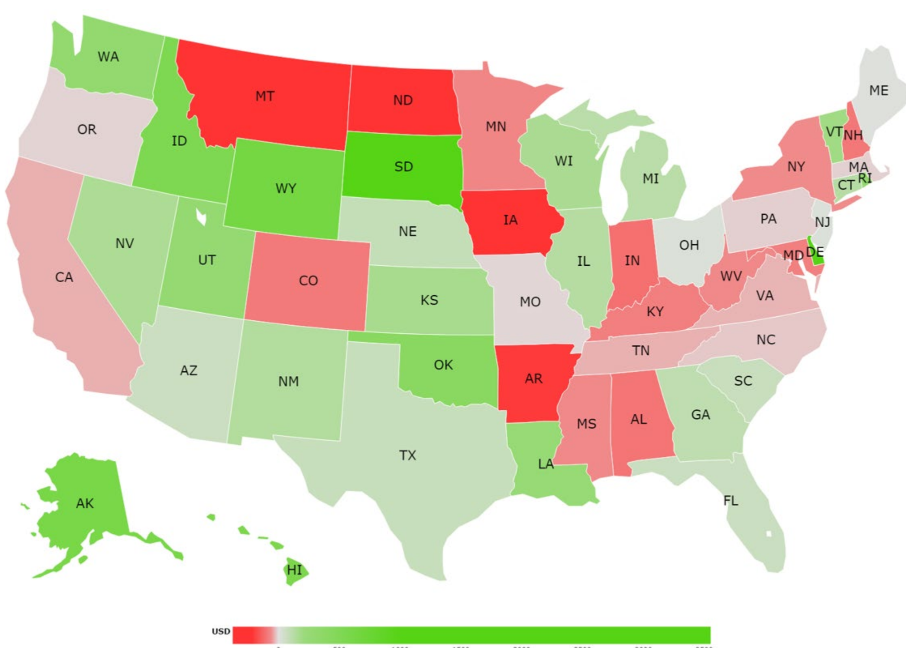


Figure 6: State Welfare Changes, 2002-2017

(a) Total welfare change



(b) Per household welfare change



2017-2019* and *2017-2022

We turn next to the years during which the tariff enacted under the Trump administration were in place, with the tariffs on China continuing into the Biden administration. Period $t-1$ in our equations is treated as 2017 and period t is either 2019 or 2022. Starting with 2017-19, in Table 5 we show that change in consumer surplus components from all changes in tariffs (row 2) and then by assuming that tariffs did not fall (row 3).[15] This distinction did not change our calculation of the loss consumer surplus from rising domestic prices (–177.1 billion in both cases)[16] and slightly increased the loss from rising import prices (from –35.0 billion to –36.1 billion). All states experience a fall in consumers surplus, and the overall loss for the nation is about $1,700 per household in 2017-19 and $2,100 in 2017-22. The state consumer surplus losses are illustrated in Figure 7 for 2017-22.

Conversely, all states gain in producer surplus in both periods, and in Table 6 we record those national producer surplus gains. The state producer surplus gains are illustrated in Figure 8 for 2017-22. Tariff revenue rises with the increase in tariffs, which offsets some of the consumer surplus losses. During 2017-2019 we find a national welfare loss due to rising tariffs (Table 6, row 3) of $7.1 billion or $57 per household, and over 2017-22 those losses nearly double (Table 6, row 5) to $13.0 billion or $103 per household. Despite these national losses, 25 states still gain in both periods from rising tariffs, as illustrated in Figure 9 for 2017-22. The states with the greatest gains per household are in the Midwest and some of the Rocky Mountain states, with mixed results for the Southeast, and conversely, many states lose in the Pacific, Southwest, and Northeast regions, because their industries rely on tariff-protected inputs.

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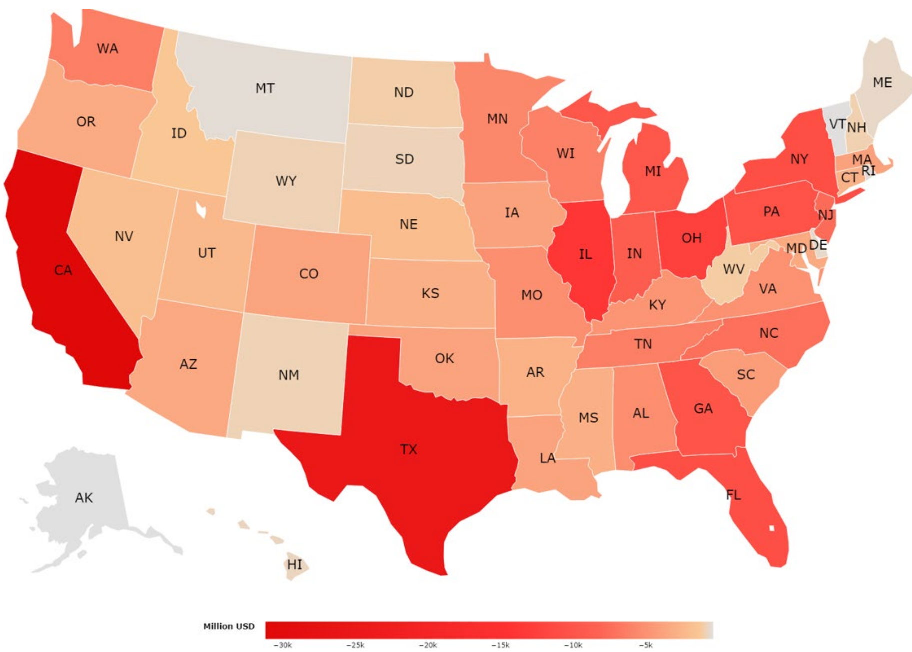
[15] To compute the values shown in rows 3 and 5 of Tables 5 and 6, we replaced any HS6 tariff that fell in the years after 2017 by its 2017 value.

[16] The predicted change in domestic unit-values from assuming that tariffs do not fall from 2017 was too small to influence our results for CV_t^D and ΔPS_t^D in later years.

