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Modeling Trade Tensions: Different Mechanisms in General Equilibrium

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Abstract

In this paper, we investigate the mechanisms through which import tariffs impact the macroeconomy in two large scale workhorse models used for quantitative policy analysis: a computational general equilibrium (CGE) model (Purdue University GTAP model) and a multi-country dynamic stochastic general equilibrium (DSGE) model (IMF GIMF model). The quantitative effects of an increase in tariffs reflect different mechanisms at work. Like other models in the trade literature, in GTAP higher tariffs generate a loss in terms of output arising from an inefficient reallocation of resources between sectors. In GIMF instead, as in other DSGE models, tariffs act as a disincentive to factor utilization. We show that the two models/channels can be broadly interpreted as capturing the impact of tariffs on different components of a country's aggregate production function: aggregate productivity (GTAP) and factor supply/utilization (GIMF). We discuss ways to combine the estimates from these two models to provide a more complete assessment of the macro effects of tariffs.

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1 Introduction

Questions related to trade policies have again come to the forefront of economic research. Most recent analyses have relied on two different modeling approaches. On the one hand, trade economists often rely on computable general equilibrium (CGE) models with considerable sectoral disaggregation and attention to input/output relations, but typically with little account of the dynamic adjustment to new policy measures. On the other hand, to answer questions related to trade policies macroeconomists have relied on dynamic stochastic general equilibrium (DSGE) models with considerably less disaggregation and more emphasis on dynamics, stock-flow consistency, policy rules, and expectations. As a result, those two approaches highlight different implications of the distortions brought about by trade policies. In this paper, we analyze a simple stylized tariff experiment to investigate the mechanisms underlying the macroeconomic impact of import tariffs in two large quantitative workhorse models: a computable general equilibrium (CGE) model (the Global Trade Analysis Project Consortiums model or GTAP) and a multi-country dynamic stochastic general equilibrium (DSGE) model (the IMFs Global Integrated Monetary and Fiscal model or GIMF). We lay out a stylized experiment: an unexpected permanent 10-percentage-point increase of U.S. import tariffs on Chinese goods, with China retaliating in kind. Both models display negative GDP outcomes as a result, albeit for different reasons.

The GTAP version used in this paper is a comparative static, multi-region, multi-sector, CGE model. Trade is motivated by the Armington (1965) assumption that goods are differentiated by country of origin and the household in each country likes varieties. Each country contains multiple sectors linked through an input-output structure to other domestic and foreign sectors. On the production side, firms minimize a cost function and demand inputs according to their relative prices. Prices of commodities are such that they clear the markets. Market clearing conditions pin down prices and wages. All production factors are in fixed net supply and fully employed.

In this setup, the presence of a tax or trade tariff represents a distortion to prices and introduces an inefficiency in the allocation of resources across sectors. A tariff generates a chain effect on prices. The input-output structure of the model governs the propagation of this shock by sector and country. Higher prices of imported inputs subject to the tariff put upward pressure on sale prices in sectors more exposed to trade and lower their demand for imported inputs. Less competitive prices will also generate a fall in external sector sales. The production of sectors interlinked through trade declines, which among other things, generates a contraction of demand for domestic factors of production. Other sectors may instead see domestic demand increase as households substitute away from more expensive imported goods. However, on net aggregate production will decline as well as the demand for production factors, as the Armington preferences and the tariff wedge on prices prevent the full offset of imports with domestic products.

When combined with the assumption that the endowment of production factors is fixed and fully employed, factor prices decline overall to clear markets, which indicates that the same endowment of factors is now allocated less optimally. The more exposed a country is to trade, the larger is the loss in productivity/efficiency that is reflected in the fall in real GDP.[1]

[1]Put in a different way, prices now allow other sectors, supposedly less productive, to substitute for more

GIMF features optimizing households and firms and a public sector that defines fiscal and monetary policies in each country. Trade flows between regions are modeled both for intermediate and final goods and also feature Armington (1965) preferences over aggregate bundles, e.g. imports of intermediate goods from China. There are also a series of frictions and rigidities, which amplify the impact of shocks in the short and medium run. Unlike GTAP, there is limited sectoral disaggregation; on the other hand, decision rules in the model are fully specified and factor endowment and their utilization can adjust.

In GIMF, higher tariffs introduce a dynamic distortion. They affect (relative) prices of import goods and firms production costs and via this wedge they impact dynamic investment decisions in the country introducing the tariff. An increase in import tariffs generates an appreciation of the exchange rate for the country imposing the tariffs, a fall in investment, capital stock, labor, and exports, in the long run. In particular, for a given (exogenous) level of productivity, the model provides an estimates of the impact of the distortion on factor supplies/utilization and quantifies the magnitude of the contraction. The inefficiency introduced by import tariffs is measured precisely by this contraction.

In sum, the two models look at the same distortion, an increase in import tariffs, from two different and complementary angles. To our knowledge, no previous work has analyzed both approaches, namely measuring the impact of trade distortions on factor supply/utilization and on factor productivity arising from changes in sectoral allocation. In the second part of the paper, we use the results from one framework, namely GTAP, as estimates of the productivity loss, arising from the trade tariffs, to complement the effect of the same change in tariffs in GIMF. We find that, in some cases, the effect of a contraction of factor supply compounds with the loss in productivity from resource reallocation delivering significantly more negative results. We also find that the estimates of GDP losses in GTAP are quite robust to changes in the elasticity of substitution between imported and domestic goods.

We are aware that this approach may lead to an overestimation of the impact of the two channels on macroeconomic variables. In a framework that jointly determines the impact of import tariffs on the supply of production factors and sectoral reallocation of resources, commodity prices and quantities will adjust through general equilibrium conditions, delivering possible smaller impacts on real output. For instance, an increase in marginal returns in sectors that endogenously reduce investment and capital might mute incentives for sectoral reallocation. Or the fact that aggregate factor supply can contract may imply less sectoral reallocation and lower productivity losses. In addition, considering all these aspects in a unified framework can allow for a transition period, characterized for instance by imperfect or sluggish substitution of production factors across sectors. However, such a model would pose non trivial computational challenges. [2] Aware of such difficulties, we aim at constructing a potential range of trade policy effects, combining both models results and approaches.

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expensive imported goods. Heterogeneous productivity of trade partners/sectors is not specifically modeled but is implicit in the existing input-output structure of the model. This view could be compared with one in a Ricardian model where less productive firms can enter in a new domestic market after imports are made expensive by the introduction of a tariff (see for instance, Caliendo et al., 2017). While in GTAP the concept is derived as an implicit inefficiency, in these new Ricardian trade models it is possible to track the entire new distribution of productivity by firm (and the related aggregate impact).

[2] McKibbin and Wilcox (1999) are an example of a model which come close to combining DSGE and CGE frameworks

This paper relates to two strands of literature. It relates to the literature on the effect of trade policies in macroeconomic models (Erceg et al., 2006, 2008 and 2018; Linde and Pescatori, 2017; Barbiero et al., 2017). Similar to GIMF, these papers mostly focus on dynamic models and on some of the main features and ingredients through which trade tariffs or subsidies have an impact on real and nominal variables. However, they lack a multi-country perspective and are not equipped to study spillovers to third countries and bilateral unbalanced trade flows (e.g. trade between the U.S. and China). In addition, they share the same limitations of GIMF in that a lack of sectoral and value chain foundation for trade flows ignores some of the channels of transmission of trade policy measures. In this paper, we aim at comparing and highlighting both the impact of trade tariffs on investment and factor supply/utilization and on reallocation of resources away from the sectors of interest. We also show how rigidities and international price settings influence trade diversion, expenditure switching and exchange rate dynamics. Accounting for unbalanced bilateral trade mitigates some of the results of the traditional two-country models. For instance, even in the case of two countries with same macroeconomic characteristics with symmetric policies, we observe a response in the exchange rate.

This paper also relates to the trade literature focusing on analyzing the impact of trade policies with more detailed attention to the production value chain (Caliendo et al., 2017; Walmsley and Minor, 2017; Caceres et al., 2019; Bekkers and Teh, 2019). Models like GTAP, or more recent contributions as in Caliendo et al. (2017) that follow a Ricardian approach to trade, are silent on the impact of trade policies on production factors and dynamic decisions.

The organization of the paper is as follows. Section 2 draws a brief overview of both GIMF and GTAP. Section 3 describes the main experiments and results. In Section 4, we discuss the sensitivity of GTAP estimates to changes in the elasticity of substitution between domestic and imported goods. In Section 5, we combine GTAP and GIMF estimates of the impact of tariff increases and analyze the mechanisms. Section 6 concludes.

2 An overview of the GTAP and GIMF models

2.1 GTAP

GTAP is a comparative static, multi-region, multi-sector, computable general equilibrium model. For a comprehensive description of the standard version of GTAP, see Hertel (1997) and Gohin and Hertel (2003).[3] In each region, there is a representative household and different firms, one for each commodity sector. Sectors produce tradable and nontradable commodities/services. All sectors are interconnected through an input-output structure. In each sector, a representative firm optimizes over the cost of all commodity inputs and primary factors, in order to produce output. The general equilibrium feature of the model assures that markets clear, both at the regional and global level. In particular, market clearing conditions ensure primary factors, which are in fixed net supply at the regional level, are fully employed. The household in each region maximizes a utility function and is constrained by a budget, which is composed of incomes from production factors and tax revenues. An Armington

[3] There have been several extensions of model, e.g. creating a dynamic version of the model by incorporating endogenous capital accumulation, accounting for international capital flows etc. (see Hertel, 2012).

assumption ensures that preferences are defined over a composite of domestic and imported goods, differentiated by countries of provenience. The shape of the utility function (usually a constant elasticity of substitution, CES) guarantees that the solution of the problem can be represented by spending shares.[4] Investment does not cumulate into capital stock and is treated as a form of households expenditure, determined by relative rates of return across regions.

To understand the mechanics brought about by a shock, it is necessary to discuss its solution algorithm. In Appendix A, we lay down the main equations constituting the standard version of the model and discuss the algorithm exploited when a region is hit by an import tariff shock, under the assumption (i.e. closure) that production factors are in fixed supplied and fully employed. Firms and household blocks in each region and for all the commodities are represented by behavioral equations. Several accounting equations and identities complete the model. The result is a complex system of non-linear equations.

When economies in the model are hit by a shock, the solution is calculated by approximating the system of equations with its linearized equivalent such that it is not necessary to solve the decision rule for each variable (i.e. it is not necessary to solve for levels of key variables). The solution set delivers the percentage deviation from each variable initial value. For the behavioral equations, such as demand of a certain commodity, this implies that deviations of main variables from initial values become a function of reduced-form elasticity parameters.

In this setup, a trade tariff shock represents a distortion to prices and introduces an inefficiency. A tariff generates a chain effect on prices. After a tariff shock, quantities and prices adjust to satisfy the firms and households (linearized) changes in demand of domestic and imported goods. The input-output structure of the model governs the propagation of the shock by sector and country. On net, the price distortion introduced by the tariff generates two main effects.

In the country imposing the tariff, higher prices of imported inputs put upward pressure on sale prices in sectors exposed to trade. They would consequently lower their demand for imported inputs substituting them to a certain extent with domestic equivalents. This in itself signals an inefficiency. The import tariff introduces a wedge that allows goods produced domestically at less competitive prices to become suddenly viable. Imperfect substitutability and higher prices of domestic inputs will generate a general increase in prices, a fall in final (domestic and external) demand for sectors more exposed to trade and a lower demand for production factors. For the country whose exports are hit by the tariff, the increase in prices in a particular export market caused by the tariff would similarly lead to a downward pressure on output and production factors, via lower external demand.

In both countries, fixed supply of production factors and the full employment condition forces factor prices to decline in order to clear the markets. In other words, misallocations or inefficiencies arising from a higher import tariff are measured in terms of the real factor prices that prevail in a new steady state, assuming that total utilization of production factors remains unaltered. Factor returns and output decline relative to a state of the world with no tariffs, indicating that those factors are now allocated less optimally.

The more exposed a country and its sectors are to trade, the larger the loss in productiv-

[4] There is a fiscal sector, that levies taxes and tariffs on imports and spends for public expenditure. However, if tax revenue falls, government spending remains endogenously unchanged.

ity/efficiency arising from the sub-optimal allocation. The fall in factor returns determines a decline in the terms of trade that is also greater the more open a country is to trade (see the case of China in the following sections).

