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Minghao Li, Edward J. Balistreri, and Wendong Zhang

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Minghao Li is Assistant Professor, Applied Statistics and International Business Department, New Mexico State University, Las Cruces, NM 88003. E-mail: minghao@nmsu.edu.

Edward J. Balistreri is Associate Professor, Department of Economics, Iowa State University, Ames, IA 50011. E-mail: ebalistr@iastate.edu.

Wendong Zhang is Assisstant Professor, Department of Economics, Iowa State University, Ames, IA 50010. E-mail: wdzhang@iastate.edu.

For questions or comments about the contents of this paper, please contact Wendong Zhang, wdzhang@iastate.edu

The U.S.- China trade war: tariff data and general equilibrium analysis

By Minghao Li,[a] Edward J. Balistreri[b] and Wendong Zhang[c]

The current trade war between the United States and China is unprecedented in modern history. This study introduces a database of tariff increases resulting from the recent trade war and quantifies the impacts using the canonical GTAPinGAMS model calibrated to the recently released GTAP version 10 accounts. We find that the tariff increases as of September 2019 decrease welfare in China by 1.9% and welfare in the U.S. by 0.3%. Impacts on sectoral revenue are reported for both countries. China's exports to and imports from the United States are reduced by 58.3% and 50.7%. Most of the reductions in bilateral trade are absorbed by trade diversion to other countries. The welfare and U.S.-China bilateral trade impacts are exacerbated by additional tariffs threatened by the United States and corresponding retaliations from China. Sensitivity analysis is conducted by increasing and decreasing import substitution (Armington) elasticities by two standard deviations. This has modest impacts on welfare and trade flow results.

JEL codes: F11, F12, F17

1. Introduction

The years 2018 and 2019 witnessed the largest trade war in modern history. In early 2018, the United States invoked Section 232 of the Trade Expansion Act of 1962 (alleging a national security threat) to increase tariffs on steel and aluminum products, which started U.S. trade disputes with major steel and aluminum exporters including China. Some of these disputes, such as those between the U.S. and Canada and Mexico, have already been resolved through negotiations. In the meantime, U.S. trade disputes with China have quickly evolved into a full-blown trade war. After Section 301 (unfair trade) investigations, the United States

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[a] **Corresponding Author:** Economics, Applied Statistics and International Business Department, New Mexico State University, 212 Domenici Hall, New Mexico State University, Las Cruces, NM, USA, 88003. (email: minghao@nmsu.edu).

[b] Department of Economics, and Center for Agricultural and Rural Development, Iowa State University. (email: ebalistr@iastate.edu).

[c] Department of Economics, and Center for Agricultural and Rural Development, Iowa State University. (email: wdzhang@iastate.edu).

increased tariffs on large swathes of Chinese goods. China was able to retaliate proportionally in early rounds but quickly ran out of U.S. exports to add tariffs to, given its large bilateral trade surplus with the United States (Li, Zhang, and Hart, 2018). As of the fall of 2019 more than 90% of products at the six-digit Harmonized Code (HS) level have experienced tariff increases from one or both countries. In addition, the United States is threatening to increase tariffs on certain consumer products and on $250 billion worth of Chinese exports that have already been taxed in earlier rounds of tariff increases. Currently, there are signs of a de-escalation. China offered to lift punitive tariffs on U.S. soybeans and pork amid its ongoing African Swine Fever outbreak, and the United States also temporarily exempted more than 400 Chinese products from tariffs and postponed the implementation date on tariff rate hikes on $250 worth of Chinese exports from October 1 2019 to October 15 2019.

General equilibrium simulation models are the standard tool for evaluating the impacts of changes in trade barriers. In the last three decades, these methods have been applied to analyze important events in international trade such as China's accession to the World Trade Organization (WTO, e.g. (Ianchovichina and Martin, 2003)), the Uruguay (Francois, 2000; Harrison, Rutherford, and Tarr, 1997) and Doha (Bouët, Mevel, and Orden, 2007) rounds of WTO negotiation, the North America Free Trade Agreement Kehoe (2003), and regional economic agreements (Kawasaki, 2015; Lee, Roland-Holst, and van der Mensbrugghe, 2004; Jugurnath, Stewart, and Brooks, 2007). Despite intense public attention on the U.S.-China trade war, there are few comprehensive general equilibrium studies of the of the resulting tariff increases. A barrier for conducting these analyses is that the dispersed tariff disputes between the United States and its trade partners and the repeated tariff increases between the United States and China have not been processed for analysis. This study fills this gap by compiling a comprehensive database on tariff increases, harmonizing them with the sectors in the recently released Global Trade Analysis Project (GTAP) 10 database, and evaluating them using a widely accepted transparent structure. Our analysis provides the foundation and reference point for future studies that might logically consider alternative trade structures and validation exercises.