Figure 7: State Consumer Surplus Changes, 2017-2022

(a) Total consumer surplus change



(b) Per household consumer surplus change

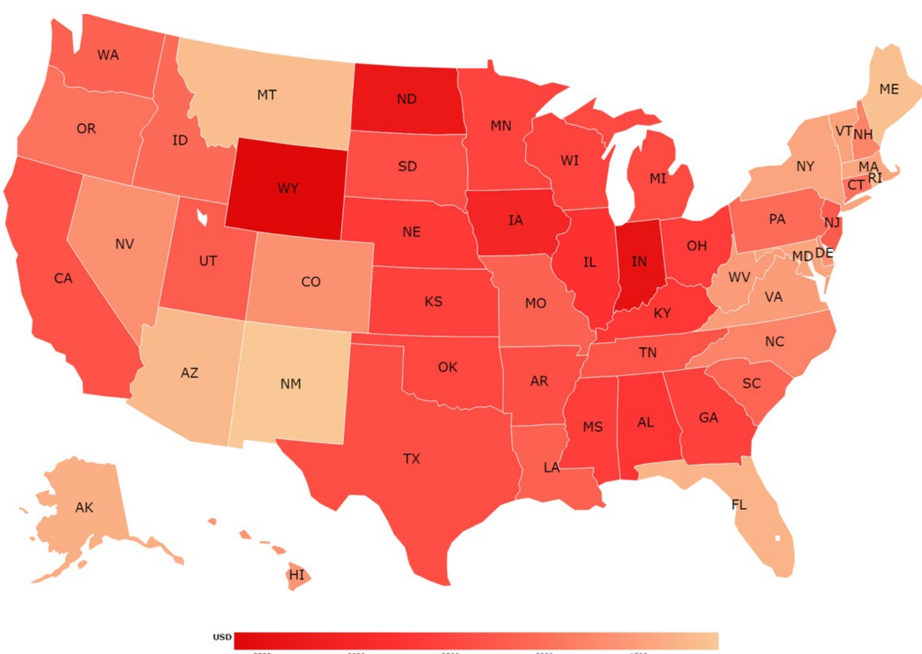
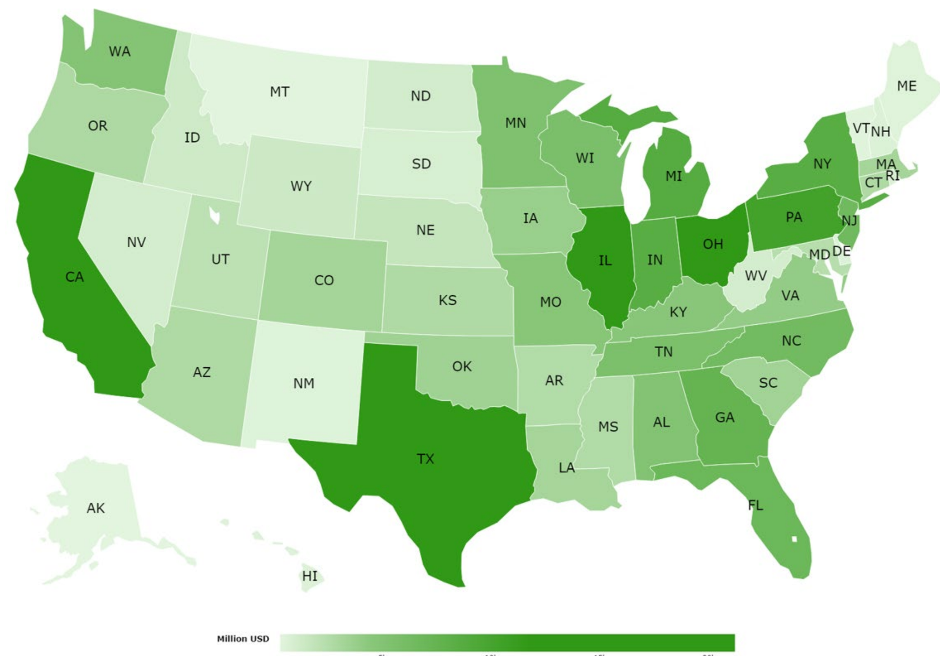