2.2 GIMF

This section provides an overview of the structure of the IMF's Global Integrated Monetary and Fiscal (GIMF) model. For a detailed description of the model see Kumhof et al. (2010). GIMF is a multi-country dynamic general equilibrium (DSGE) model with optimizing households and firms and with a public sector that defines fiscal and monetary policies in each country. In each region, agents operate in incomplete markets. There are two types of households, optimizing and liquidity-constrained. The optimizing agents are overlapping-generations (OLG) households with finite planning horizons a la Blanchard (1985), whose horizons embody some degree of myopia. Liquidity-constrained households consume according to the same preferences but consume only their current income since they have no access to financial markets.

A continuum of firms produces consumption and investment goods using labor and capital with a constant-return-to-scale technology and Hicksian neutral factor productivity. The model features a financial accelerator in the spirit of Bernanke, Gertler and Gilchrist (1999) and several types of nominal and real rigidities that amplify the impact of shocks and justify a role for stabilization policies. There are several layers of production. In each layer, there are different sets of nominal or real rigidities and agents face competitive input markets and monopolistically competitive output markets. The significant flexibility of these layers makes the model a useful framework for addressing various types of macro policy questions.

For the purpose of the present paper, it is important to highlight the part of the model related to international trade and tariff policies, described in more details in Appendix B. This block shares some similarities with GTAP. Each country or region is populated by households who have preferences for a variety of goods from different provenience (Armington assumption). All bilateral trade flows are explicitly modeled, as are the relative prices for each region.

The main differences between the two models are the limited sectoral disaggregation and the presence of dynamically consistent decision rules in GIMF. Dynamic consistency in the model is not only insured by movements of quantities and prices but also by a nominal exchange rate. The non-linear equations are solved for the fully dynamic decision rules using Newton methods. This implies that, different from the static version of GTAP used here, GIMF allows us to study long-run outcomes as well as full transition paths, after the economy is hit by a shock. The short-run dynamics are then characterized by several nominal and real rigidities and monetary and fiscal policy reaction functions. Specifically for the external sector in the model, adjustment costs on investment and imports and the possibility to account for different types of currency invoicing (and exchange rate pass-through) shape macroeconomic variables' reaction functions.

International linkages are also different in GIMF. Similarly to GTAP, the magnitude of the trade linkages is the main determinant of spillover effects from shocks in one region to other regions in the world.[5] However, linkages also relate to the dynamics of global savings. Savings

[5]The model also allows for technological spillovers in that an improvement in the technology of one country

and investment in each region pin down the dynamic of net foreign asset positions and the real interest rate. Preferences and relative prices pin down the scale of the international linkages.[6] In the initial steady state, we solve for a zero trade balance, and therefore zero foreign asset position. However, the presence of multiple regions allows for bilateral trade deficits. To equate total imports and exports, each country's bilateral position is just rescaled. While net imports or exports positions are muted by this process, the relative importance of trade links with each partner remain unaltered.

In GIMF, tariffs introduce a dynamic distortion (see Appendix B.1 for more details). If a country raises tariffs, the prices of import components of consumption and investment bundles increase generating a negative impulse on domestic demand and pressure on inflation and interest rates. At the same time, the goods of the affected trade partners are less competitive and their exports fall. Absent any exchange rate dynamics, the net export position of the country imposing the tariff may improve putting pressure on asset markets. To restore consistency of the overall external balance with the intertemporal conditions for asset holdings, the currency of the country imposing the tariff appreciates.

A comparison with Erceg et al. (2018) would also help shed light on the transmission channels of a trade shock. Their model is very similar to GIMF but features two countries, perfectly symmetric initial trade flows and producer currency pricing (PCP, i.e. the fact that prices are rigid in the currency of the producers). [7] In this setup, if the two countries:

- impose the same import tariffs;
- are identical in terms of all macroeconomic characteristics; and,
- implement permanent measures,

the import tariffs would generate equal and opposite forces on import pricing equations and external trade balances. The symmetry will also involve same pressure on both countries' inflation and interest rates. In this case, the exchange rate would not move. However, the tariff would still have (symmetric) allocative effects in both countries. It would introduce a distortion that would impact investment and labor supply.

In GIMF, even if the above three conditions were to hold, the initial asymmetry of bilateral trade flows would generate movements in exchange rates to satisfy the intertemporal condition for bond holdings (uncovered interest rate parity, UIP, condition). This would add to the effects of the pure distortion introduced by the tariff.

Finally, if the two countries are both different in terms of macroeconomic factors and the initial trade flows are asymmetric, the trade shock would generate a complex set of reactions that would ultimately put pressure on the external balances, interest rates and inflation. The exchange rate in this case needs to jointly rebalance the external sector and satisfy the UIP condition. The movement in the exchange rate amplifies the impact of the tariff distortion

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not only leads to a lower cost in that country, but also to a higher demand for the respective goods and lower costs in all trading partners.

[6]In the initial steady state, bias parameters are also used to calibrate the model to replicate the relative scale of the bilateral trade relationships present in the data.

[7]Producer currency pricing (PCP) imply producers set prices in the domestic currency while letting prices in the foreign market adjust to ensure that unit revenues are equalized across markets.

on investment and exports. In the short run, macroeconomic dynamics are exacerbated by several types of nominal and real rigidities, namely adjustment costs of investment and imports and imperfect flexibility in prices.

In the long run, local production substitutes for some imports from abroad in the country imposing tariffs, absent any rigidity. However, similarly to the case of GTAP, imperfect substitutability between domestic and foreign goods, dictated primarily by Armington-type preferences, does not allow domestic production to expand enough to completely offset the initial fall in investment and exports. A contraction of factors supply/utilization (measuring the distortion introduced by higher tariffs) and imperfect substitutability of goods are key in underscoring a loss in output for the country imposing tariffs.

In all, the exchange rate plays an important role as a rebalancing factor in DSGE models like GIMF, both in the short and long run, especially as contracts are set in incomplete markets. Linde and Pescatori (2017) show that the exchange rate plays a key role in DSGE models in the case of import tariffs, for the so called Lerner symmetry (Lerner, 1936) as long as markets are not complete. When markets are complete, optimal contracts ensure that the marginal utility from an additional unit of currency is proportional between home and foreign consumers in all states of the world, therefore preventing sharp swings in the exchange rate.

2.3 Parameterization and data

In this section, we describe the baseline models parameters and specifications used for the quantitative exercise.

GTAP. The version used in this paper comprises six regions with thirteen sectors in each region ($j = 13$).[8] The regions are: the U.S.A., China, Euro Area (Euro), Japan, Emerging Asia (Asia) and the Rest of the World (RestWorld). Emerging Asia includes Hong Kong SAR, Indonesia, India, Korea, Malaysia, Philippines, Singapore, Thailand, and Taiwan province of China.

Elasticities of substitution for the different commodities are estimated by the GTAP consortium using a complex variety of data. This version of the GTAP model uses the GTAP database v10 (2014), which in line with previous versions collects data from a complex set of sources, including single countries' Input-Output Table or Social Accounting Matrix (SAM), and COMTRADE data from international financial institutions (IMF and World Bank).[9]

Table C.1 in Appendix C displays the details about sectors/commodities and elasticity of substitution for each of them. The elasticity of substitution between domestic and foreign goods ϵ_j averages just above 3 and the elasticities of substitution among imported varieties θ_j for different sectors are set to roughly double this value, following the rule of two (Hertel et al., 2009). This signifies that it is twice (technologically) as easy to substitute import partners than it is to substitute between domestic products and the import basket.

The parameters quantifying distribution shares of domestic versus imported input commodities and for imported commodities between partner countries are taken from the data, for each

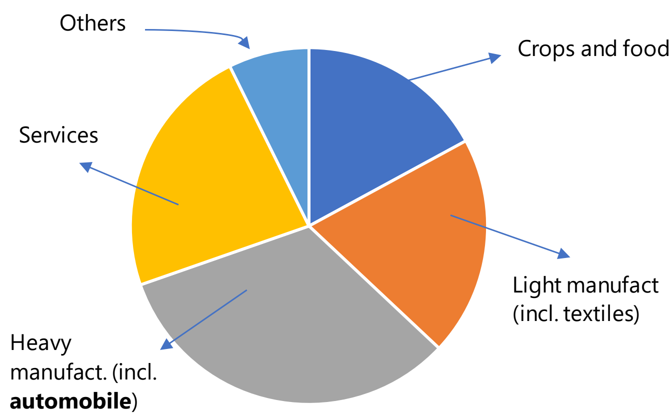
[8] GTAP features a total of 121 economies and 65 sectors; these can be aggregated into broader regions and sectors as needed.

[9] A detailed description of the database and a downloadable version of the GTAP v10 are available at: https://www.gtap.agecon.purdue.edu/databases/v10/index.aspx.

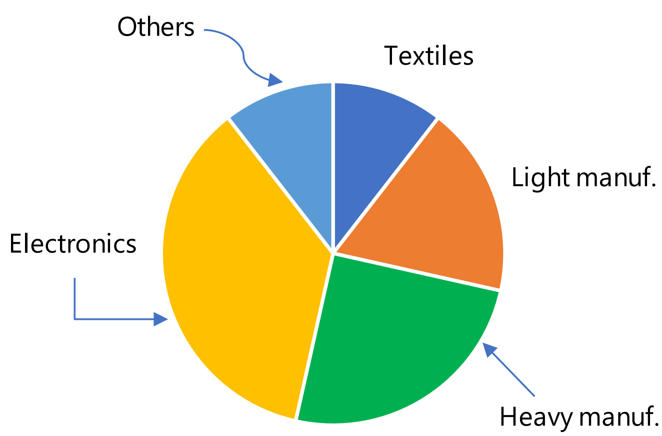
sector j, region r and import country s. Given the elasticity of substitution, these values are then calibrated to replicate import shares of output and by partner region in the data (as well as the domestic input-output shares) for each region. Figure 1 displays the sectoral linkages between the main two global economies, the U.S. and China. The share of exports by each sector portrays the deep trade ties between the U.S. and China in the electronics and manufacturing sectors, which are part of global value chains. Finally, Table C.2 in Appendix C reports the values of the resulting bilateral trade flows by region, from the perspective of exports of each region.

Figure 1: Trade by sector in GTAP

Panel A: USA



Panel B: China



Source: IMF calculation. In percent of total exports.

GIMF. In this paper we use a version of the model with the same six regions used to calibrate GTAP. We exploit a rich database to calibrate the several layers of the model: internal IMF databases as well as external sources, including IMF World Economic Outlook (WEO), IMF Direction of Trade (DOTS), IMF Government Financial Statistics (GFS), UN population and labor force data, WB COMTRADE. The version applied here relies on data as of 2017. Key parameters and ratios are reported in Table C.3, Appendix C. The other parameters key for international trade flows are the elasticities of substitution ϵ_j and θ_j. We set values for $j \in \{final, intermediate\}$ parameters to 1.5 for the benchmark simulations (see also Erceg et al, 2008).

Table C.4, Appendix C, summarizes the bilateral trade flows as a share of GDP between all six regions, from the perspective of exports of each region. These flows include the export and import of intermediate and final (consumption and investment) goods.[10] We calibrate the model in its initial steady state assuming that the aggregate trade balance for each region is zero.[11] Hence, the flows in the table reflect the relative importance of trading partners for each region not necessarily single absolute magnitude of bilateral flows. For instance, imports and exports between China and the U.S. are heavily unbalanced in the data (with a strong surplus for China and consequent deficit for the U.S.), while the model depicts a much milder position. However, it correctly accounts for the relative importance of the U.S. as one of the main destination markets for Chinese production.

The mentioned treatment of trade imbalances in GIMF and differences in data used in GTAP explain most of the difference observed between the two trade matrices in Table C.2 and C.4. In addition in GTAP, regions comprising more than one country are allowed to trade "within" themselves. In GIMF, there is not intraregional trade. Overall, despite the difference, the relative importance of each partner in the total trade flows is similar in the two models.