While this paper is the first comprehensive evaluation of the current U.S.-China trade war, several preliminary studies exist. Balistreri et al. (2018) combine a global CGE model and a regional CGE model of the United States and find that the tariff increases up to the $50 billion round in August 2018 cost Iowa, a major agricultural state in the United States, about 1% of Gross State Product. Using the GTAP model, Carvalho, Azevedo, and Massuquetti (2019) find that tariff increases in the $50 billion round decrease welfare by $39.7 billion to $43.1 billion for China and $19.3 to $23.6 billion for the United States. Guo et al. (2018) use the Eaton and Kortum (2002) model to evaluate a 45% tariff increase, proposed by then presidential candidate Donald Trump, on all Chinese exports. In their scenarios where China retaliates with 45% tariff increases on U.S. exports, Guo et al. (2018) find real wage changes by -0.37% to 0.08% in China and -0.75% to -0.32% in the United States. Since these studies either only use tariff increases in earlier rounds or use hypothetical tariff increases on all exports, their results cannot fully and accurately capture the impacts of the trade war.

This paper first introduces a harmonized database (Li, 2019) of all tariff increases in the recent trade disputes (which is made available for free download); and, second, analyzes the impacts of these tariffs on welfare, sectoral output, and trade patterns. We investigate the tariff changes within the established canonical Lanz and Rutherford (2016) GTAPinGAMS model calibrated to the GTAP version 10 accounts. Using this *off-the-shelf* model provides a transparent reference point for evaluating the tariff data under a generic neoclassical economic structure.

First, we find that under the accumulated tariffs implemented as of September 2019, China's welfare falls by 1.9% while U.S. welfare falls by 0.3%. Second, the tariffs have substantial effects on the output of targeted sectors as well as related sectors. Third, China's export to and import from the U.S. will be reduced by 58.3% and 50.7% respectively under the accumulated tariffs as of September 2019. There is significant trade diversion as China increases its penetration into the markets in the EU, Canada, and Mexico, resulting in modest decreases in overall import and export for both countries. These results are robust to a wide ranges of trade elasticities (i.e. Armington elasticities).[1] For China and the United States, the magnitudes of welfare loss from the trade war are comparable to welfare gains from China's WTO accession, the Uruguay round of WTO negotiation, and even global free trade.

The rest of this paper is structured as follows. Section II offers a description of the model and describe the tariff database. Section III presents results on overall welfare, industry output value, and trade flows. Section IV discusses the limitation of the GTAPinGAMS model and discuss findings in the context of other important events in international trade.

2. Method

2.1 *The canonical GTAPinGAMS model and scenarios*

The GTAPinGAMS model (Lanz and Rutherford, 2016) is a Computable General Equilibrium (CGE) model which we calibrate to the recently released GTAP 10 database. The model structure is developed and documented by Aguiar, Narayanan, and McDougall (2016). This model adopts a particular trade structure consistent with the Armington (1969) assumption—goods under a given commodity classi-

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[1] Current observed trade responses are not as large as the model indicates. This likely reflects sluggish responses and perhaps expectations of a pending resolution in the short-run. The trade elasticites in the GTAP model are generally interpreted as medium to long-run responses.

fication from different countries are treated as imperfect substitutes. The Armington elasticities of substitution are the most crucial parameters for assessing trade responses (McDaniel and Balistreri, 2003). Besides the main results, we conduct sensitivity analyses using one and two standard deviations around the original estimates adopted in GTAP, which come from Hertel et al. (2007).

We maintain the 57 sectors in the GTAP 10 database but aggregate the 140 GTAP countries and regions to 22. In particular, countries in the EU are aggregated into one region. The United States and countries that are among the top 20 steel and aluminum exporters to the United States (if not in the EU) are maintained as individual countries. Leading trade partners of China and the United States are among these countries. Other countries are aggregated to a rest-of-world (ROW) region. We solve the global multi-regional version of the GTAPinGAMS model as otherwise parameterized in Lanz and Rutherford (2016).

2.2 Tariff increases and scenarios

In March 2018, the United States increased tariffs on aluminum and steel by 10% and 15% respectively. Canada, China, the European Union (EU), India, Mexico, and Turkey each retaliated with proportional tariff increases on U.S. goods. In May 2019, agreements were reached between the United States and Canada and Mexico to end U.S. tariffs on steel and aluminum and the retaliatory tariffs from Canada and Mexico. In June and August of 2018, the United States imposed 25% additional duty on $50 billion worth of Chinese imports related to China's "Made in China 2025" industrial policy. China responded with 25% additional tariffs on the same amount of U.S. products, notably agricultural products such as soybeans.