Figure 8: State Producer Surplus Changes, 2017-2022

(a) Total producer surplus change



(b) Per household producer surplus change

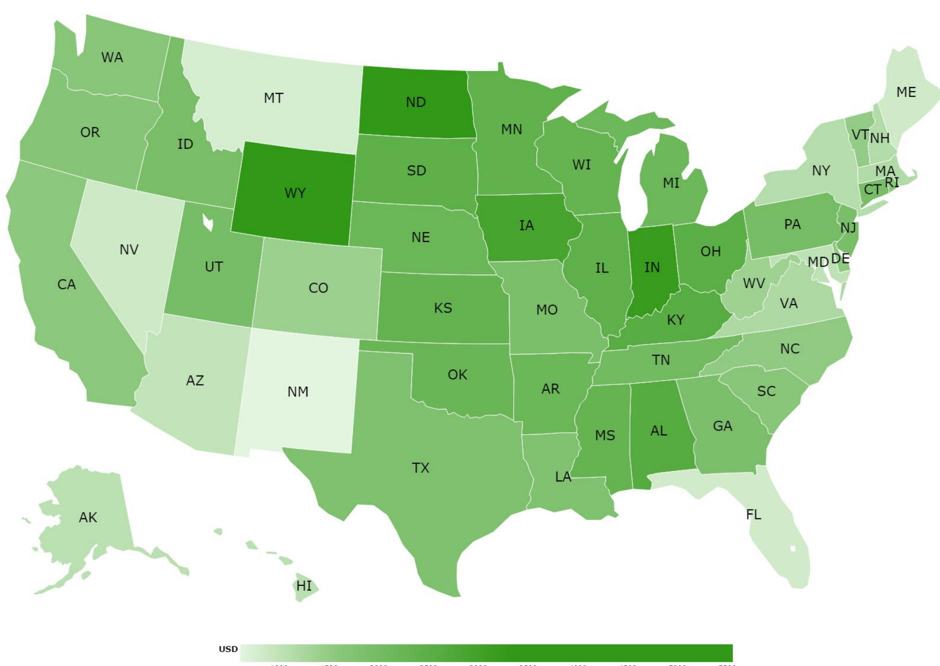
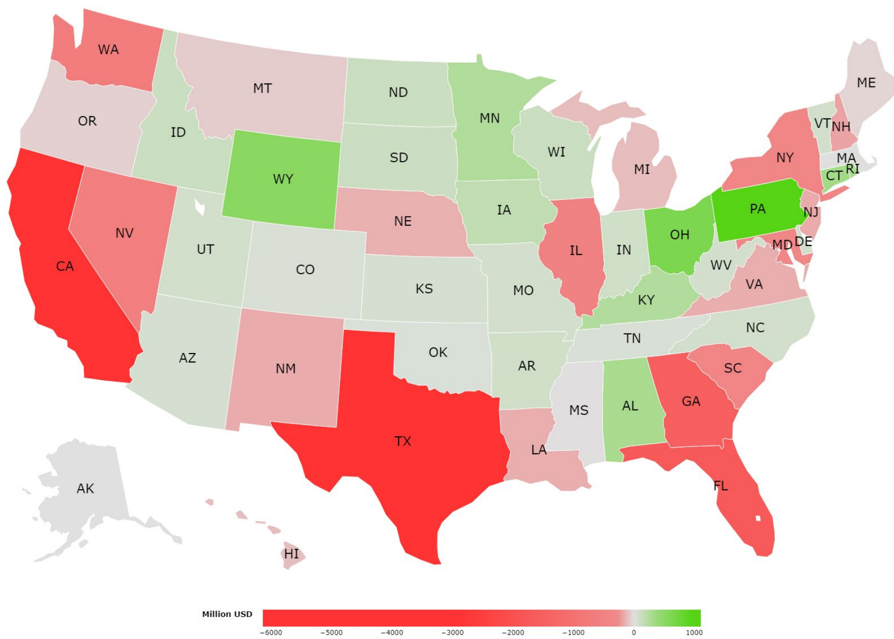
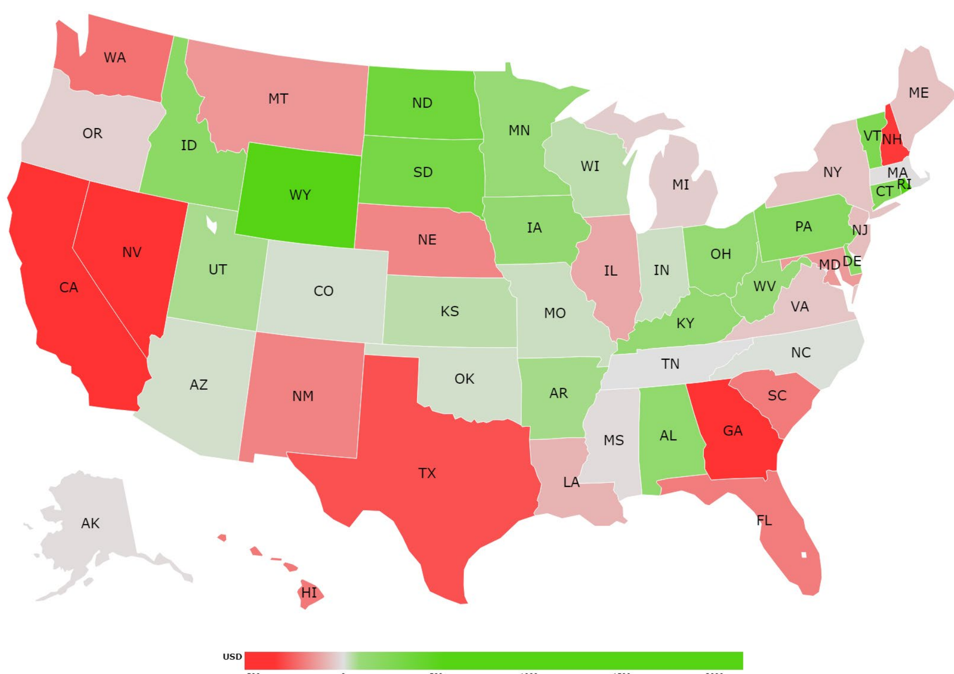


Figure 9: State Welfare Changes, 2017-2022

(a) Total welfare change



(b) Per household welfare change



To give one specific example, Wyoming shows up as having among the highest welfare gains per household (Figure 9), and also the highest gains in producer surplus (Figure 8) and loss in consumer surplus (Figure 7). The reason for all these results is that Wyoming is an exporter of coal to other states, such as Texas. The tariffs on imports from China applied to coal, too, and raised the import and domestic prices. That led to a producer surplus gain in Wyoming in its local state sales – which had an offsetting consumer surplus loss from industries using coal – and also in its sales to other states including Texas. That gain in the coal sector is enough to give Wyoming one of the largest producer surplus and welfare gains over 2017-22, despite the tariffs (including on coal imports from China) leading to a national welfare loss.

It may seem surprising that the national welfare losses in 2017-22 are twice as large as in 2017-19, given that the tariff increases directed at China under the Trump administration were completed by the end of 2019, and other tariffs such as on washing machines and solar panels have since expired. To understand the 2017-19 results, it is essential to recognize that the *applied tariffs* that we are using are averages over each year, and that the tariffs directed at imports from China were still increasing during 2019: our results for that year therefore reflect an *annual average* of different tariff levels on China. By the end of the year, however, the tariffs were fixed at their highest level, which was a 25% increase over the 2017 tariff on many imports from China, and that tariff has remained up to 2022. This explains why welfare cost that we calculate for 2017-2022 is twice as high as for 2017-2019.

Beginning in mid-2018 and continuing through 2019 and later years, there were *product exclusions* permitted on the China tariffs, so that specific 10-digit HS categories (or a portion of a 10-digit code) were exempted from the tariffs; see the discussion in section 2. For these reasons, the national losses that we calculate for 2017-19 and 2017-22 are considerably lower than other literature, such as Amiti et al. (2019a,b) and Fajgelbaum et al. (2020a, b), who examine the impact of tariffs in the 2018 tariff war and then update their results to 2019.[17] As we have already discussed, these authors use the *end-of-year statutory tariffs* in 2019 when calculating the welfare costs for that year, which do not reflect the lower tariffs that were applied earlier in the year and also do not reflect any product exclusions. Both these sets of authors find that the import costs of the tariffs initiated by the Trump administration – the equivalent of $-CV_t^M$ as shown in Table 5 – to be $100 billion or more in 2019, whereas we find an importer cost of about one-third as high ($36 billion) for that year and still less than one-half as high ($45 billion) up to 2022 (Table 5, rows 3 and 5). Accepting that product exclusions are an important reason for this difference, we still want to check whether there is any other aspect of our calculations that could explain our lower estimates.