3 Transmission channels of tariff policies: a stylized experiment

The goal of this section is to conduct a positive analysis of the impact of an import tariff policy using both GTAP and GIMF.[12] We will set forth a simple experiment which will serve two purposes: (i) a quantification of the losses or gains arising from import tariffs using a stylized experiment; and (ii) the mechanisms and transmission channels present in these two workhorse models. Figure 2 reports the impact on GDP and export volumes of a 10-percentage-point increase in tariffs in the U.S. on all imports from China, with China

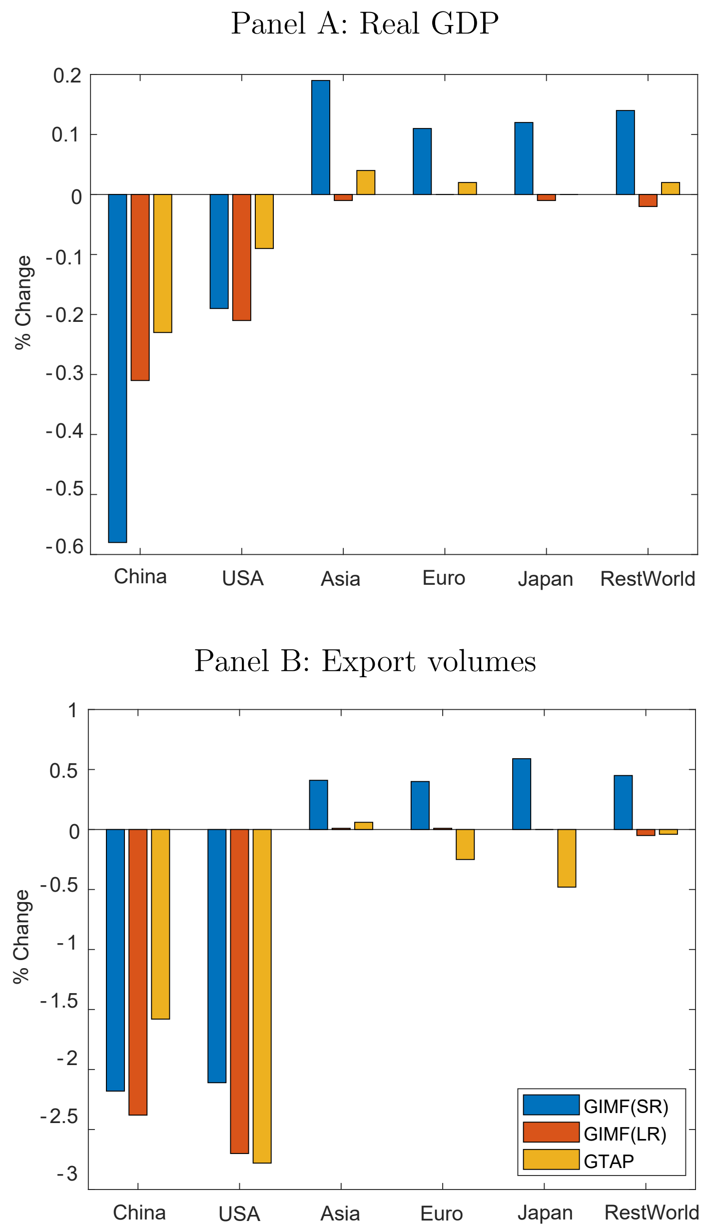
[10] Trade in services is not recorded in neither DOTS nor COMTRADE. We impose the same direction of trade flows as we observe in the data for goods. For the purpose of this paper, this simplification does not alter our results.

[11] We make this assumption to avoid that any non-zero net asset position could jump in value as the U.S. dollar appreciates or depreciates. In the model, all the net foreign asset positions are expressed in U.S. dollars, for modeling purpose, while in reality this would be incorrect. Asset positions would not immediately increase or decrease in value as the dollar fluctuates. In GTAP, we do not need to take any stand on the initial deficit or surplus of the trade balance as the model does not solve for an initial fixed point/steady state of the economy.

[12] As already mentioned, the model in Erceg et al. (2018) and GIMF share many properties, in particular rigidities, incomplete markets, flexible exchange rate, price setting. Our work differs as we consider multiple regions. That has a two-fold advantage. It allows us to analyze spillovers on third countries. It will also enable the possibility of initial stationary states with unbalanced bilateral trade.

retaliating in kind (i.e. imposing the same 10-percentage-point tariff on all imports from the U.S.). The charts plot the percent difference of all variables from baseline for both GIMF and GTAP. In the case of GIMF, we report both the short-term (year 1) and long-term (LR) results. The fiscal revenue from higher tariffs is rebated back in the form of lump-sum transfers to households. To highlight the channels of transmission of tariff policies, we divide the analysis of the results into a description of channels that affect the main two countries involved in the trade war and channels that generate spillovers to other trade partners.

Figure 2: 10-percentage-point increase in U.S. and China bilateral import tariffs: macroeconomic variables



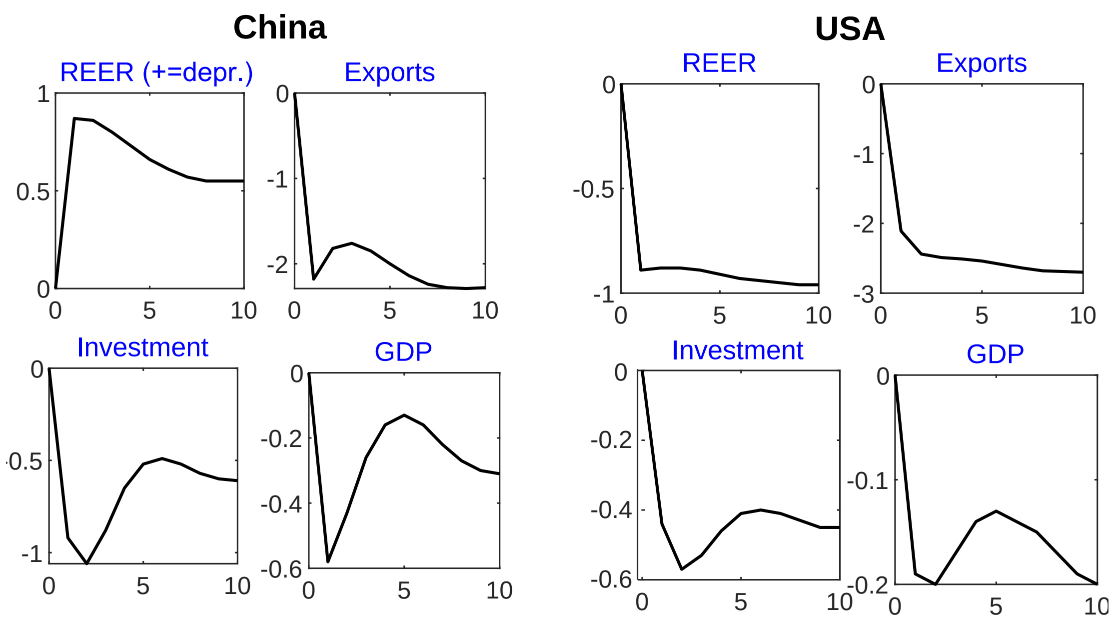
Source: IMF calculation. In percentage deviation from steady state.

3.1 The channels in GIMF

3.1.1 Effects on the countries involved in the trade war

In the short run (SR, year 1), the dynamics affecting external demand for U.S. and Chinese goods determine the immediate effects of the tariffs on GDP. The exports of both countries fall from the contraction of bilateral import demand. In the case of GIMF and of most DSGE frameworks, the movements of the exchange rate exacerbate the impact of an import tariff on total resources (investment and labor supply) by further affecting export flows. As shown in more details in Appendix B.1, the exchange rate has a fundamental role of maintaining consistency between trade flows, the balance of payments and intertemporal conditions (UIP) in financial markets. Figure 3 shows that after the 10-percentage-point increase in bilateral tariffs the exchange rate jumps and both U.S. and China exports plummet (as shown also in Figure 2).

Figure 3: 10-percentage-point increase in U.S. and China bilateral import tariffs: Exchange rate and exports



Source: GIMF simulations. In percentage deviation from steady state.

Given the asymmetry of the U.S.-China trade flows (Table C.4, Appendix C), the U.S. dollar appreciates against the renminbi. Even though the increase in tariffs is symmetric and it applies to all bilateral trade, the fact that Chinas exports to the U.S. are significantly larger in volumes and values means that the U.S. import tariff increase imposes a larger shock on China, while the retaliation represents a smaller one for the U.S.[13] In the current version of GIMF, we use a local currency pricing (LCP) specification with a high pass-through of the exchange rate (in the short run) therefore our results are close to the case of producer currency pricing (PCP).[14]

[13]In order for China to hit the same dollar amount in trade, the tariff rate increase would need to be much higher than 10 percentage points.

[14]With a standard LCP assumption, goods are priced and rigid in the currency of the country where

Despite asymmetric trade flows, the U.S. and China's total exports contract by similar magnitude (-2.1 percent for the U.S. and -2.2 for China) in the short run. The reasons are related to exchange rate dynamics. Because of the real depreciation of the renminbi, China's exports towards other destinations increase, partially offsetting the loss in U.S. markets.[15] Conversely for the U.S., lower exports to other partners, as the dollar appreciates, adds to the loss of China's external demand. Despite the fact that in percent terms the losses in exports are comparable for both countries, those translate into quite different declines in real GDP. China faces a larger contraction (-0.66 percent in China versus -0.19 percent in the U.S.), as exports represent a larger share of Chinas GDP.

The long-run dynamics in GIMF are determined by the response of firms investment to increased distortions, resulting from the tariffs, which affect both external demand and firms' profitability in both countries. The contraction of investment leads to a lower capital stock and a lower marginal product of labor. This in turn decreases firms demand for labor and the lower real wage also reduces labor supply (so that labor markets clear).

In the long run, the channel of lower firms' profitability, generated by the tariff wedge, works at full strength as rigidities disappear. On the one hand, the increase in tariff makes U.S. markets less profitable for Chinas firms and Chinese markets less profitable for U.S. firms.[16] The losses in terms of external demand are larger in the case of China as its exports to the U.S. are more significant (asymmetric trade flows). On the other hand, higher import prices also lead to additional effects. While it is true that they generate an increase in the demand for domestic goods in both countries (so called *expenditure switching*), the Armington preferences prevent perfect substitution of foreign goods with domestic production. This means that the bilateral tariff ends up introducing a wedge in production costs in both markets. In sum, these joint effects will generate pressures for a contraction of factor (capital and labor) supply/utilization.

In addition to this channel, in the long run, changes in the nominal exchange rate are fully passed on to trade prices. In the case of China, this partly offsets the stronger negative impulse to investment (although, conversely also amplifies the cost of import goods). In the case of the U.S., the appreciation of the dollar has the effect of hurting also exports to other destinations, although reducing import costs. The case of China is similar albeit just in reverse, with the depreciation of the renmimbi supporting exports but increasing further the cost of imports. Considering all the forces, on net, Chinese and U.S. long-run investment declines are quite comparable. This is in stark contrast with the investment dynamics in the short run.

Figure 4 displays the response of investment and labor supply both in China and the U.S. after the bilateral 10-percentage-point increase in U.S. and China import tariffs. As just

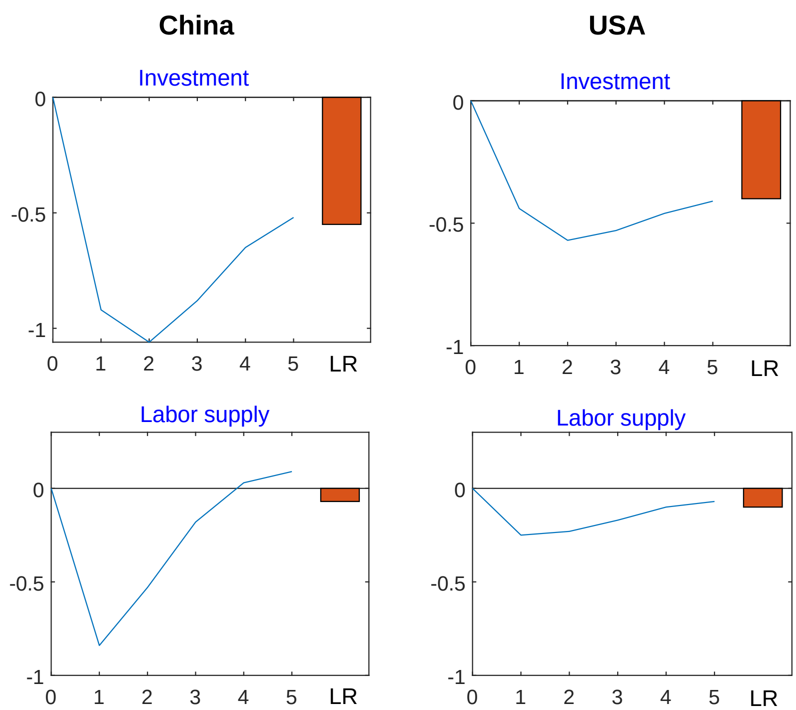
they are consumed. For this reason, there is little or no pass-through of exchange rate onto domestic prices for imported goods. In that case, our results of a bilateral tariff increase would underscore a much lower contraction of exports for the U.S., in the short run. Results under a specification with LCP invoicing and low pass-through are available from the authors upon request.