In September 2018, the United Stated raised tariffs by 10% on $200 billion worth of products from China and China retaliated with 5% to 10% tariffs on $60 billion worth of products from the United States. After the negotiation between China and the United States broke down, the 10% tariffs applied by the United States on $200 billion Chinese goods increased to 25% in June 2019, and China's tariffs on $60 billion U.S. exports increased to 5% to 25%. In September 2019, the United States increased tariffs by 15% on the first batch of products from a list of $300 billion Chinese exports and China responded by increasing tariffs on the first batch of products from a list of $75 billion U.S exports.

As of the writing of this article, the U.S. tariff on the second batch of $300 billion Chinese exports and China's retaliation are scheduled to go into effect on December 15, 2019. Furthermore, the United Stated is threatening to increase tariffs on $250 billion worth of Chinese exports, including those taxed in the $50 billion round and the $200 billion round, from 25% to 30% on October 15, 2019.

We construct three scenarios with different tariff increases:

Scenario 1: Steel-aluminum Tariff increases due to the U.S. steel and aluminum tariffs and retaliatory tariffs from China, the EU, India, and Turkey.

U.S. tariffs on Mexico and Canada, and corresponding retaliatory tariffs have been removed, reflecting the results of later negotiations.

Scenario 2: September 2019 Tariff increases in scenario 1 and additional tariff increases between the United States and China, including the $50 billion round, the $200 billion/$60 billion round, and the first wave of the $300/$75 billion round tariff increases. This is the scenario that captures the current tariffs imposed by China and U.S.

Scenario 3: December 2019 tariffs Cumulative tariff increases in scenario 1 and 2, and scheduled tariff increases on $250 billion Chinese products from 25% to 30% , and the second wave of the $300/$75 billion round tariffs. This represents all implemented tariff increases and announced threats between the United States and China.[2]

2.3 Data processing

Tariff increases listed above are collected from original government announcements. The raw tariff increases, mostly at the eight-digit HS code level, are aggregated to the six-digit HS code level by simple averaging. Six-digits HS products are assigned to GTAP sectors using a crosswalk from 2012 HS code to 2007 HS code, then from the 2007 HS code to GTAP sectors. GTAP-sectors-level Tariff increases are calculated as the trade-value-weighted average of six-digits HS level tariff increases. The trade value are based on 2016 values from the UN Comtrade database. For consistency, we use values reported by the United States for all trade flows. Original tariff increase data, six-digits HS level data, GTAP-sectors-level data, documents and data processing codes are freely available for download (Li, 2019).

3. Results

3.1 Trade-weighted tariff increases

We first report, in Table 1, the trade-weighted cumulative tariff increases in different rounds of trade disputes. The tariff lists of both countries contain products with little trade volume, highlighting the importance of using trade-weighted tariff increases. The trade-weighted average U.S. tariff increase on Chinese exports is about 21.7% by the September 2019 and by 30.5% by December 2019. The corresponding Chinese retaliations increase trade weighted tariffs by 20.7% by September 2019 and by 24.0% by December 2019. By December 2019, China's retaliation will be lower than the U.S. tariffs both in trade weighted tariff increase and in the

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[2] China's retaliations for the $250 billion tariffs has not been announced yet and are not included. Also China recently exempted tariffs on selected products including soybeans and pork, and the United States also exempted about 400 types of Chinese products. Since these exemptions are highly dependent on the results of the upcoming trade talk, they are not included.

amount of trade affected.

For important Chinese products with more than 5% share of China-U.S. export, ″Other Machinery and Equipments″ took the hardest hit (33.7% trade-weighted tariff increase), followed by ″Lumber″ (20.6%), and ″Electronic Equipment″ (18.8%). If the threat of additional tariffs on \$300 billion Chinese goods were to be implemented, tariffs on important Chinese exports to the United States will be above 25% across the board except for ″Other manufacturing″, with tariffs on ″Other Machinery and Equipments″ and ″Electronic Equipment″ raised to as high as 42.0% and 30.4%. Among important U.S. exports to China with more than 5% export share, ″Motor vehicles and parts″, ″Oil seeds (Soybeans)″, and ″Other machinery and equipments″ experience the highest tariff increases after the September 2019 round. Notably, China's tariff increases on intermediate industrial inputs (e.g. ″Chemical Rubber Products″ and ″Forestry″) are modest, possibly reflecting China's dependence on certain inputs from the United States. In China's retaliation by December 2019, ″motor vehicles and parts″ from the United States will see a 9.1% tariff increase from scenario 2.