9. Could the Welfare Cost be Higher?

Aggregation Bias

One reason that our calculated welfare costs could be low is from our use of 6-digit HS data, which is the finest level available for state-level imports but might lead to a downward bias due to aggregation. To address this concern, we add structure to our model by assuming that the 10-digit products within each 6-digit HS category are CES substitutes for each other. We illustrate these HS10 products in Table 7 for the HS6 code 841869, Refrigerating or Freezing Equipment. This HS6 code was also shown in Table 3, and in Table 7 we reorganize the data for 2019 into the share of expenditure on imports from China (*ch*) on each HS10 item that has no duty, $s_{ch,t}^{h,no}$, and the share of expenditure on the dutiable portion, $s_{ch,t}^{h,d}$, with these two shares

[17] In addition to Amiti et al. (2019a,b) and Fajgelbaum et al. (2020a,b), other estimates of the cost of the Trump trade ware are summarized in Russ (2019) and Clausing (2024).

summing to unity.[18] Recall from our earlier discussion in Table 3 that the first two and last two HS10 items shown in Table 7 have product exclusions. In the second item (Drinking Water Coolers), nearly all the expenditure is on the nondutiable share, but that is not the case for items 1, 6 and 7. Evidently, the product exclusions in these cases are applied to a *portion* of the products within these HS10 categories (which is mentioned as a general possibility in HTS Chapter 99). The question then arises as to whether we have adequately captured the welfare cost of the tariffs on these items by using Duties/Customs value calculated at the 6-digit HS level, which is 0.056 from Table 3.

To answer this question, we will treat the portion of each HS10 category that is subject to the product exclusion, and the portion that is not, as CES substitutes with the same elasticity σ *within* the 10-digit category as *between* them. The expenditure shares shown in Table 7 for 2019 apply when the tariff and product exclusions are in place, while in 2017 there are zero tariffs for this HS6 code. In that year, we do not know the expenditure shares on the items *within* each HS10 that are later subject to a tariff. Nevertheless, for each HS10 category we can still make a calculation of the CES price index between $t-1=2017$ and $t=2019$, by using the 2019 shares and the change in the tariff. That calculation is made using the so-called Lloyd (1975)-Moulton (1996) price index:[19]

$$LM_{ch,t}^{h} = \left[s_{ch,t}^{h,no} + s_{ch,t}^{h,d}(1+\tau_{ch,t}^{h,d})^{\sigma-1}\right]^{1/(\sigma-1)} \quad , \tag{30}$$

where $1+\tau_{ch,t}^{h,d}$ is one plus the tariff on the dutiable portion of each HS10 category, calculated as the Duty/Dutiable value, as shown in column (3) of Table 7.

[18] For consistency with our earlier notation, the share on the dutiable portion includes the duty paid, and the total expenditure in each HS10 item equals the customs value plus the duties paid.
[19] We are using the "reverse" Lloyd-Moulton index, calculated from the second-period shares. A different formula applies when using the first-period shares.

Table 7: Additional Details of Trade for U.S. Imports from China, HS6 841869, Refrigerating or Freezing Equipment

	Nonduty share	Dutiable share	$1+\tau_{ch,t}^{h,d}$	L-M index, σ=0	L-M index, σ=2.5	L-M index, σ=1000
2019	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
1. Icemaking Machines	0.83	0.17	1.25	1.035	1.045	1.246
2. Drinking Water Coolers	0.999	0.001	1.25	1.000	1.000	1.242
3. Soda and beer dispensing	0.001	0.999	1.25	1.247	1.247	1.248
4. Centrifugal Liquid Chilling	0.00	1.00	1.17	1.174	1.174	1.174
5. Reciprocating Liquid Chilling	0.00	1.00	1.24	1.241	1.241	1.241
6. Absorption Liquid Chilling	0.43	0.57	1.25	1.128	1.144	1.245
7. Refrig/freezing equip, nes	0.39	0.61	1.25	1.138	1.155	1.249
Total	**0.732**	**0.268**	**1.248**	**1.056**	**1.069**	**1.246**

Notes: The seven rows for each year are the HS10 products within this HS6 category. See also the data for 2019 in Table 3. L-M denotes the Loyd-Moulton index in (30), which depends on the value of σ.

In column (4) of Table 7, we show the Lloyd-Moulton index for each HS10 category with $\sigma = 0$. By construction, $LM_{ch,t}^{h}$ in that case equals one plus Duty/Customs value.[20] In the final row of Table 7, we see that computing the Lloyd-Moulton index over the *total* dutiable and nondutiable values gives 1.056, which is *identical* to the calculation of the total Duty/Customs value for 2019 in Table 3. The assumption that $\sigma = 0$ means we are treating the HS10 products – and the dutiable and nondutiable items *within* each HS10 product – as purchased in fixed proportions, so there is no deadweight loss from having the duty applied on *only a portion* of the HS10 items; i.e. applying the uniform tariff of 0.056 over all items in this HS6 code would have the same deadweight loss as the uneven application of tariffs that actually occurred.

As we raise the value of σ above 0, however, then we find a greater deadweight loss from the uneven application of tariffs provided that $0 < s_{ch,t}^{h,d} < 1$. This result is illustrated by

[20] This result for $\sigma = 0$ occurs because the share on the dutiable portion includes the duty paid, and the total expenditure on each HS10 equals the customs value plus the duties paid; see note 18.

observing that the Lloyd-Moulton index rises with σ, as seen by comparing columns (4), (5) and (6) for HS10 products 1, 6 and 7 in Table 7. The intuition for this result is that the deadweight loss of tariffs grows as demand becomes more elastic. For example, calculated over the total shares (in the final row of Table 7) we obtain $LM_{ch,t}^{h} = 1.069$ for σ= 2.5 and $LM_{ch,t}^{h} = 1.246$ for σ=1,000. The latter value is very close to the tariff $1 + \tau_{ch,t}^{h,d} = 1.248$ in column (3) of the final row, and also closely reflects the statutory tariff of 0.25.