[15]Results in GIMF from an experiment but for the case when China does not retaliate help to shed light on the role of the exchange rate in muting the impact on Chinese exports. The depreciation of the renminbi in that case is stronger and helps compensate for the loss in exports to the U.S. Detailed results are available from the authors upon request.

[16]It is as exports of both countries and therefore firms' revenues were taxed.

mentioned, the dynamics of investment and labor are quite steep in the short run and milder in the long run. Tariffs have the strongest impact on firms investment in China, in the short run. In the medium and long run, expenditure switching and increased exports to other destinations due to currency depreciation help support Chinese investment, relative to the short run when rigidities prevented a full adjustment. For the U.S. the differences between short and long run are less stark. The appreciation of the dollar attenuates firms higher import costs in the presence of short-term rigidities. In the long run, with full exchange rate pass-through, it weighs negatively on firms sales and consequently investment. However, expenditure switching partly offsets this negative impulse. The dynamics of investment and labor supply tracks closely the path of real GDP in both countries.

Figure 4: 10-percentage-point increase in U.S. and China bilateral import tariffs: impact on production factors in GIMF



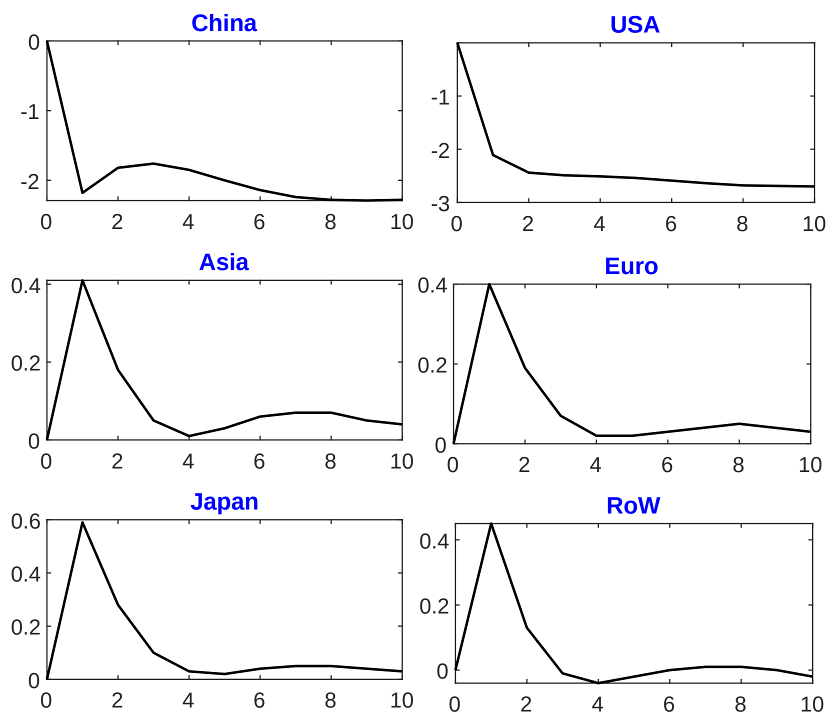
Source: IMF calculation. In percentage deviation from steady state.

3.1.2 Spillovers to third countries

In this section, we analyze the impact of the trade tensions between the U.S. and China on third countries not involved in the trade dispute. Trade diversion is the main source of spillover, in the short run. Nominal and real rigidities and changes in bilateral exchange rates govern the magnitude of the phenomenon.

China and U.S. total imports show a sluggish response to the import tariffs because of import adjustment costs, and partially because of the gradual pass-through of the exchange rate to import prices. This generates a diversion of U.S. and China imports towards countries not involved in the tariff dispute (Figure 5). Trade diversion is very pronounced in the short run, but the impulse fades away quite quickly towards the medium run. It is important to clarify that the trade diversion is sizable in the short run in GIMF because total imports are costly to adjust while bilateral trade relationship can be changed freely (though subject to elasticity of substitution and bias parameters). The U.S. and China intensify imports from other partners, while the adjustment costs realistically prevent rapid contraction in the total demand for foreign goods. This leads to an increase of exports of countries other than China and the U.S. and, as a result, an increase in their GDP in the short run (Figure 2, Panel A).

Figure 5: 10-percentage-point increase in U.S. and China bilateral import tariffs: exports in GIMF



Source: IMF calculation. In percentage deviation from steady state.

As seen in Figure 2 (Panel B) in the long run there is no significant increase in total exports for countries not involved in the trade dispute. There are several forces at work. Rigidities are no longer present and all trade partners can now fully adjust their domestic demand and aggregate imports. In addition, in the long run the impact of the exchange rate is fully factored in trade prices and it represents either a rebalancing or additional negative force for the countries involved in the dispute. For those reasons, trade diversion towards third countries is typically weaker in the long run (see for instance the case of the euro area).

Figure 6 reports a matrix with all the changes in bilateral trade flows, in the long run. Changes in total exports of the two countries involved in the trade dispute are the result of different dynamics of bilateral trade flows. The model predicts a fall in exports for the U.S. towards all destinations, as a direct effect of the appreciation of the dollar and the full pass-through to import prices. As a result, while the U.S. bilateral trade balance with China improves somewhat, the aggregate trade balance remains broadly unchanged, reflecting the offsetting loss of other markets as the dollar appreciates. This result highlights the role of the exchange rate, which maintains consistency between external balance and intertemporal equilibrium conditions.
Exports to China experience the largest contraction because of the increase in bilateral tariffs, but the appreciation of the dollar weighs in as additional factor. China's exports to the U.S. also display a very significant fall and are the only reason why total exports contract. Chinas exports to partners other than the U.S. in fact increase as a result of the depreciation of the renmimbi. Hence, on net, China export losses appear more muted in the long run and this occurs at the expenses of other trade partners. The U.S. is the only market where third countries maintain some gain in market share.

Figure 6: 10-percentage-point increase in U.S. and China bilateral import tariffs: changes in bilateral exports in GIMF

	Asia	China	Euro	Japan	RestWorld	USA
To Asia		1.3	-0.2	-0.0	-0.2	-1.3
To China	-1.3		-1.5	-1.3	-1.5	**-22.6**
To Euro	0.2	1.5		0.2	-0.0	-1.1
To Japan	0.0	1.3	-0.2		-0.2	-1.3
To RestWorld	0.2	1.5	0.0	0.2		-1.1
To USA	1.5	**-17.2**	1.3	1.5	1.3	

Source: IMF calculation. In percentage deviation from steady state.

3.2 The channels in GTAP

3.2.1 Effects on the countries involved in the trade war

In GTAP, the position of both China and the U.S. also worsens as bilateral import tariffs increase (Figure 2). However, the channels of transmission are different. GTAP does not model nominal exchange rates explicitly. Instead, the focus is on the impact of tariffs on the relative price of all goods and production factors. The change in factor prices reflects the assumption that production factors are in fixed net supply. The input-output structure embedded in the model allows for the transmission of changes in relative prices (costs) along the production chain across sectors within a country and between countries. The resulting relative price of imported goods in both the United States and China induces firms and households in these countries to increase their demand for either domestically produced goods or for imports from third countries whose goods become relatively more competitive.

This mechanism underpins the dynamics of production in specific sectors. Figure 7, Panel A, displays the percentage change from baseline of the production in the U.S. and Chinese sectors that are more exposed to trade. The picture clearly displays a reallocation of resources between sectors in the two countries. Electronics is the Chinese sector with the largest linkages with the United States. Chinas production and exports of electronics fall as a result of the increase in U.S. import tariffs and the increase in its price relative to similar sectors in the U.S. and other countries. As a mirror image, the production of electronics increases in the U.S.

Similarly, a decline in agricultural production and exports in the U.S. corresponds to reinvigorated agricultural production domestically in China, as agricultural imports become more expensive. The automotive sector (cars and car parts) in the two countries is also very exposed to trade. Its production declines in the U.S. and correspondingly increases (albeit more modestly) in China. Both the net contraction of exports and the increase in domestic production in the two countries involved in the trade dispute lead to a reduction in world trade, especially in the sectors that are more integrated in the global value chain. Interestingly, the aforementioned three sectors (electronics, agriculture and automotive) also exhibit the largest reduction in production in the countries that are not involved in the trade dispute, most likely because of the disruption of global trade. Other sectors show more modest changes.[17]

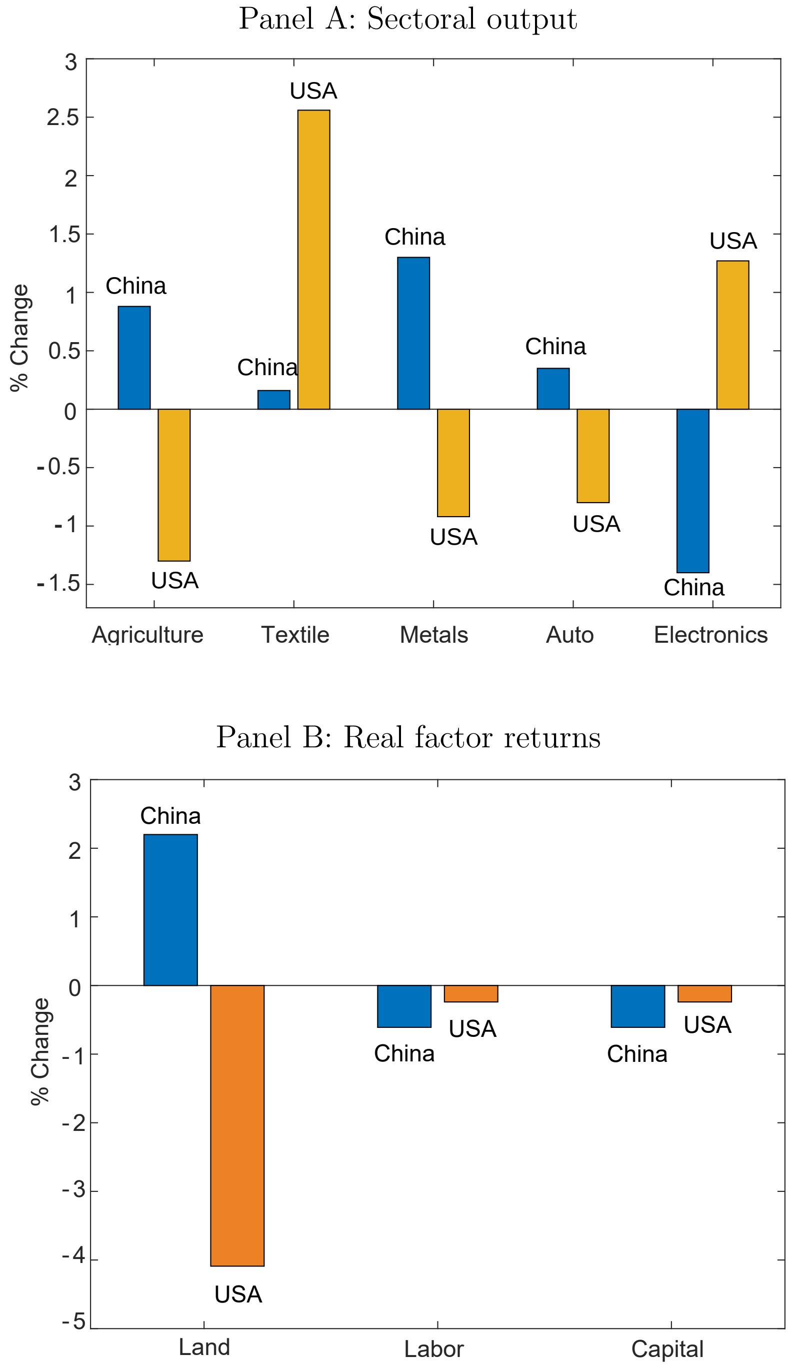
As demand for goods more exposed to trade falls, there is a downward pressure on demand for production factors in leading sectors. In the presence of a hard constraint on total factor endowment/employment at the regional level, this implies a sharp fall in their prices until factors are somewhat reallocated to other sectors. Lower factor prices (production costs) and higher demand for domestic goods generate a reallocation of primary factors from trade-exposed sectors to sectors less exposed to trade. As a result, the (super-imposed) reallocation of resources leads to a loss of aggregate efficiency in the countries involved in the trade dispute that materializes in a decline in factor real returns. These changes are measured as deviation of production factor prices from a price index representing the numeraire in the model (Figure 7, Panel B).