Table 1. Trade-weighted tariff increases (%)

	$E_{cn,us}$	US tariffs on China		$E_{us,cn}$	China's tariffs on US	
		Sep. 2019	Dec. 2019		Sep. 2019	Dec. 2019
Other Machinery & Equipment	21.5	33.7	42.0	19.0	14.5	18.0
Chemical Rubber Products	8.6	18.7	25.7	16.9	12.5	13.3
Motor vehicles and parts	2.7	24.0	28.8	14.3	34.2	43.3
Oil Seeds	0.0	25.0	30.0	12.3	33.1	33.2
Electronic Equipment	30.1	18.8	30.4	9.1	11.8	14.2
Forestry	0.0	24.3	27.8	4.5	6.5	9.0
Paper & Paper Products	1.2	20.9	26.8	3.7	15.3	19.7
Non-Ferrous Metals	0.5	25.0	26.8	3.1	29.8	34.3
Lumber	6.0	21.6	28.1	2.3	20.0	23.0
Other Food	1.3	26.3	30.8	1.8	27.8	30.0
Petroleum & Coke	0.2	46.7	55.5	1.7	25.9	28.4
Other Animal Products	0.1	31.8	36.3	1.0	22.7	26.1
Other Mining	0.1	24.9	29.8	1.0	20.2	20.5
Other Grains	0.0	25.0	30.0	1.0	24.9	34.9
Iron & Steel	0.4	32.6	35.0	0.9	23.4	23.8
Fabricated Metal Products	3.8	22.3	29.7	0.8	16.8	20.9
Beverages and Tobacco products	0.0	12.9	18.6	0.8	29.9	34.3
Textiles	4.3	15.6	24.5	0.7	12.2	14.7
Non-Metallic Minerals	1.6	19.4	26.3	0.6	14.9	17.7
Other Crops	0.1	23.6	26.6	0.6	22.2	29.1
Other Manufacturing	7.2	7.1	18.9	0.6	16.5	22.2
Other Meat	0.0	35.6	40.6	0.6	54.5	54.9
Plant Fibres	0.0	25.0	30.0	0.5	25.0	30.0
Veritable & Fruit	0.2	29.5	39.1	0.4	48.6	48.6
Leather	4.6	18.1	28.2	0.4	20.4	24.3

Oil	0.0	25.0	30.0	0.3	5.0	5.0
Milk	0.0	15.6	15.8	0.3	23.5	24.5
Fishing	0.0	23.3	27.8	0.2	1.6	1.6
Wheat	0.0	25.0	30.0	0.2	24.3	34.3
Vegetable Oils	0.0	22.2	25.7	0.1	23.3	30.8
Gas	0.0	25.0	30.0	0.1	25.0	25.0
Coal	0.0	25.0	30.0	0.1	29.9	29.9
Other Transport Equipment	0.8	23.4	28.1	0.1	16.9	19.4
Wearing Apparel	4.9	16.4	19.2	0.1	24.7	25.6
Cattle	0.0	22.9	26.9	0.0	0.1	0.1
Wool	0.0	25.0	30.0	0.0	24.6	24.6
Cattle Meat	0.0	25.0	30.0	0.0	23.5	23.5
Sugar	0.0	33.7	37.5	0.0	11.4	11.4
Gas Distribution	0.0	25.0	30.0	0.0	25.0	25.0
Processed Rice	0.0	25.0	30.0	0.0	25.0	25.0
Cane & Beet	0.0	25.0	30.0	0.0	30.0	37.5
Paddy Rice	0.0	25.0	30.0	0.0	25.0	25.0
Electricity	0.0	25.0	30.0	0.0	0.0	0.0
Weighted Average	0.0	21.7	30.5	0.0	20.7	24.0
Total Value of Exports ($billion)	495.0			117.0		

Note: The tariff increases are from the trade war database by Li (2019). $E_{cn,us}$ represents the sector's share in Chinese exports to the United States. $E_{us,cn}$ represents the sector's share in U.S. exports to China. Trade flows are based on 2016 data reported by the United States from the UN Comtrade database. In 2016, total export to the world is $2,097 billion for China (reported by China) and $1,450 billion for the U.S. (reported by the U.S.). Items in the table are ranked by their shares in China's export to the United States

3.2 Welfare

This section reports percentage changes in overall welfare across countries (Figure 1), for the three scenarios. Welfare calculations are based on equivalent variation. Overall, the steel and aluminum tariffs have minor effects on welfare compared to the trade disputes between the United States and China. With the accumulated tariffs as of September 2019 (scenario 2), welfare in the United States decreases by 0.3% and welfare in China decreases by 1.9%. Accumulated tariffs as of December 2019 (scenario 3) further increase China's welfare loss to 2.3% and U.S. welfare loss to 0.4%. Most other countries and regions, especially major exporters of manufactured goods to the United States, gain from the trade disputes between the United States and China. Viet Nam, Mexico, and Qatar, gaining 1.2%, 0.83%, and 0.69% of welfare respectively under scenario 2, are the largest winners in the U.S.-China trade war.