The finding that $LM_{ch,t}^{h}$ approaches $1 + \tau_{ch,t}^{h,d}$ as $\sigma \to \infty$ is no accident and simply reflects the algebraic properties of (30). In addition, it turns out that if we use the Lloyd-Moulton formula *across* the HS10 components in Table 7 to compute an overall Lloyd-Moulton index for the HS6 category, we get nearly exactly the same result as shown in the final row: the aggregate index rises from 1.056 to 1.069 to 1.246 as σ rises from 0 to 2.5 to 1,000.[21] So even without having the HS10 details for each state, we can get much the same result by taking into account the shares *within* each HS6 category that are subject to duty and that are not, as done in the last line of Table 7. That is a calculation that we can readily make for every HS6 import into every state, as we do next. The remaining question is: what elasticity should we use between the dutiable and nondutiable portions of each HS6 category?

We have borrowed σ= 2.5 from Fajgelbaum et al. (2020a, b), who estimate it as the elasticity of substitution *between varieties (i.e. countries)* within each HS10 category. That substitution between varieties is surely more elastic than the HS10 items *within* an HS6 code, so we will treat σ= 2.5 as an upper-bound on the elasticity within and between HS10 categories.[22] Despite this upper bound, it will still be convenient to consider an extreme degree of substitution

[21] This result reflects that fact that CES index aggregates quite well, and it is available on request.
[22] Fajgelbaum et al. (2020a,b) use an elasticity of 1.5 between HS10 products.

like σ= 1,000, because that is a way to "trick" the Lloyd-Mouton index into using the duties $\tau_{ch,t}^{h,d}$ calculated as Duties/Dutiable value rather than Duties/Customs value.

Using the Lloyd-Moulton index also makes the calculation of the change in national tariff revenue particularly simple. For this index, the 2019 or 2022 shares $s_{ch,t}^{h,no}$ and $s_{ch,t}^{h,d}$ are *fixed* in (30) from the data at the HS6 level, regardless of the value for σ. This means that in our calculation of the change in tariff revenue in (29), the shares shown on the first line and the elasticities on the second do not change with σ, but only the change in prices shown on the second line, $\left(\Delta\ln \hat{p}_{ijt}^{n} - \overline{\Delta\ln \hat{p}_{\iota\circ}^{n}}\ \right)$, is affected: the change in import prices is computed as $\Delta \ln LM_{ct}^{h}$ rather than $\Delta \ln(1+\tau_{ct}^{h})$.[23] As we raise σ, the higher values for $\Delta \ln LM_{ct}^{h}$ leads to greater substitution away from high-tariff foreign regions and a reduction in tariff revenue.

2017-2019 with CES Model and $\boldsymbol{\sigma > 0}$

Using the CES model described above, we now re-examine the welfare costs of U.S. tariffs for 2017-19. In Table 8, we begin in rows 1 and 2 by repeating our earlier results: row 1 uses applied tariffs calculated for each country as Duty/Customs value at the HS6 level; and row 2 assumes that tariffs that did not fall over this period, which is maintained for the remaining cases. The remaining cases use the Loyd-Moulton index with a particular value for $\sigma > 0$ to calculate the CES 6-digit tariffs. This exercise was illustrated for a single HS6 code in Table 7 (compare columns (4) with (5) or (6)), and now we repeat it for every HS6 code. *Whenever an HS6-importer has dutiable value below its customs value – due to a product exclusion or any other reason – then using $\sigma > 0$ will result in higher welfare costs.*

[23] More precisely, $(LM_{ct}^{h} - 1)$ rather than τ_{ct}^{h} is used at the HS10-country level to compute the average tariffs for each FAF sector and foreign region as in (1). Those average price changes by sector-region are then used to compute the final term on the second line of (29), which leads the substitution away from high-tariff foreign regions within each FAF sector and therefore a reduction in tariff revenue.

Table 8: U.S. National Welfare Change in the CES Model

Period and HS6 tariffs used:	Value for σ	$-CV_t^M$ (\$ bill)	$-EV_t^M$ (\$ bill)	$\Delta\hat{B}_t$ (\$ bill)	ΔW_t (\$ bill)	$\Delta W_t/HH_{US}$ (\$)	States with $\Delta W_{it} > 0$
2017-2019							
1. $\frac{Duty}{Customs\ value}$	0	-35.0		29.2	-6.2	-50	25
2. and $t_{2017} \leq t_{2019}$	0	-36.1		29.3	-7.1	-57	25
3. $LM_{ch,t}^h$ index	2.5	-37.1		28.9	-8.5	-68	25
4. $\frac{Duty}{Dutiable\ value}$	+∞	-50.0		23.5	-26.8	-214	16
5. and use EV_t^M	+∞		-58.3	23.5	-35.1	-281	14
6. and statutory tariffs (HS6 ave.)	+∞		-89.0	8.4	-80.9	-646	4
7. and statutory tariffs (HS6 max)	+∞		-90.3	8.2	-82.5	-659	3
2017-2022							
8. $\frac{Duty}{Customs\ value}$	0	-43.6		32.5	-11.7	-93	28
9. and $t_{2017} \leq t_{2019}$	0	-45.0		32.6	-13.0	-103	25
10. $LM_{ch,t}^h$ index	2.5	-45.7		32.1	-14.1	-112	24
11. $\frac{Duty}{Dutiable\ value}$	+∞	-62.3		26.2	-36.6	-290	12
12. and use EV_t^M	+∞		-71.8	26.2	-46.1	-365	10

Notes: Rows 1–2 and 8–9 repeat those values from Tables 5 and 6 and assumes that σ = 0. Rows 3 and 10 uses the Lloyd-Moulton index with σ = 2.5. In rows 4–7 and 11–12 we let σ → +∞ in our CES model. See also the notes to Tables 5 and 6.

In row 3 of Table 8, we use the Loyd-Moulton index with $\sigma = 2.5$. Summing across all states we obtain an importer cost, $-CV_t^M$, of \$37.1 billion, which is \$1 billion more than obtained with $\sigma = 0$ (row 2). There is also a small decline tariff revenue, and the overall welfare cost becomes \$68 per household, or \$11 per household higher than the loss of \$57 when $\sigma = 0$. We regard \$11 as an upper-bound on the extent of aggregation bias in our initial calculation.