The change in real factor prices is reflected at the aggregate level in a fall in real GDP. Given the importance of electronics in Chinese exports and GDP, the impact of factor reallocation away from electronics generates a larger loss of efficiency for China, with GDP falling 0.23 percent, compared to a decline of 0.09 percent in the U.S. (Figure 2). In other words, fewer factors of production need to be reallocated in the U.S.

Changes in terms of GDP in GTAP capture something conceptually different than in GIMF. In GTAP, a concept of long-run efficient prices and allocations is intrinsically implicit in the initial equilibrium characterized by input-output relations across sectors and countries. In the initial steady state, for instance, the U.S. imports electronics from China because its prices are more competitive, despite the initial level of tariffs.

[17]More detailed results are available from the authors upon request.

Figure 7: 10-percentage-point increase in U.S. and China bilateral import tariffs: factor reallocation in GTAP

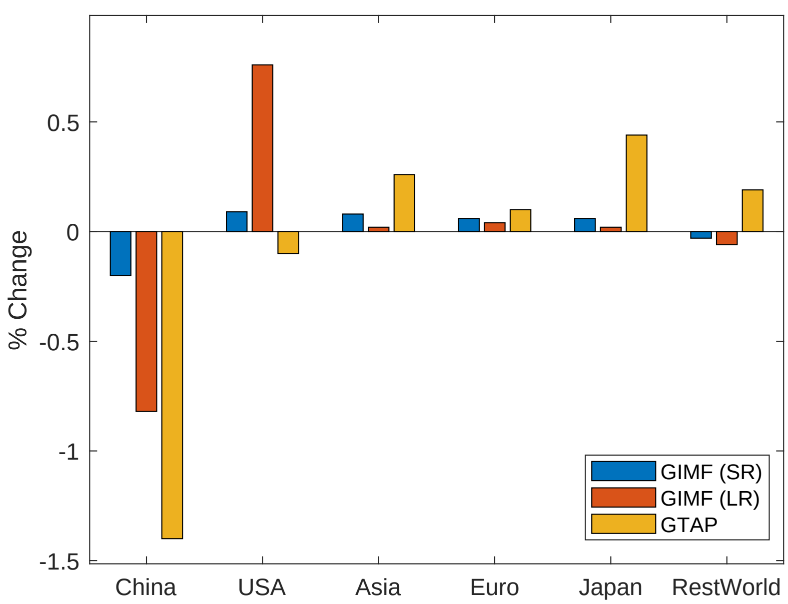


Source: IMF calculation. In percentage deviation from steady state.

After an increase in import tariffs, misallocations or inefficiencies are measured in terms of

the factor and goods prices that would prevail in the new steady state. Production factors are simply reallocated but their supply/utilization does not change. On the contrary, their change underpins the main results in GIMF.
A comparison of the terms of trade is informative of the differences in the adjustment that takes place in the two models. The latter variable shows larger responses in GTAP. Our interpretation is that relative prices have to react by more to reestablish the initial full employment of resources. In the next section, we will show that the terms of trade have to react even stronger when the values of elasticities of substitution are low to reestablish the equilibrium of full employment, since quantities are less reactive to prices.
Figure 8 displays the percent deviations from baseline of the terms of trade in our experiment. In China, export prices decline relative to import prices leading to a worsening of the terms of trade in both models. In the case of the U.S. however, the two models deliver somewhat surprisingly opposite signs for the change in the terms of trade. In GIMF, relative U.S. export prices increase, mostly owing to the exchange rate appreciation. In GTAP, ex-tariff export prices for the U.S. conversely fall. It is more difficult to trace exactly what is causing this result in GTAP, given the complexity of the model in terms of sectoral disaggregation, elasticity of substitution and input-output linkages. One explanation could be that, as the exchange rate does not play the same rebalancing role in GTAP, primary factors of production do not contract and factor prices decline (Figure 7), these would translate into lower export prices causing U.S. terms of trade to mildly decline (though much less than for China). In general, and for all other countries, as we already mentioned, changes in the terms of trade are larger in GTAP.

Figure 8: 10-percentage-point increase in U.S. and China bilateral import tariffs: terms of trade



Source: IMF calculation. In percentage deviation from steady state.

3.2.2 Spillovers to third countries

In this section, we lay out a brief analysis of the spillovers to third countries in GTAP. Spillovers are difficult to trace entirely given the complexity of the linkages generated by the model input-output structure, sectoral disaggregation and specific elasticities of substitution. In this framework (Figure 9), net trade spillovers appear to be dominated by the impact of tariffs on the external position of China and the U.S., absent movements in bilateral (nominal) exchange rates in GTAP. For instance, the increase in trade flows from Asia to third countries present in GIMF disappears and total flows are dominated by an increase in exports to the U.S. One possible interpretation is that the intensity could be associated to a typical diversion of U.S. imports from China towards Asia in specific sectors (say in the electronics sector) and to some extent to the mechanism described in the previous section, i.e. a stronger U.S. domestic production. Likewise the increase in China's exports, which is stronger in GTAP than in the case of GIMF, could be related to linkages of the electronics sector: an increase in U.S. demand of Asian electronics inputs generates a chain reaction of higher demand of Chinese electronics from Asia.

The previous rationales could explain why bilateral exports between China and U.S. worsen relative to the case of GIMF and improve towards other destinations. In sum, in GTAP trade diversion can be generated by two types of channels: (i) a more complex sectoral input-output structure and (ii) a larger (than in the case of GIMF) expansion of domestic production resulting from the fixed net employment of production factors. In GIMF, the diversion is influenced by: (i) the expansion of each country's domestic production and (ii) by the dynamics of bilateral exchange rates. Also, rigidities in GIMF drive a significant portion of the trade diversion in the near term.

Figure 9: 10-percentage-point increase in U.S. and China bilateral import tariffs: Changes in bilateral exports in GTAP

	Asia	China	Euro	Japan	RestWorld	USA
To Asia	-1.2	6.7	-0.8	-1.7	-0.7	7.5
To China	-1.0		-0.7	-1.6	-0.6	**-43.8**
To Euro	-0.7	7.6	-0.4	-1.0	-0.6	1.4
To Japan	-1.2	6.1	-1.1		-0.7	0.8
To RestWorld	-0.8	7.2	-0.7	-1.0	-0.8	1.1
To USA	7.5	**-39.2**	4.4	4.6	3.0	

Source: IMF calculation. In percentage deviation from steady state.

4 Sensitivity analysis in GTAP

In previous sections, we have highlighted how GTAP is solved in linearized form and its key behavioral equations are functions of elasticities of substitution. In addition, GTAP embodies larger elasticities than do other macroeconomic frameworks, including GIMF (see Tables C.1 and C.3, Appendix C). In this section, given it's important role in GTAP, we examine the sensitivity of the results to changes in the elasticity of substitution between domestic and imported goods and among goods from different source countries.[18]

Previous studies have focused their sensitivity analysis on several GTAP statistics, such as welfare measures (i.e. the equivalent variation for the representative household) and terms of trade (Hertel et al., 2004; McDaniel and Balistreri, 2003).[19] They find that varying the elasticity of substitution between domestic and imported goods has a large impact on terms of trade, exports and welfare measures. Our findings confirm those results. However, in this section, we focus on the sensitivity of estimates of real GDP.

In the benchmark calibration, the elasticity of substitution between domestic and foreign goods ϵ_j is estimated from the data and is sector specific (see Appendix C for details). The simple average across sectors yields a value just above 3, higher than values for the comparable parameter in GIMF. As noted earlier, the elasticity of substitution between imported goods from different source countries, θ_j, is set to double the elasticity between domestic and foreign goods. To study the importance of these parameters for estimates of real GDP related to trade questions, we perform the same experiment in Section 3.1 but with varying the elasticity of substitution ϵ_j and θ_j. We multiply both parameters by 0.5 and 2 and obtain a *low* and *high* level of elasticities of substitution in the different sectors. The low value is roughly equivalent to the elasticity of substitution in GIMF, between domestic and foreign goods (this leaves the elasticity of substitution between foreign sources of imported goods higher in GTAP than in GIMF).

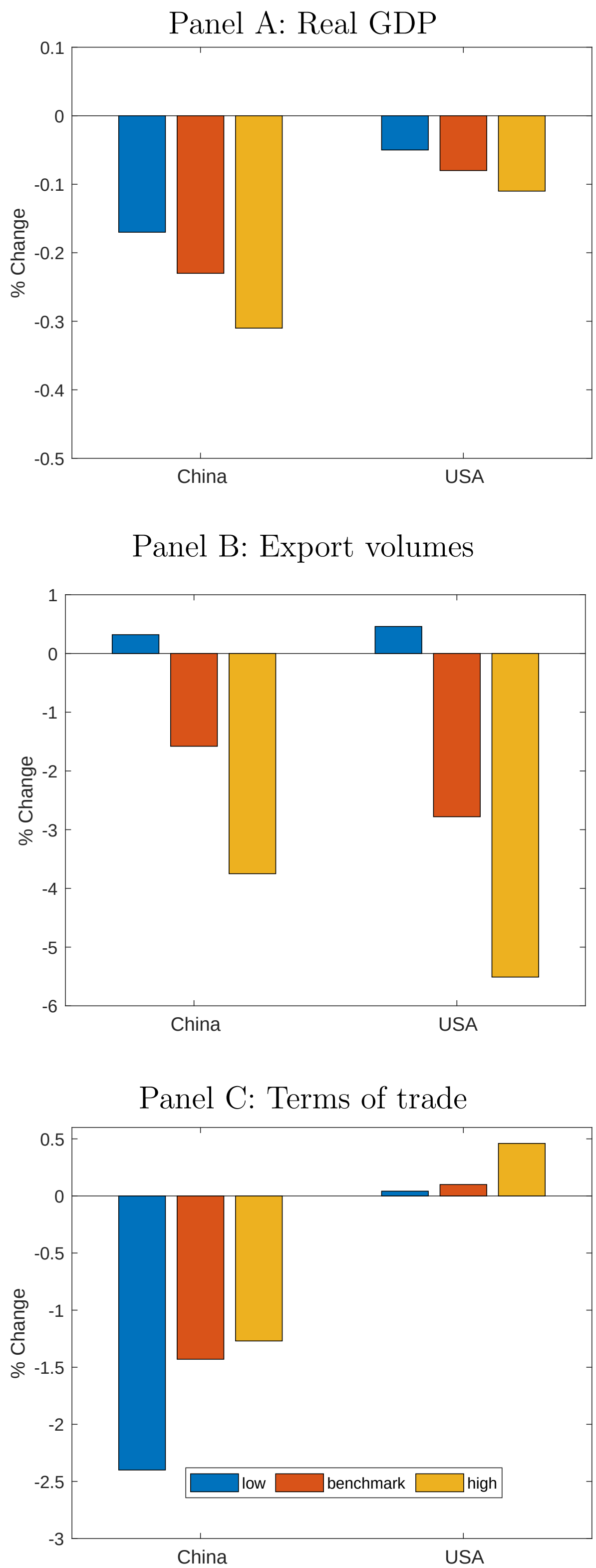
In the case of GTAP, absent investment dynamics affecting capital stocks and with a full employment of factors, the response of real GDP is primarily influenced by changes in allocative efficiency. The increase in import tariffs creates changes in relative prices and external demand for each region. The higher the elasticity of substitution the stronger the impact of the shock on exports and GDP. The pressure on prices is even higher given that the model is solved with the full employment constraint. As a result, more resources shift between sectors.

Figure 10 displays the change in real GDP, exports and terms of trade for the bilateral 10 percentage-point increase in U.S. and China import tariffs exploited in section 3.1 with the three levels of elasticity of substitution between domestic and imported goods ϵ_j (and between imported source countries θ_j). The figure shows that the strength of exports response is increasing in the elasticity of substitution. Terms of trade also appear to be very sensitive to changes in the elasticity of substitution as well, in line with results in previous studies. In the case of China, the decrease in the terms of trade leads to a positive impulse to exports that is higher (lower) the lower (higher) the elasticity of substitution.