Given the scale of the trade distortion, the estimated welfare impacts seems modest. One reason is that the sizable tariffs are limited to U.S.-China trade. Trade diversion to and from other countries substantially offsets the impacts. The results are also consistent with high optimal tariffs—a well known suspicious feature of Armington models.[3] The tariff increases generate beneficial terms-of-trade impacts that help to offset the adverse welfare impacts. Error bars are included in Figure 1 to illustrate the range of results when we increase and decrease the trade elasticities by two standard deviations (as reported in their original estimation (Hertel et al., 2007)). Deviations from the central trade elasticities has little impact on the welfare impacts, but does play a role in the sectoral responses reported below.

3.3 Sectoral Impacts in the United States and China

While welfare change is essential for aggregate policy decisions, there are important distributional impacts that cleave with import-competing and exporting sectors. In this section, we present changes in revenue by sector. Figures 2 and 3 present the major sectoral impacts for the United States and China. The first-order effect of a tariff increase is to depress revenue in exporting sectors and increase revenue in import-competing sectors that are targeted. These impacts explain the revenue growth of the U.S. iron and steel sector under scenario 1 (Figure 2). It can also explain the decline in the U.S. oilseed sector (largely soybeans). In scenarios 2 and 3 sizeable tariffs on Chinese electronic products support the U.S. electronic equipment sector. For China, the electronic equipment sector suffers significantly

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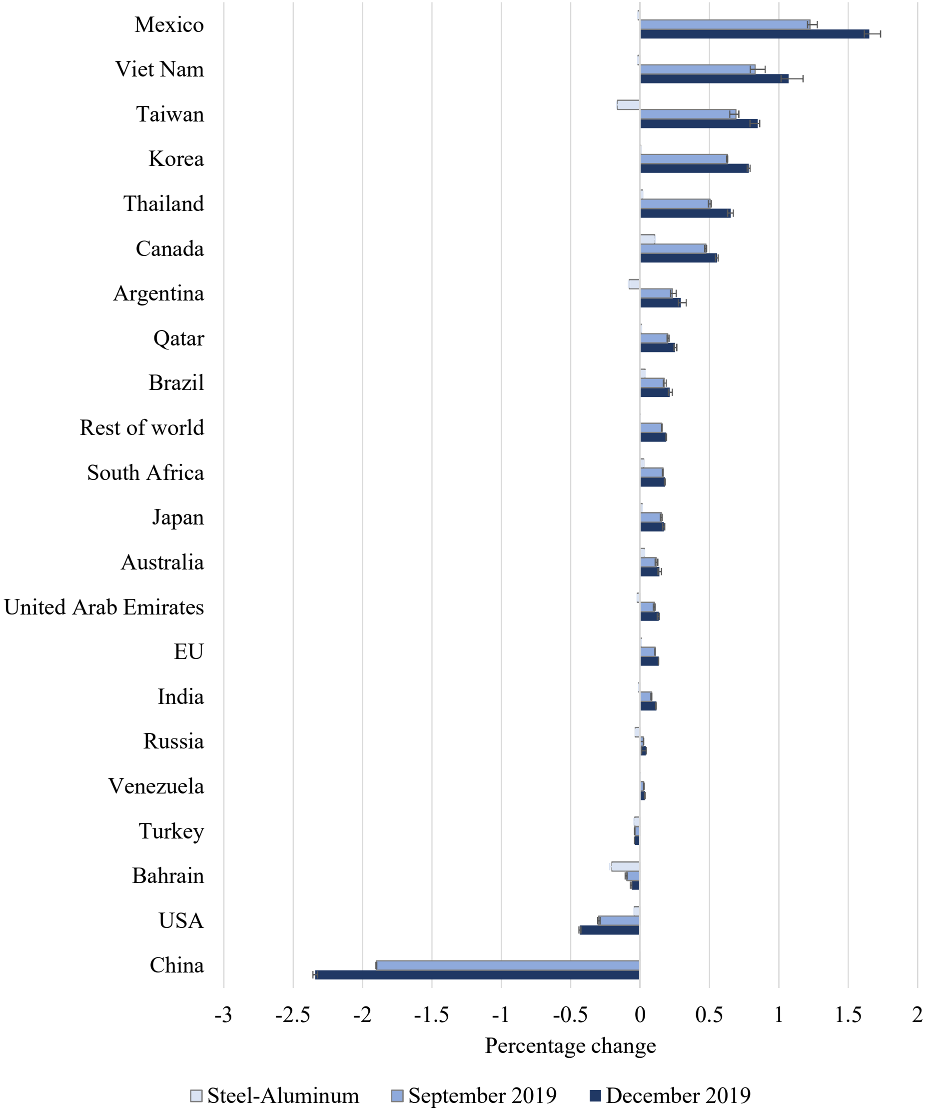
[3] See Brown (1987), Balistreri and Markusen (2009), and Balistreri and Rutherford (2013) for a critiques of the Armington structure and implied optimal tariffs. In fact, for China Balistreri and Rutherford (2013) show that the qualitative welfare impact of a marginal move away from observed tariffs is sensitive to the particular trade structure: Armington (1969) versus Melitz (2003).