Moving on, in row 4 of Table 8 we let $\sigma \to \infty$ in the Loyd-Moulton index. Even though $\sigma \to \infty$ is an unrealistic assumption, we adopt it here because which is equivalent to using Duty/Dutiable value to measure the 6-digit tariffs (and it also allows for a simple re-calculation of tariff revenue). In this case we see that the importer cost, $-CV_t^M$, rises by about one-third from $37.1 billion (row 3) to $50 billion (row 4). By coincidence, this is quite close to the national cost for importers over the period 2017-22, which was $45 billion in Table 5 (row 5). That $45 billion estimate used 2022 tariffs that mostly reflect the *end-of-year* 2019 values (because the U.S. tariffs did not rise substantially after that), but still has product exclusions; whereas the $50 billion estimate in Table 8 (row 4) omits product exclusions by using Duty/Dutiable value to measure tariffs, but still has applied tariffs that reflect the annual average tariffs in 2019 rather than end-of-year values.

Using statutory tariffs for 2019 taken from Fajgelbaum et al. (2020a, b) will allow us to both omit product exclusions and use the end-of-year tariffs. Before taking that step, however, we adopt another feature of Fajgelbaum et al. (2020a, b), which is their use of an equivalent variation formula rather than a compensating variation. Specifically, they measure the change in national welfare by $\Delta W_t = \Delta \hat{B}_t - EV_t^M$, where the equivalent variation is defined in vector notation by the first equality in:

$$EV_t^M = \boldsymbol{q}_{t-1}^{M\prime} \Delta \boldsymbol{p}_t^M = \widetilde{\boldsymbol{M}}_{t-1}^{\prime} \Delta \boldsymbol{\tau}_t^M \quad . \tag{31}$$

In this expression, $\boldsymbol{q}_{t-1}^M$ is the vector of import quantities and is multiplied by the change in import prices, $\Delta \boldsymbol{p}_t^M$. For a small country, the net-of-tariff import prices are fixed, in which case we can multiply those by the quantities to obtain the net-of-tariff import values, $\widetilde{\boldsymbol{M}}_{t-1}^{\prime}$, as in the second equality, which are multiplied by the change in tariffs, $\Delta \boldsymbol{\tau}_t^M$. It can be seen that (31) is a Laspeyres index of the change in tariffs, evaluated with the *initial-period* import values. That formula contrasts with our Tornqvist index in (24), where we make use of the average of initial-period and final-period shares, and therefore allow for substitution away from products with the greatest tariff increases. For that reason, we expect to find that $EV_t^M > CV_t^M$.[24] That expectation is confirmed in Table 8 (row 5), where we find moving to the equivalent variation formula raises the importer cost from $50 to $58.3 billion.

Finally, we replace the tariffs we have been using (Duty/Dutiable value) with the end-of-year statutory tariffs in 2019. Fajgelbaum et al. (2020a, b) provide these at the HS10 level, but because our calculations are made at the HS6 level we need to aggregate them, which we do in two ways: taken the simple average of the HS10 tariffs within a HS6 category; and taking the maximum value of HS10 tariffs within each HS6. The former averaging approach will understate the HS10 tariffs, whereas the latter maximum approach will overstate them. In any case, the results are not too different, and we find that the importer cost, now measured by $-EV_t^M$, rises about another one-half from its former value of $58.3 billion (Table 8, row 4) to $89 or $90 billion (in rows 6 and 7). This value is less than $100 billion or more as obtained by Fajgelbaum et al. (2020b) and Amiti et al. (2019b) for the importer cost, but we have shown how to get close to their estimates by using the extreme assumption that $\sigma \to \infty$.

While Amiti et al. (2019a,b) do not use an equivalent variation formula, we continue to do so here and consider another aspect of their work. These authors use a high enough value for import elasticities that their calculated tariff revenue falls from 2018 to 2019. We have not checked 2018, but we can obtain a high degree of substitution away from imports by using the HS6 statutory tariffs to form the sectoral average tariff in equation (1), and then using the

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[24] It is well known that with a rising tax, we expect that $EV_t^M < CV_t^M$ when both are measured as areas to the left of the appropriate Hicksian demand curves. But neither of the formulas we are using for EV_t^M and CV_t^M are exact measures of these concepts, and instead we find $EV_t^M > CV_t^M$ for the reasons explained.

increase in those sectoral statutory tariffs to calculate the *final term* in (29), which reflects substitution away from regions with the greatest tariff increase (for example, away from China which is included within Southeast Asia in the FAF data).[25] Due to this substitution, the increase in tariff revenue in Table 8 is much reduced from $23.5 billion (in rows 3, 4 and 5) to $8.4 or $8.2 billion (in rows 6 and 7). Using that small increase in tariff revenue, the national welfare costs is $80.9 or $82.5 billion, and the per household welfare cost becomes $646 or $659.

These estimates are quite close to the deadweight loss of $620 per household in 2019 calculated by Amiti et al. (2019b), so by using the CES model with $\sigma \to \infty$ we have shown how such a high estimate can be obtained. Not surprisingly, the number of states that gain from the tariffs is reduced as the welfare cost grows. Our initial estimates were that half the states gained (Table 8, rows 1, 2 and 3), but that number falls in the successive calculations to only 3 or 4 states gaining (rows 6 and 7).

2017-2022 with CES Model and $\boldsymbol{\sigma > 0}$

Finally, we re-examine the welfare costs of U.S. tariffs for 2017-22, in the bottom portion of Table 8. We first repeat our earlier results: in row 8 we use the HS6 tariffs calculated for each country as Duty/Customs value; and in row 9 we assume that tariff do not fall from 2017. Both of these calculations assume that $\sigma = 0$. Then in row 10 we use the Loyd-Moulton index with $\sigma = 2.5$. We find that the welfare cost per household increases by $9 from $103 (row 9) to $112 (row 10) . This is quite close to the upper-estimate for the aggregation bias of $11 per household for 2017-19, so we treat that bias as not exceeding about $10 per household.