[18] Sensitivity tests for GIMF are also available from the authors upon requests.

[19] Hertel and Huff (2001) provide an analytical decomposition of the equivalent variation for the representative household in region r that allows for non-homothetic preferences and products differentiated by origin (Armington assumption).

Figure 10: 10-percentage-point increase in U.S. and China bilateral import tariffs: sensitivity to trade elasticities in GTAP



Source: IMF calculation. In percentage deviation from steady state.

Intuitively, this is because the lower (higher) elasticity of substitution between domestic and foreign goods increases (reduces) trade diversion by lessening (boosting) expenditure switching and countries, such as China, with more competitive terms of trade gain. The sensitivity of the results for the U.S. points to opposite dynamics but the story is founded on similar principles. Exports decline by more when partners can substitute more easily from more expensive U.S. goods (i.e. when elasticity is higher). The real GDP response is weaker (stronger) the lower (higher) the elasticity of substitution, as substitution of foreign goods with domestic production (expenditure switching) is lessened (strengthened).

Despite high sensitivity of exports and welfare measures to the elasticity of substitution (McDaniel and Balistreri, 2003), the range of GDP results lies in a very small neighborhood (0.1 for the U.S. and 0.2-0.3 for China).[20] The condition of full employment in the standard version of GTAP is the reason behind that result. Domestic production is more stable as resources remain invariant. Relative prices and terms of trade adjust in order to maintain those constraints at the regional level.

5 Combining insights from both models

In previous sections, we examined the mechanisms underlying changes in trade and GDP in both GIMF and GTAP as import tariffs increase. In GIMF, the change in investment and demand for labor caused by tariff distortions generates a contraction of utilized factors. In GTAP, in the standard version used in this paper, primary factors do not change. Productive resources are reallocated across sectors. Hence, this version of GTAP can be used to complement the analysis of similar questions in GIMF by adding a sectoral perspective (i.e. an estimate of the loss in productivity arising from resource reallocation across sectors). Since GIMF does not feature any endogenous mechanism to quantify the impact of these trade distortions on productivity, we can use the results from GTAP to provide a more complete view on the impact of increased tariffs in GIMF.

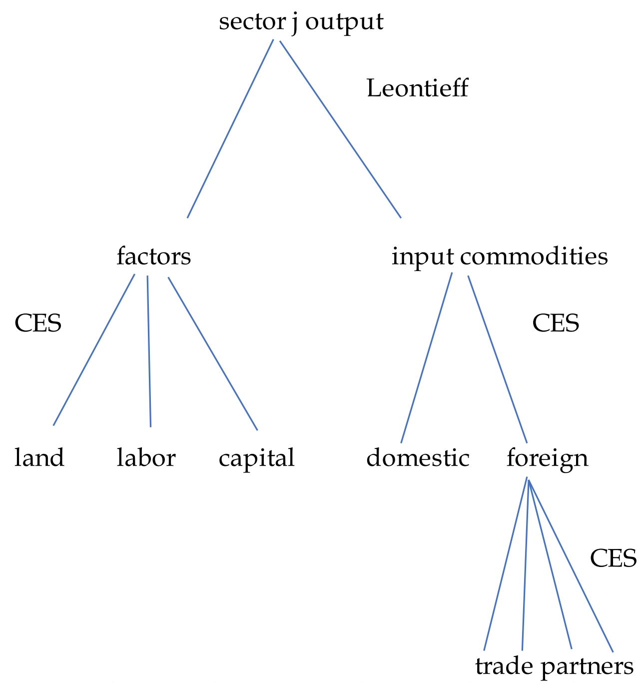
We can interpret the real GDP results in GTAP as follows. In GTAP, we can write aggregate factor endowments in each region, $Q^E_{z,r}$ with $z \in \{capital, labor, land\}$, as the integral over the endowments utilized in the different sectors j:

$$Q^E_{z,r} = \sum_j Q^E_{z,j,r}, \tag{1}$$

for each z. The results shown in the previous sections in terms of percentage changes of real GDP are the (weighted) sum of changes in output of different sectors. In that framework, the production functions in each sector are a complex CES nest of inputs (other commodities) and production factors (land, labor and capital), with also some exogenous productivity factors (Figure 11).

[20] McDaniel and Balistreri (2003) find that the choice of the elasticity can be crucial in determining welfare gains or losses from a given policy reform. Hertel et al. (2003) show that the welfare measure, i.e. the equivalent variation for the representative household, could be decomposed into two parts: (i) allocative efficiency and (ii) terms of trade. The elasticities of substitution ϵ_j and θ_j affect both of those terms. However, as shown by our results, when the model is solved with the full employment constraint, the largest variation is observed in the second component, which is then the one responsible for the high sensitivity in welfare measures.

Figure 11: Sectoral production schemes in GTAP



In GIMF, domestic aggregate production for both tradable and non tradable goods depends on labor, capital, and some exogenous productivity factors. We can map changes in real GDP from different sectors in GTAP into a change in an aggregate production function comparable with the aggregate production in GIMF. The the change in the function expressed in terms of both an Hicksian neutral and labor augmented productivity factor is as follows:

$$\delta log F(A, A^L; Q^E_{z,r}) = \delta log(A) + \delta log f(Q^E_{z,r}, A^L Q_{labor,r}), \tag{2}$$

Given the conditions of full employment and market clearing in GTAP, factor endowments are constant at the aggregate level for each region (see Appendix A):

$$\delta Q^E_{z,r} = \frac{\delta Q^E_{z,r}}{Q^E_{z,r}} = q^E_{z,r} = 0, \tag{3}$$

for each z and r. With (log) separability of the functions in (2), the previous equation implies:

$$\delta log F(A; Q^E_{z,r}) = \delta log(A) + \delta log f(A^L), \tag{4}$$

In other words, the percentage change in GDP from previous simulations in GTAP can be viewed as a percentage change in productivity, a residual of an aggregate production function. Because of its highly aggregated production structure and absence of multiple sectors, GIMF on its own cannot capture the inefficiencies arising from reallocating resources across sectors (with implicit differing levels of productivity). We can then use the GDP impact from GTAP to provide an estimate of the productivity impact in GIMF resulting from an increase in import tariffs. This could be seen as the loss in productivity arising from pure reallocation of production factors away from sectors exposed to trade (assumed to be more competitive).[21] Since this change in productivity in GTAP is measured in terms of factor prices, we are agnostic about which measure of productivity would be impacted, whether TFP or the labor augmenting technological factor.

There is an argument to advocate for both approaches. Literature has documented losses of productivity in terms of TFP from sectoral misallocation of both labor and capital (Restuccia and Rogerson, 2017; Restuccia, 2019). There would also be a good argument for implementing the shock as a change in labor productivity, as reallocation of workers often leads to a loss is productivity in terms of misallocation of sector-specific human capital (Kambourov, 2009). This is even more important as the content of services in the consumption basket increases. We are aware that using estimates from one framework, GTAP, to generate an exogenous change in productivity in GIMF would lead to an overestimation of the overall effect of an increase in import tariffs on real GDP. One of the main reasons is that estimates of lost productivity from reallocation of production factors would be lower in a framework that allows factors to contract. In addition to this caveat, as we show in this section, changes in TFP deliver very large GDP responses in DSGE models, especially for countries where investment shares of GDP are significant. Shocks to labor specific productivity would have a more modest impact on output. In sum, providing estimates using both TFP and labor productivity generates a range of possible full effects of import tariffs on economic outcomes. We apply the percentage changes in GDP from GTAP as a shock to labor-augmenting productivity as well as to TFP for all regions in GIMF, in addition to the bilateral U.S.-China import tariff increase. Since the changes in GDP for countries not involved in the trade dispute are extremely small in GTAP, we report only the results for China and the U.S.[22] Figure 12 displays the results in terms of percentage change from baseline of real GDP in GIMF under the benchmark simulations as in section 3 and two alternative simulations in which we also add the shock to labor productivity (Panel A) and TFP (Panel B) as a consequence of the sectoral reallocation (or rather misallocation) of resources. The magnitude of the shock on long-run productivity is calibrated to match the decrease in GDP displayed in Figure 2 for GTAP (-0.09 percent for the U.S. and -0.23 percent for China) and is applied to both tradable and nontradable goods production. The impact on productivity is assumed to unfold gradually, reaching the long-run level after 5 years.

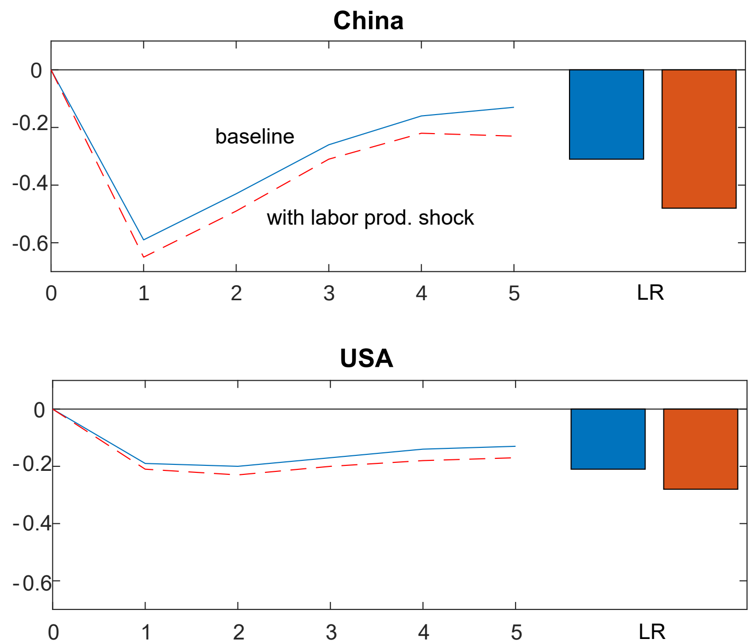
In the case of China, accounting for the productivity loss from resource reallocation leads to about 0.5 percentage point worse GDP contraction in the long run, when the GTAP estimates are mapped into TFP changes. The relative impact in China is so much larger than the relative impact in the U.S. because in GIMFs baseline, investment in China makes up a much larger share of GDP than it does in the U.S. (see Table C.3 in Appendix C).

[21] We can also use GIMF to estimate the impact on GDP from a contraction of factor supply/utilization and impose that as a shock in GTAP. Results are available from the authors upon request.

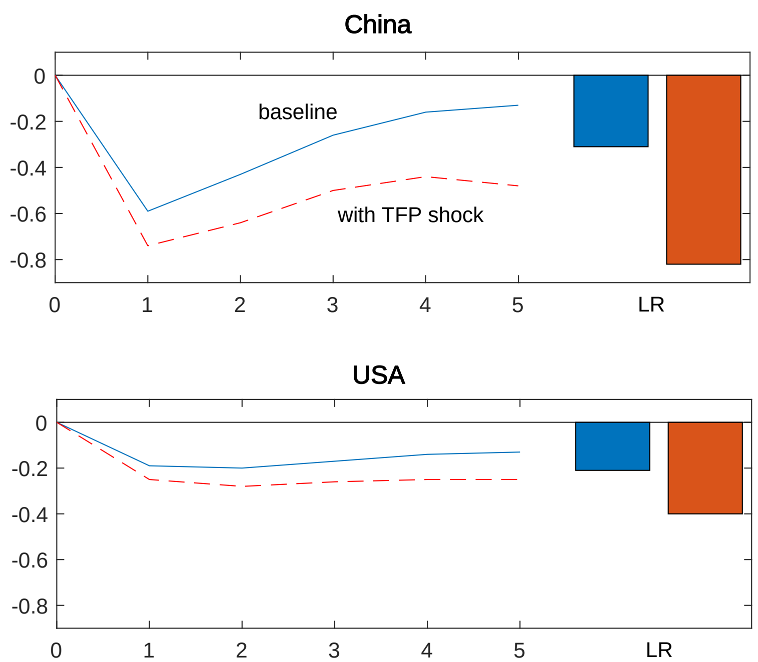
[22] The authors can provide the full set of results upon request.

Figure 12: 10-percentage-point increase in U.S. and China bilateral import tariffs: Combining two approaches

Panel A: Labor productivity shock



Panel B: Total factor productivity shock



Source: IMF calculation. In percentage deviation from steady state.