under these barriers. We present the results in both percentage and absolute change ($Billion) to reveal the importance of the trade dispute to the individual sector and the economy as a whole. For example, in scenario 2, the revenue of the U.S. oilseed sector declines by over 19.4% or $8.3 Billion, and the revenue of the Chinese electronic equipment sector declines by 3.1%, which is a loss of more than $72.1 Billion.

We also highlight second-order effects that operate through upstream and downstream sectors. For example, in the United States the transport equipment (other than cars and truck) sector suffers a loss from the steel and aluminum tariffs due to higher input costs, and the service sectors like the retail and wholesale trade sector in the United States and China suffer significant revenue reductions.

Figure 1. Welfare impacts across regions (% change)



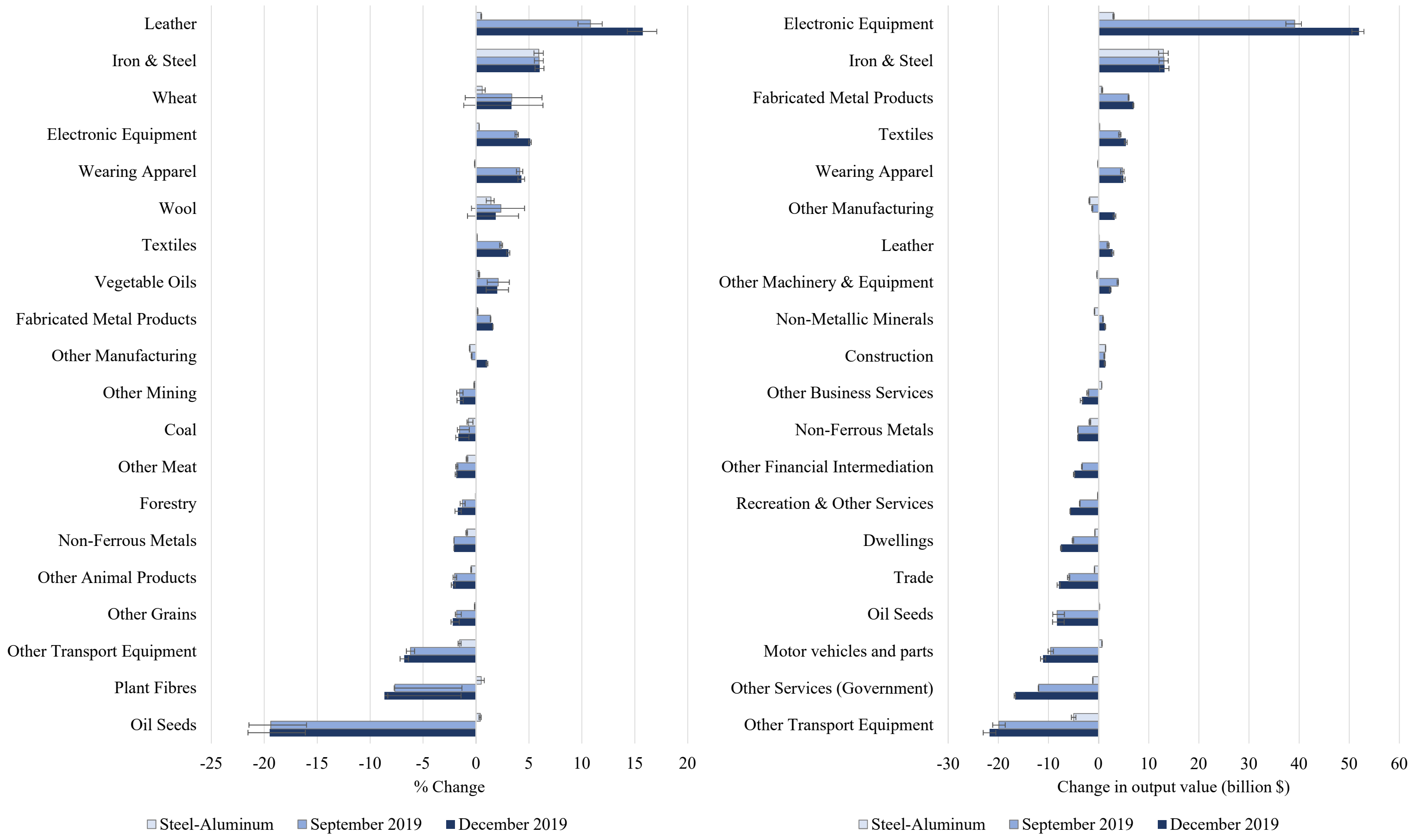


Figure 2. US revenue changes (% and $B) by sector (top 10 winners and losers)