We next allow $\sigma \to \infty$ in the CES model, in which case the Loyd-Moulton index equals

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[25] Notice that we do not modify the term $\tau 2_{jt}^{n}$ in (29), which is still measured as defined in (2) using the weighted average of applied tariffs at the HS6 level, and we do not modify the import shares.

one plus the Duty/Dutiable value at the HS6 level. Similar to what we found for 2017-19, the importer cost, $-CV_t^M$, rises by about one-third from $45.7 billion (row 10) to $62.3 billion (row 11). The welfare cost per household increases from $112 to $290. This exceeds the welfare cost per household of $214 over 2017-19 by about one-third, reflecting the fact that some tariffs were in effect for only a portion of 2019.[26] Expressed as an equivalent variation, the welfare cost is likewise higher: $365 per household (row 12), which again exceeds the annual cost of $281 during 2017-19 by about one-third.

10. Conclusions

Our goal in this paper was to use a state-level dataset to obtain estimate of the state welfare costs due to changes in tariffs. To achieve that goal we have relied on the FAF data, which details the transportation of all goods across state lines and international borders. Because that dataset aggregates to eight foreign regions, we have merged it with Census data on trade and tariffs at the 6-digit HS level, which is the finest level available for state trade flows. We run initial regressions to confirm that the FAF data show full passthrough of tariffs to import unit values, and also estimate the (partial) passthrough to domestic unit values.

We model the substitution between domestic state and foreign regions for each sector as determined by a translog expenditure function. Those estimated translog parameters are needed to calculate welfare gains or losses due to variety change (when a state or foreign region starts or stops its sales to another state), and also for the calculation of the change in tariff revenue. Tariff revenue is assumed to be distributed on a per-capita basis, so states with greater production will experience a welfare gain from tariffs on those products (due to rising producer surplus) while

[26] Recall that the welfare cost is evaluated at an average expenditure between the initial and final periods (in constant $2017). So the growth in real imports from 2019 to 2022 also raises the average annual welfare cost in 2017-22 as compared to that in 2017-19.

those with little production will lose (due to falling consumer surplus).

Over 2002-17, we find that 28 states benefitted from reduced tariffs under new free trade agreements, with national gains of $5.8 billion or $50 per household annually. These national gains were eliminated by the tariff increases over 2017-2019 with national losses of $57 per household, which rise to $103 over 2017-2022. Our results are unique in showing that 25 states still gained. These national losses from tariff increases are much lower than in other studies for the 2017-19 period that use *end-of-year statutory* rather than *applied* tariffs. The applied tariffs are lower due to *product exclusions* that were permitted, which exempted certain HS10 products from tariffs, and because they are an average of tariffs used within the year.

Product exclusions can explain, however, only a portion of the difference between our low welfare costs and the higher costs in Amiti et al. (2019a, b) and Fajgelbaum et al. (2020a, b). There are also differences in the methods of calculations: Fajgelbaum et al. (2020a, b) use a Laspeyres index of tariff changes to measure the equivalent variation; and Amiti et al. (2019a, b) uses a high degree of substitution away from tariff-impacted products (so that total tariff revenue falls from 2018 to 2019). In addition, there are differences between the tariff increases after 2017 calculated from Duty/Dutiable value, which we have used, and from the statutory tariffs used by Fajgelbaum et al., that we have not explained: the mean value of the former is significantly less than the latter, as was discussed just after Table 2 and illustrated by two examples of HS10 products in Table 3 (note b). So understanding more fully the "calculated duties" reported by Census and how the applied tariffs obtained from these duties compare with statutory tariffs is an important area for further research.

Appendix A: Possible Underestimation of Calculated Duties from Census

The data provided by Census on "calculated duty" is described as follows:[27]

> Estimates of calculated duty do not necessarily reflect amounts of duty paid and should, therefore, be used with caution. The inclusion in the figures of some U.S. products returned after processing and assembly abroad, for which a portion of the value is eligible for duty free consideration, may cause these duty figures to be somewhat overstated as a result. In cases where articles are dutiable at various or special rates, a dutiable value is shown but no duty is calculated. Thus, there is an understatement in the estimates of calculated duty to the extent that these situations exist.

The first case, of overstatement of duties due to U.S. products returned after processing, would apply to some U.S.-Mexico trade but is unlikely to apply to other countries subject to Section 201/232/301 tariffs after 2018, and especially not to China. The second case, of understatement due to "various or special rates", could potentially apply to special duties on China and other countries. Because the welfare costs explored in this paper are predominantly due to the Section 301 tariffs on China, we focus on that country in this Appendix.

As described in the above quotation, the data provided by Census on "calculated duty" might be underestimated in "cases where articles are dutiable at various or special rates, [so that] a dutiable value is shown but no duty is calculated." To explore this possibility, we start with the 10-digit Census trade data on U.S. imports from China for 2018 and 2019. We first check for those observations where "a dutiable value is shown but no duty is calculated". The value of these observations is compared with total imports from China, as shown in the first two rows of the Table A1. It can be seen that *less than 1.5 percent* of the dutiable value or customs value are composed of observations that have a dutiable value but no calculated duty.

[27] Source: https://usatrade.census.gov/.

Next, we merged the 10-digit Census trade data on U.S. imports with the statutory tariff increases reported by Fajgelbaum et al. (2020a, b) and focus on tariffs that rose from 201. The results from this merged dataset are reported in the third and fourth rows of Table A1. We find that *less than 0.03 percent* of the dutiable value or customs value are composed of observations that have a dutiable value but no calculated duty. We conclude that the potential underestimation of calculated duties described by Census hardly occurred for the tariffs applied on imports from China in 2018 and 2019..

Table A1: U.S. Imports from China with Dutiable Value but no Duty

		Dutiable value of imports from China ($ million)			**Customs value of imports from China ($ million)**		
Sample:	Year	Without Duty ($ mill)	Total imports ($ mill)	Ratio (percent)	Without Duty ($ mill)	Total imports ($ mill)	Ratio (percent)
All imports From China	2018	3,631	256,492	1.42%	4,651	543,287	0.86%
	2019	3,902	265,250	1.47%	5,012	452,647	1.11%
Imports from China with a tariff increase	2018	17.7	141,911	0.01%	66.1	259,388	0.03%
	2019	40.7	218,733	0.02%	55.2	271,664	0.02%

Notes: The columns listed as "Without duty" have a dutiable value shown in the Census import data, but no duty is calculated. The column "Ratio" is computed as Ratio = Without duty/Total imports, using the data from the previous two columns.