Shocks to labor specific productivity, in addition to the increase in the tariff, lead to more contained response in terms of GDP, just over 0.1 percentage point worse GDP loss for China, as the reaction of investment is more muted.[23]

6 Concluding remarks

In this paper, we examine the mechanism and macroeconomic impact of import tariffs drawing a comparison between two workhorse models: a computational general equilibrium model of trade, GTAP, and a multi-country dynamic stochastic general equilibrium model, GIMF.
We use these two models to highlight different and complementary channels of transmission. In GIMF, an increase in import tariffs generates an appreciation of the exchange rate of the country imposing the tariffs, falls in investment, labor and exports, both in the short and long run.
Similar to other models in the trade literature, GTAP features losses from tariffs as arising from a reallocation of resources between sectors. If prior to the tariff hike, it was more advantageous or efficient to import a specific good than producing it domestically, tariffs may make domestic goods artificially more viable at the cost of lower aggregate efficiency. In all countries involved in a trade dispute, any unilateral or bilateral increase in import tariffs brings about a reallocation of resources across sectors. As a result, there is an aggregate loss in productivity.
In sum, the two models look at the same distortion, an increase in import tariffs, from two different, but complementary perspectives. In the second part of the paper, we use the results from one framework, namely GTAP, as estimates of the productivity loss that arises from the resource reallocation across sectors due to the increase in trade tariffs. This productivity loss is then used in GIMF, which does not have similarly a detailed sectoral structure, to provide a potentially more complete estimate of the macroeconomic impact of increases in tariffs. We find that in some cases accounting for the productivity impact of resource reallocation more than doubles GIMF's GDP results in the long run.

[23]The full set of results is available from the authors upon request.

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Appendix A: A description of GTAP algorithm

In this Appendix, we will illustrate the main equations and the solution algorithm for GTAP. As already mentioned in section 2, with the objective of minimizing data needs GTAP is solved in its corresponding linearized version and the variables of interest are solved as percentage changes. For the purpose of the present paper, we will highlight the equations that are crucial to describe the mechanisms and channels operating in the model when tariff measures change. In each block of the model, a superscript j indicates a sector producing commodity j and a superscript i the commodity or primary factor inputs (from other sectors). The two superscripts j and i can refer to the same commodity if the same type of commodity is used to produce other goods in the same sector. For example, to produce other goods in the manufacturing sector one can use other manufacturing commodity inputs.

A.1 Market clearing conditions

In this section, we lay out the main accounting equations that define a Walras equilibrium. They close the model and ensure the consistency of all the other blocks.

A.1.1 Non-tradable goods and primary factors

Here are conditions for demand (D) and supply (S) of primary factors and marginal services (such as transportation) for each region, r:

$$\sum_j Q_{S,i,j} = \sum_j Q_{D,i,j} + Q_{H,i}, \tag{A.1}$$

where i =commodities, j =sectors, H =household. We transform equation (A.1) into its linearized form by first taking total differential.

$$\sum_j dQ_{S,i,j} = \sum_j dQ_{D,i,j} + dQ_{H,i}, \tag{A.2}$$

and then multiplying each member by its respective Q/Q and both sides of the equation by P_i.

$$\sum_j P_i \frac{Q_{S,i,j}}{Q_{S,i,j}} dQ_{S,i,j} = \sum_j dQ_{D,i,j} P_i \frac{Q_{D,i,j}}{Q_{D,i,j}} + P_i \frac{Q_{H,i}}{Q_{H,i}} dQ_{H,i}, \tag{A.3}$$

Notice that values are $V_x = P_x Q_x$ and lower case letters indicate proportional (percentage) changes.

$$\sum_j V_{S,i,j} q_{S,i,j} = \sum_j V_{D,i,j} q_{D,i,j} + V_{H,i} q_{H,i}, \tag{A.4}$$

If we need to iterate on equation (A.4), we do not need to calculate the levels of V. We can use the fact that $\frac{dV}{V} = p + q$.

When equation (A.4) refers to primary factor supply, it becomes:

$$0 = \sum_j V_{D,i,j} q_{D,i,j}, \tag{A.5}$$

as primary factors are fully employed and in net fixed supply at the regional level.

A.1.2 Tradable goods

In the tradable sectors, markets clear at the global level:

$$\sum_r \sum_j Q_{S,i,j,r} = \sum_r \sum_j Q_{D,i,j,r} + \sum_r Q_{H,i,r}, \tag{A.6}$$

Using the previous approach, we can rewrite (A.6) in linearized form:

$$\sum_r \sum_j V^w_{S,i,j,r} q_{S,i,j,r} = \sum_r \sum_j V^w_{D,i,j,r} q_{D,i,j,r} + \sum_r V^w_{H,i,r} q_{H,i,r}, \tag{A.7}$$

in this case prices are world prices P^w_i.

A.2 Price transmission channels

The following equations describe how policy shocks are transmitted to prices and through them to demand and supply equations defined in the next sections.

$$p^m_{i,r} = t_{i,r} + p^w_i \tag{A.8}$$

$$p_{D,i,j,r} = t_{D,i,j,r} + p^m_{i,r}$$
$$p_{S,i,j,r} = t_{S,i,j,r} + p^m_{i,r},$$

where $p^m_{i,r}$ is the (change in) domestic market price of commodity i in region r, $t_{i,r}$ is the (percentage) change in import tariff on commodity i in region r and $t_{D,i,j,r}$, $t_{S,i,j,r}$ are taxes or subsidies $t_{i,r}$ is the (percentage) change in taxes or subsidies on commodity i sector j and region r.

A.3 Zero-profit condition

The assumption of perfect competition implies a zero-profit condition in each sector j. This condition entails that the sum of the value of sales or revenue is equal to the sum of the value of all demanded inputs, in each sector j and region r:

$$\sum_i P_{S,i,j,r} Q_{S,i,j,r} = \sum_i P_{D,i,j,r} Q_{D,i,j,r}, \tag{A.9}$$

It can also be written in terms of cost $S_{D,i,j,r}$ or revenue $S_{S,i,j,r}$ shares:

$$\sum_i p_{S,i,j,r} S_{S,i,j,r} = \sum_i p_{D,i,j,r} S_{D,i,j,r}. \tag{A.10}$$

A.4 Income in each region

The representative household in each region receives income as payouts of the (fixed) factor endowments E, such as labor, capital and land and all the revenue from taxes (rebated back). The total income (Y_r) can be written as:

$$Y_r = \sum_E \sum_j P^E_{S,i,j,r} Q^E_{S,i,j,r} + taxes \tag{A.11}$$

The linearized form is achieved as usual through total differentiation and then rearrangement of terms.

$$Y_r y_r = \sum_E \sum_j V^E_{S,i,j,r} \left[p^E_{S,i,j,r} + q^E_{S,i,j,r} \right] + taxes \tag{A.12}$$

A.5 Behavioral equations

Key equations define the behavior of firms and households. They represent the solution to the optimization problems of firms and households. When linearized, they define the change in the demand (and implicitly supply) of commodity i or primary factors f as a function of a series of elasticities of substitution. The model will not be solved for the decision rules that underpin the solution to firms' and households' problems.

A.5.1 Industry demand for inputs

The (representative) firm's problem in each sector j is to minimize costs under the constraint that to produce a certain amount of output it needs to demand a variety of inputs, determine via a "nested" CES technology.

$$min \sum_i P_{D,i,j,r} Q_{D,i,j,r} \tag{A.13}$$

$$s.t.\ Z_{j,r} = \left[\sum_i B_{D,i,j,r} \left(Q_{D,i,j,r} \right)^{-} \frac{(1-\sigma_j)}{\sigma_j} \right]^{-\frac{\sigma_j}{(1-\sigma_j)}},$$

where σ_j is the sector specific elasticity of substitution between inputs i and primary factors. The quantity $Q_{D,i,j,r}$ is obtained by combining different type of commodities, some domestic $Q^H_{D,i,j,r}$ and some foreign $Q^F_{D,i,j,r}$, using the same CES technology as in (A.13), with sector specific elasticity ϵ_j. The quantity $Q^F_{D,i,j,r}$ is finally obtained using commodity inputs from different source countries $s \neq r$, with sector specific elasticity θ_j.

First-order conditions for the problem in (A.13) imply that:

$$P_{D,i,j,r} = \lambda B_{D,i,j,r} Q_{D,i,j,r}^{-\frac{1}{\sigma_j}} \left[\sum_i B_{D,i,j,r} \left(Q_{D,i,j,r} \right]^{-\frac{(1-\sigma_j)}{\sigma_j}} \right]^{-\frac{1}{(1-\sigma_j)}}, \tag{A.14}$$

each j, which can be solved for quantities:

$$Q_{D,i,j,r} = Q_{D,k,j,r} \left(\frac{B_{D,i,j,r} P_{D,k,j,r}}{B_{D,k,j,r} P_{D,i,j,r}} \right)^{\sigma_j}, \tag{A.15}$$

for each commodity $k \neq i$. Substituting into equation (A.13) for $Z_{j,r}$, we can obtain the optimal quantity demand:

$$Q_{D,i,j,r} = B_{D,i,j,r}^{\sigma_j} P_{D,i,j,r}^{-\sigma_j} \frac{1}{\left[\sum_i B_{D,i,j,r}^{\sigma_j} P_{D,i,j,r}^{-(\sigma_j-1)}\right]^{-\frac{\sigma_j}{(\sigma_j-1)}}} Z_{j,r}, \tag{A.16}$$

substituting in the unit cost:

$$C(Z_{j,r}, P_{D,j,r}) = \frac{\sum_i Q_{D,i,j,r} P_{D,i,j,r}}{Z_{j,r}}, \tag{A.17}$$

we can obtain:

$$C(Z_{j,r}, P_{D,j,r}) = \left[\sum_i B_{D,i,j,r}^{\sigma_j} P_{D,i,j,r}^{-(\sigma_j-1)}\right]^{\frac{1}{(\sigma_j-1)}}, \tag{A.18}$$

Now using this expression for unit costs we can substitute in (A.16) to obtain an alternative expression for the optimal demand of commodity i in sector j in each region r:

$$Q_{D,i,j,r} = B_{D,i,j,r}^{\sigma_j} P_{D,i,j,r}^{-\sigma_j} \left[C(P_{D,j,r})\right]^{\sigma_j} Z_{j,r}, \tag{A.19}$$

The objective is now to linearize this expression. First we take the total differential and then using the usual notation $x = \frac{dX}{X}$, we can rewrite equation (A.19) as:

$$q_{D,i,j,r} = \sigma_j \left[c(Z_{j,r}, P_{D,j,r}) - p_{D,k,j,r}\right] + z_{j,r}. \tag{A.20}$$

We can substitute $c = dC/C$ with it's original expression in terms of prices (A.18).

$$q_{D,i,j,r} = -\sigma_j S_{D,i,j,r} p_{D,i,j,r} + z_{j,r}, \tag{A.21}$$

where $S_{D,k,j,r}$ is the cost share of input i. The product $-\sigma_j S_{D,i,j,r}$ is jointly estimated using data.

From (A.13) we can find the expression for $z_{j,r}$, for instance when the demand of one commodity/input changes:

$$z_{j,r} = S_{D,i,j,r} q_{D,i,j,r} \tag{A.22}$$

Similarly, we can express the optimal supply of commodity i to sector j:

$$q_{S,i,j,r} = \phi_{i,k} p_{S,k,j,r} + z_{j,r}, \tag{A.23}$$

where $\phi_{i,k}$ is the conditional supply elasticity of substitution between inputs and it depends on the share of prices of each input in the firm's cost function $S_{S,i,j,r}$ and each input transformation parameter α_j. This elasticity will be a joint combination of those deep parameters and will be determined from the data.

A.5.2 Household's demand

The total utility for the household in region r is a Cobb-Douglas function of sub-utilities:

$$U_r = (U_{cons,r})^{\beta_{cons,r}} (U_{sav,r})^{\beta_{sav,r}} (U_{gov,r})^{\beta_{gov,r}} . \tag{A.24}$$

$U_{sav,r}$ and $U_{gov,r}$ depend on the quantity of savings (sav) and government expenditure (gov). As a consequence of the total utility being a Cobb-Douglas function, the optimal choice of savings and government expenditure can be expressed in shares of the total income, Y_r.

$$U_{x,r} = \beta_{x,r} \frac{Y_r}{P_{H,x}} \; x \in [sav, trans]. \tag{A.25}$$

with the following equation representing the equivalent linearized version:

$$u_{x,r} = y_r - p_{H,x} \; x \in [sav, trans]. \tag{A.26}$$

Similar to other behavioral functions, the demand for consumption goods (determined by maximizing utility subject to the budget constraint) is given by:

$$q_{H,i,r} = \sum_k \eta_{H,i,k,r} p_{H,i,r} + \eta_{H,i,r} y_r \tag{A.27}$$

where $\eta_{H,i,k,r}$ is the uncompensated elasticity between commodity i and k and $\eta_{H,i,r}$ is the elasticity of spending to income.