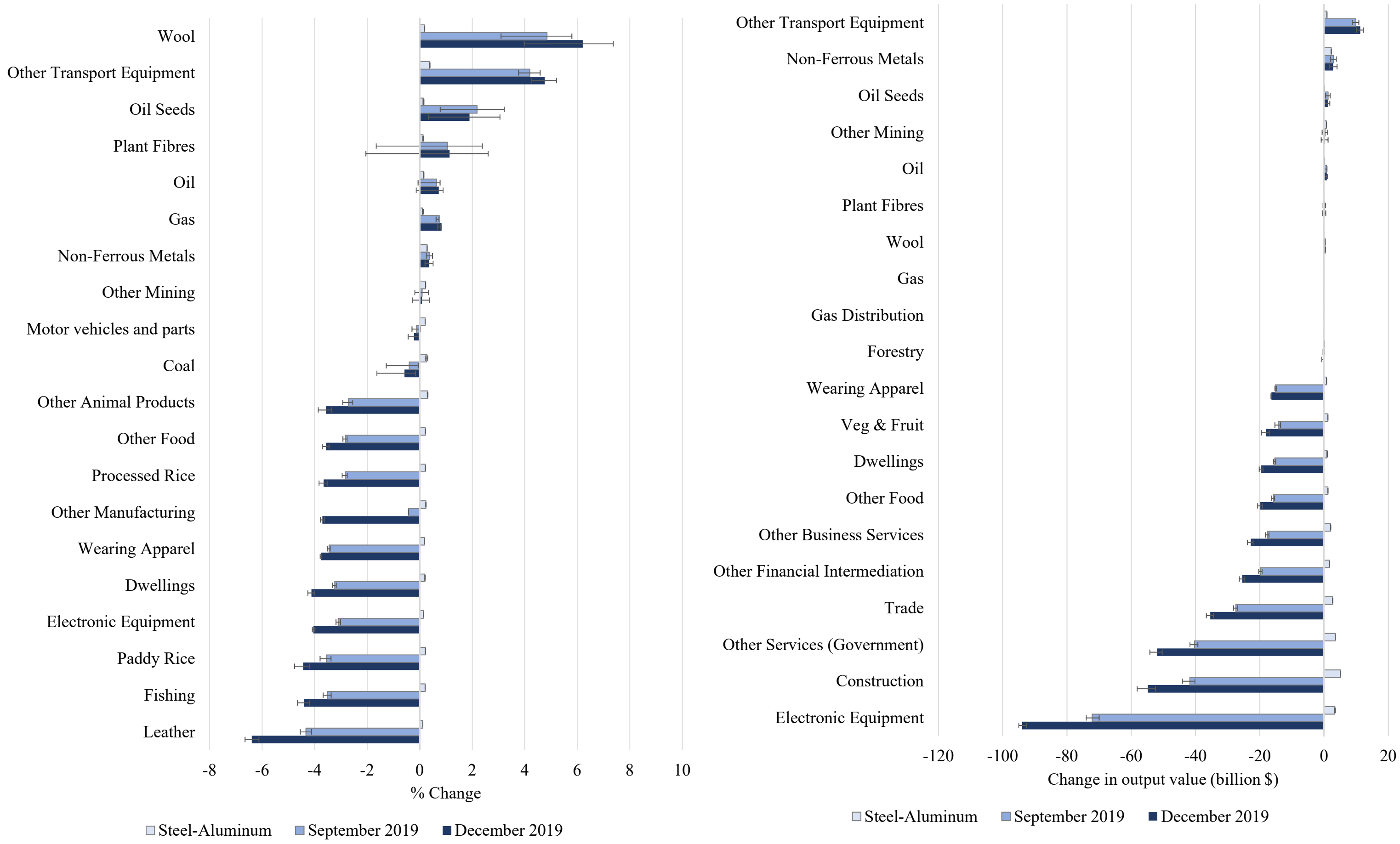


Figure 3. China revenue changes (% and $B) by sector (top 10 winners and losers)

Table 2. Change in the pattern of international trade (%)