Appendix B: Translog Parameters

We estimate the translog parameters γ^n using the method of moments procedure described in Feenstra and Weinstein (FW, 2017, pp. 10160-61), except simplified from them because we have assumed a perfectly competitive market structure so that there are no markups.[28] The procedure used by FW for translog builds on that in Feenstra (1994) for CES and Broda and Weinstein (2006) who added a grid search to the CES procedure. We implemented a grid search in the translog procedure but, as we shall describe.

Equation (14) has been double differenced with respect to time and with respect to a benchmark country *k*. We chose the benchmark country as a foreign region with the greatest sales to the United States. Then using the FW procedure (simplified as described just above), results in a nonlinear equation from which we obtain the estimate of γ^n shown in the column (1) of Table B1 (with the t-statistic shown in the next column). In 25 out of the 42 sectors, the nonlinear estimation converges to a positive estimate for γ^n, and all but three of these (Tobacco products, Natural sands, and Nonmetallic minerals) are significantly different from zero, most with very high t-statistics. In the other sectors we find the lowest sum of squared residuals using a grid search over values of γ^n between 0 and 5 at increments of 0.01; these estimates are shown in bold in Table 1. In three of these sectors we find interior values for γ^n, and in the other 14 cases the lowest sum of squared residuals is obtained at the upper bound of $\hat{\gamma}^n = 5$. Several of these sectors, such as Machinery, Other transportation equipment, Precision instruments, and Misc. manufactured products, however, should be treated as differentiated goods. We therefore performed a second estimation to obtain more interior values of $\hat{\gamma}^n$ for differentiated goods.

[28] This means that we treat $H_{ct} \equiv 1$ and $Z_{ct} \equiv 0$ in Feenstra and Weinstein (2017, pp. 10160-61), in order to obtain the estimating equations for γ^n in each sector.

Table B1: Estimates of the Translog parameter γ^n in each Sector

	First γ^n (1)	t_stat	Second γ^n (2)	t-stat	Final γ^n (3)
Live animals and fish	**5**		0.326	16.91	0.326
Cereal grains	**5**		**5**		**5**
Other agric. prods.	0.494	2.98	0.117	12.88	0.494
Animal feed	0.028	29.69	0.039	29.30	0.028
Meat, poultry, seafood	0.914	2.72	0.718	3.39	0.914
Milled grain prods.	0.096	17.16	0.137	10.87	0.096
Other foodstuffs	**5**		0.207	4.70	0.204
Alcoholic beverages	0.765	5.18	0.771	5.46	0.771
Tobacco prods.	2.865	1.49	0.858	6.90	0.858
Building stone	**5**		**5**		**5**
Natural sands	2.937	0.61	**5**		**5**
Gravel	**5**		**5**		**5**
Nonmetallic minerals	16.425	0.19	0.372	12.12	0.372
Metallic ores	0.307	10.90	0.403	17.14	0.307
Coal	0.277	21.64	0.313	28.36	0.277
Crude petroleum	0.135	280.16	54.24	0.20	**5**
Gasoline	**5**		0.182	14.84	**5**
Fuel oils	**5**		0.118	26.90	**5**
Other coal and petro.	0.452	5.89	0.160	31.90	0.452
Basic chemicals	**5**		0.262	18.26	0.262
Pharmaceuticals	0.104	16.78	0.059	30.09	0.104
Fertilizers	0.335	7.75	0.498	7.16	**1.47**
Other chemical prods.	0.157	12.81	0.155	15.06	0.157
Plastics and rubber	0.261	8.44	0.148	16.81	0.261
Logs	1.640	1.73	0.368	7.15	1.640
Wood prods.	**5**		**5**		**5**
Newsprint and paper	0.043	54.28	0.035	61.81	0.043
Paper articles	**0.77**		**0.77**		**0.77**
Printed prods.	**0.10**		0.150	7.59	0.150
Textiles and leather	**5**		0.333	9.50	0.333
Nonmetal min. prods.	**1.47**		0.035	41.90	**1.47**
Base metals	0.642	4.15	0.179	24.81	0.642
Articles of base metal	0.105	13.15	0.073	18.45	0.105
Machinery	**5**		1.122	4.31	1.122
Electronics & office equip.	0.235	60.94	0.236	67.41	0.235
Motor vehicles & parts	0.380	10.85	0.313	16.45	0.380
Other transport equip.	**5**		1.007	6.70	1.007
Precision instruments	**5**		0.315	9.78	0.315
Furniture, etc.	0.075	46.90	0.063	59.93	0.075
Misc. manuf. prods.	**5**		0.164	19.13	0.164
Waste and scrap	0.184	23.57	0.067	58.23	0.184
Mixed freight	0.044	33.257	0.039	59.88	0.044

We speculate that one reason for the nonlinear estimation to not converge is that the unit-values we are using for import and domestic prices are quite volatile. We tried dropping the observations with domestic shares altogether and estimating (14) using only observations with import shares, but that did not improve the incidence of nonconvergence. So instead, we retained the domestic shares and adjusted the import data: in particular, we used the *predicted import price* as shown in (18), where the unit-value is replaced with the average import tariff in each sector. That approach results in the estimates shown in column (2) of Table B1.

With this second method, 36 out of the 42 sectors converge to highly significant estimates for γ^n, and all but one (Paper articles) of the remaining six sectors result in $\hat{\gamma}^n = 5$ from the grid search. To arrive at our final estimates for γ^n, shown in column (3), we use the method two estimates for those four sectors just mentioned and shown at the bottom of the table; and we retain the method one estimates of $\hat{\gamma}^n = 5$ for goods such as Gasoline, Fuel oils and products above these items in the table that we treat as homogeneous while also imposing this value for Crude petroleum. For other products we choose the estimate from either method one or two that resulted in the most reliable estimate of γ^n, but we retain the method one estimate of $\hat{\gamma}^n = 1.47$ for Nonmetallic mineral products and impose this relatively high value on Fertilizers, too, since we judge these sectors to be similar and quite homogeneous.[29]

[29] If we did not impose $\hat{\gamma}^n = 5$ for Crude petroleum, as well as of $\hat{\gamma}^n = 1.47$ for Fertilizer and Nonmetal mineral products, then we find significant product variety effects in these products. For example, we find large variety effects due to state imports of Crude petroleum from Canada and from Venezuela that are sometimes zero (due to an embargo on Venezuela), and state imports of Fertilizer or Nonmetal mineral products from other states that occur only in certain years.

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