A.6 Effect of a tariff increase

In this section, we will draw a brief sketch of how the model functions after a policy shock. After any shock, the model is solved in its linearized form, which consists of a system of differential equations. To solve for each variable proportional change dx/x, we compute the slope of tangents to the initial equilibrium and use the linearized equations described above to calculate the consequent other variable changes. The numerical results reported in section 3 are obtained using Gragg's method (see Harrison and Pearson, 1994). The idea of a multi-step simulation is to break each of the shocks into several smaller steps. In each step, the linearized equations are solved for these smaller shocks.
For simplicity, we assume only two regions, $r = U.S., ROW$ and assume the U.S. increases $t_{i,US}$ for all imported commodities i. Assume also that only one sector $j = electronics$ imports from ROW. The algorithm goes as follows:

1. From equation (A.8), prices of imported goods increase and are passed into increase in demand and supply prices, $p_{S,i,j,US} = p_{D,i,j,US} > 0$ for the sectors j and the household in the U.S.

2. Quantities demanded by household, government and firms of sector j goods fall as in equations (A.21) and (A.27).

3. Total activity in sector j importing intermediate goods from abroad falls, $z_j < 0$ (equation (A.22)).

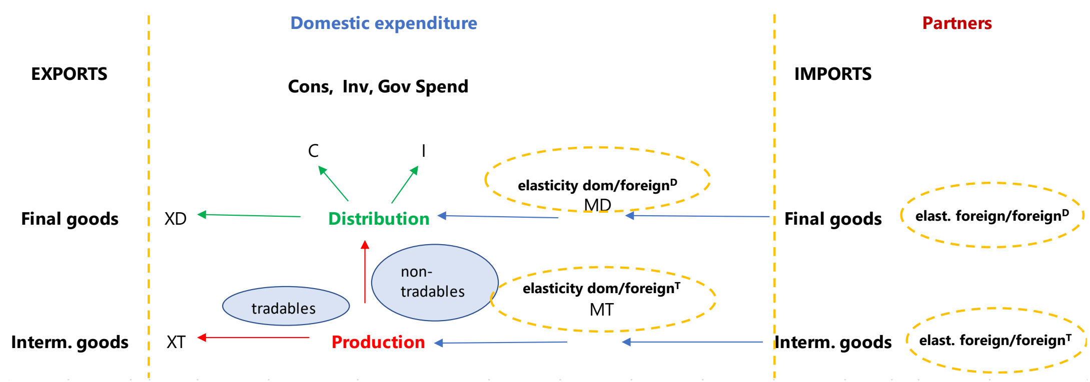
4. Demand for primary factors and nontradable services falls as per equation (A.21) (this equation refers to both commodity inputs and primary factor demand).
5. A this point market clearing conditions for primary factors and tradable goods are not satisfied.
6. In particular, the full employment condition for primary factors in the U.S. from equation(A.5) is not satisfied.
7. The algorithm calculates the (percentage) changes in prices that are compatible with returning these equations to equilibrium by steps (calculating tangent slopes using a grid in the case of the Euler method).
8. As a result, prices of primary factors fall to reestablish the equilibrium (so that the demand, especially in sectors other than sector j, increases).
9. Commodities supplied by all sectors increase (through (A.22)) as a result of increase in domestic demand for them as the fall in these primary factors/input prices makes domestic goods in general cheaper.
10. Because of the Armington assumption (embedded in the elasticities), these increases in domestic demand and production do not fully compensate for the fall in imported goods from ROW for commodity j.
11. In order for the global market clearing condition (A.7) to be satisfied, prices in the ROW have to decrease, so that the supply in some sector for goods imported by the U.S. decreases.
12. This may imply prices in the U.S. increase relative to the ROW, meaning that the terms of trade for the U.S. increases (and there is an implicit appreciation of the exchange rate).

These steps obviously rely on the assumption that in the U.S. only one sector, j, imports and also it simplifies the ramification of changes in prices that have to be compatible with equilibrium conditions (market clearing) because of the linkages between sectors. Sector j could be exporting to other countries and/or selling to other sectors domestically. In the actual model, changes in quantities and prices are difficult to trace given the complexity of the input/output structure.

Appendix B: International trade in GIMF

In this section, we describe the international trade block in GIMF. Figure B.1 displays a simplified representation of the relationship of each region in the model with its respective external sector. Countries or regions in the model produce tradable (final, D, and intermediate, T) and nontradable (N) goods. Import agents for intermediate and final goods are domestically owned by each country but located in each export destination country (i.e. the serve also as export agents). Import agents in turn sell their output to foreign distributors (final goods) or goods producer (intermediate goods) at prices that are rigid in foreign currencies (i.e. local currency pricing), in the short run.

Figure B.1: International trade flows in GIMF



In each region, domestic distributors combine imported final goods with domestic goods in several stages, with a nested CES technology:

1. First, they assemble imported final goods from import agents located in their own regions according to a CES function similar to (A.13), governed by the elasticity of substitution between imported goods from different trading partners, σ_j where $j \in \{D, T\}$.

2. In a following stage, distributors combine foreign (TF) with domestically (TH) produced intermediate tradable goods, according to a similar function with the key parameter being the elasticity of substitution ϵ_T.

3. A similar function also depicts the technology used by consumption and investment goods producers in each region, where they combine foreign (DF) with domestically (DH) produced final goods. The combination is determined by the elasticity of substitution ϵ_D.

At each of those stages, changes to volumes of total imported goods incur (quadratic) import adjustment costs to prevent instantaneous responsiveness of demand to relative price change. Prices of imported goods are a weighted average of prices by destination. The price of imports from each destination is converted in local currency through the exchange rate and is augmented by any tariff imposed by each import region.

A.1 Effect of a tariff increase

In this section, we describe the main transmission mechanism of an import tariff increase in GIMF. To this aim, we sketch the key equations of the model that determine the main effects of the tariff on macroeconomic variables.

An import tariff τ_m will influence the aggregate demand for foreign imported varieties, Y_t^M, relative to the demand for domestic goods, Y_t^H. This relative demand is also influenced by prices prevailing abroad relative to domestic ones, $\frac{P_t^*}{P_t}$ and by the exchange rate ϕ_t. The vector Θ contains parameters that govern the intensity of the response of the relative demand for imported goods, including key elasticities of substitution.

$$\frac{Y_t^M}{Y_t^H} = f\left(\Theta; \tau_m, \phi_t, \frac{P_t^*}{P_t}\right).$$

In the short run, this equation implies a full pass-through of the exchange rate to import prices (PCP, for simplicity). In the case of imperfect pass-through, the effect of the exchange rate on import demand is muted and ϕ_t and $\frac{P_t^*}{P_t}$ would be just replaced by a general notation of prices of imported goods, P_t^M.

Trade policies also affect the balance of payments in each region. This can be expressed in equilibrium in terms of foreign asset holdings, after substituting for the following law of one price for domestic goods consumed abroad:[24]

$$P_t^X = P_t \frac{(1+\tau_m^*)}{\phi_t},$$

where P_t^X is the price of goods produced domestically and exported, paid by consumers in the foreign countries and P_t is the price paid for the same good domestically. The domestic price is augmented by the import tariff applied by the foreign country τ_m^* and the converted using the exchange rate. Symmetrically, we can write the same equation for the price of goods produced abroad and imported into the domestic market, P_t^M. The balance of payment equilibrium can be written as:

$$B_t^F = B_{t-1}^F R_t^* + \frac{P_t^X}{(1+\tau_m^*)} Y_t^X - \frac{P_t^M}{(1+\tau_m)\phi_t} Y_t^M,$$

where the holding of foreign assets (bonds), B_t^F, depends also on a state B_{t-1}^F and the foreign return factor R_t*, not only on the trade balance.

Finally, the balance of payments in equilibrium needs to satisfy an intertemporal condition for foreign bond holdings (Euler equation).

$$1 = \beta E_t \left[\Lambda_{t,t+1} \frac{P_t}{P_{t+1}} \frac{\phi_{t+1}}{\phi_t} R_t^*\right],$$

where $\Lambda_{t,t+1}$ is the pricing kernel used to value future consumption streams. Through the pricing kernel, this equation is combined with the intertemporal condition for domestic bond

[24] For the sake of simplicity, we omit the dividend flows related to firms' ownership. We also simplify the notation used in Kumhof et al. (2010).

holdings:

$$1 = \beta E_t \left[\Lambda_{t,t+1} \frac{P_t}{P_{t+1}} R_t \right],$$

The combination of the two equations leads to the uncovered interest rate parity (UIP) condition, which draws consistency between interest rates and exchange rate between two countries, in the presence of incomplete markets. Import tariffs do not affect directly those two equations. However, they end up generating a shock to each of the economies affected and therefore interact with nominal and real rigidities of the countries of interest. This generates, among other things, a change in interest rates. The impact on interest rates also depends on (monetary/fiscal) policy reaction functions.
The exchange rate will have to react to preserve dynamic consistency dictated by the UIP condition with the balance of payments. In the case of GIMF and for most DSGE frameworks, the movements of the exchange rate exacerbate the impact of an import tariff on total resources by further affecting export flows.

Appendix C: Details on the parameterization

In this section, we report the detailed values of the elasticity of substitution between domestic and imported goods ϵ_i and for imported goods from different source countries θ_i in GTAP. For each elasticity, the values are the same by region but differ by sector or commodity i. In the following table, we specify the thirteen sectors.

Table C.1: Elasticity of substitution in GTAP

	ϵ_i	θ_i
Crops	2.5	4.9
Meat and livestock	3.2	7.4
Extraction	4.9	11.9
Processed food	2.1	4.4
Textile and apparel	3.7	7.4
Light manufacturing	3.6	7.6
Iron and steel	3.0	5.9
Aluminum and other metals	4.2	8.4
Auto and parts	2.8	5.6
Heavy manufacturing	3.2	6.7
Electronics	4.4	8.8
Transportation services	2.1	4.6
Other services	1.9	3.8

Table C.2: Trade flows between partner regions: GTAP

	Asia	China	Euro	Japan	RestWorld	USA
To Asia	22.8	22.4	5.5	27.8	12.2	12.1
To China	20.9		4.5	25.9	9.0	8.7
To Euro	10.2	13.2	41.5	9.0	25.3	17.4
To Japan	7.1	8.2	1.5		4.4	5.2
To RestWorld	26.4	37.5	39.4	21.5	31.6	56.7
To USA	12.5	18.7	7.5	15.8	17.4	

Source: IMF calculation. In percent of total exports.

Table C.3 displays the key parameters for the main countries involved in the trade dispute. One model period is one year. Most of the parameters are calibrated according to Kumhof et al. (2010), especially for the case of the U.S., except for some parameters that are key to pin down the specific behavior of the Chinese economy.

Table C.3: Key parameter values in GIMF

	USA	China
Real adjustment costs of imports	1.0	1.0
Capital as share of GDP	39.5	45.1
Investment as share of GDP	16.9	26.1
Discount factor (β)	0.982	0.973
Share of liquidity-constrained households (ψ)	0.25	0.25
Frisch elasticity of labor supply	0.5	0.5
Elasticity of substitution btw domestic and foreign goods	1.5	1.5
Elasticity of substitution among foreign goods	1.5	1.5
Coeff. on deviation from inflation target (monetary rule)	1.0	1.0
Coeff. on deviation from output target (monetary rule)	0.0	0.0

Table C.4: Trade flows between partner regions: GIMF

	Asia	China	Euro	Japan	RestWorld	USA
To Asia		25.4	7.8	26.6	19.6	12.4
To China	19.5		8.2	22.8	20.4	10.3
To Euro	8.5	17.1		8.9	32.6	14.0
To Japan	5.9	8.8	2.6		5.1	4.9
To RestWorld	54.9	24.2	68.0	23.3		58.4
To USA	11.3	24.4	13.4	18.3	22.3	

Source: IMF calculation. In percent of total exports.