		Importer						Total
Exporter	Scenario	U.S.	China	EU	Canada	Mexico	Others	Exports
U.S.	Steel-aluminum		-1.6	-2.0	-3.0	0.3	0.4	-0.9
	September 2019		-50.7	-2.7	-3.1	-1.2	-1.1	-6.4
	December 2019		-54.9	-3.1	-3.3	-1.4	-1.8	-7.2
China	Steel-aluminum	-0.5		0.4	1.3	0.1	0.2	0.1
	September 2019	-58.3		9.0	11.7	12.2	7.2	-4.4
	December 2019	-72.5		11.3	14.7	15.6	9.1	-5.4
EU	Steel-aluminum	-0.9	0.3	0.3	1.3	0.0	0.1	0.2
	September 2019	6.9	-0.3	-0.2	2.3	1.8	-0.9	0.2
	December 2019	9.4	-1.1	-0.4	2.5	2.2	-1.2	0.2
Canada	Steel-aluminum	-1.8	0.8	1.0		-0.2	0.7	-0.9
	September 2019	1.1	1.6	-1.7		-0.1	-2.3	0.3
	December 2019	1.9	0.5	-2.4		-0.4	-3.0	0.5
Mexico	Steel-aluminum	0.0	0.5	0.6	1.1		0.4	0.2
	September 2019	6.5	-6.2	-6.4	-6.3		-7.8	2.4
	December 2019	8.5	-8.5	-8.4	-8.4		-10.0	3.1
Others	Steel-aluminum	-0.4	0.3	0.3	1.6	0.1	0.2	0.2
	September 2019	9.5	-0.9	-0.3	1.9	2.0	-0.9	0.5
	December 2019	12.6	-1.7	-0.5	2.0	2.4	-1.2	0.5
Total Import	Steel-aluminum	-0.7	0.1	0.2	-0.8	0.2	0.2	
	September 2019	-4.6	-5.3	0.2	0.2	2.1	0.4	
	December 2019	-5.2	-6.4	0.1	0.3	2.8	0.4	

3.4 The pattern of trade

In Table 2 we report the percent change in trade flows. Major shifts in trade patterns are mostly focused on the United States and China. With cumulative tariff increase as of September 2019 tariffs, exports from China to the United States fall by 58.3%, and exports from the United States to China fall by 50.7%. [4] We show significant trade diversion as total Chinese exports fall by only 5.3%, with major penetration into the EU (+9.0%), Canadian (11.7%), and Mexican (12.2%) markets. While the U.S. intent is to promote exports the trade disruptions have the opposite effect. It is notable that U.S. exports fall to each of the major trading partners (China, the EU, Canada, and Mexico).[5] Overall, U.S. exports fall by 6.4% under the tariffs accumulated as of September 2019. With the threaten tariffs in scenario 3, exports from China to the United States will decrease by 72.5%.

4. Conclusion and Discussion

This paper introduces a data source for the tariff increases resulting from the recent trade disputes and documents the impacts of these tariffs using a standard off-the-shelf general-equilibrium simulation model. We find modest impacts on overall welfare, but large impacts on sectoral revenue and the pattern of international trade.

The welfare impacts estimated by this study (-1.9% for China and -0.3% for the United States by September 2019) are comparable to those of previous significant trade events. For example, the welfare impacts of China's WTO accession is estimated to be 1.24% by Li and Zhai (2000) and 2.2% by Ianchovichina and Martin (2003). Similarly, for China's WTO accession, Chen and Ravallion (2004) estimated a 1.5% increase in China's mean income, and Wang (2003) estimated a 2.9% increase in China's cumulative GDP by 2010. For other major trade agreements, papers reviewed by Francois (2000) find the WTO agreements in the Uruguay round increase China's welfare by -0.2% to 1.7%, and U.S. welfare by 0.1% to 0.9%. Ballard and Cheong (1997) estimated that the establishment of a Pacific free trade area including China and the United States would increase China's welfare by 1.4% and U.S. welfare by 0.13%. Results from this paper demonstrate that the U.S.-China trade war is among the most significant trade events in recent history.

Key limitations of the GTAPinGAMS model that we employ include parametric and structural uncertainty. In order to look at some preliminary parametric sensitivities we present results based on the econometric standard errors on

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[4] With low (high) Armington elasticities, China's exports to the United States fall by 56.3% (60.1%) and exports from the United States to China fall by 46.7% (53.8%).

[5] Our analysis does not currently consider the renegotiated NAFTA, also known as the United-States- Mexico-Canada Agreement. However, since the new NAFTA largely maintains tariff-free trade in most goods, we expect it to have little impact at the aggregate level.

the elasticities of substitution between regional varieties (the trade elasticities). We leave an exploration of structural sensitivity for future research. Significant progress has been made in the adoption of advanced trade structures in a computational setting. In fact, the recent work of Balistreri and Tarr (2018), Costinot and Rodríguez-Clare (2014), and Balistreri, Hillberry, and Rutherford (2011) suggests considerable differences across models that consider trade induced variety and productivity adjustments. Our intention is to encourage this analysis by establishing a transparent reference point for more elaborate empirical simulation environments. We are also hopeful that the compiled database for the U.S.-China trade war will facilitate these and other future applications.

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