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International Trade Policy and Quantitative Models

A Practitioner's Guide

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Abstract

Quantitative international trade models are essential tools for policy analysis. This paper provides guidance for quantifying and solving trade models for policy simulations using the popular programming languages Python, Julia, Matlab, and R. The solution follows simple linear steps and can easily be modified to add different components; thus, it can be extended to a wide class of models. Using the tools provided, the paper shows that an additional 25 percent ad valorem tariff between high-income and non-high-income countries has a substantial negative effect on real disposable income in all countries, ranging between 0.5 and 7.4 percent. The magnitude of the impact is highly heterogeneous for both income groups, but significantly larger on average for the non-high-income countries.

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International Trade Policy and Quantitative Models: A Practitioner's Guide*

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*A visual web-based implementation of this toolkit is available online for ad hoc policy simulations: Trade Policy Simulator: Tariffs (link). Authors' webpage and GitHub (link) host the latest version of the code. We thank Claudia Rivas Rios and Ryan Hahn, who created the website that hosts the policy simulation tool and improved its design. We are grateful to Daria Taglioni for her crucial support for this project. We thank Cristina Constantinescu for kindly sharing the consolidated tariff data. We also thank Nicolas Cogorno, David Hummels, Tony Fujs, Daniel Lasso, Eunhee Lee, Isambert Leunga, Caglar Ozden, Guido Porto, Maria Reyes Retana, and Bob Rijkers. All errors are our responsibility. The project benefited from funding through the Umbrella Facility for Trade 2.0, a World Bank administered multi-donor trust fund that supports the World Bank's work on trade, which receives contributions from the governments of Japan, Sweden, Switzerland, and the United Kingdom as well as from the European Commission. The findings, interpretations, and conclusions expressed in this paper are entirely those of the authors. They do not necessarily represent the views of the International Bank of Reconstruction and Development, the World Bank, or the International Monetary Fund, and their affiliated organizations or those of the Executive Directors, or the countries they represent.

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1 Introduction

The most fundamental role of quantitative trade models is to shed light on the mechanisms that characterize international trade flows and to analyze their implications. Their basic function is actually similar to simpler methods like supply and demand graphs, as they are also tools used to improve our economic intuition. Supply-demand charts employ visual aids to show how different shocks impact economic outcomes through shifting curves. Different from them, quantitative models employ algebra and mathematical programming instead of charts. But in the end, the goal should be the same, to show how different mechanisms work as the system reaches an equilibrium, instead of spitting out numbers from an opaque black box. This paper's goal is to open the box and make a practical trade model as transparent as possible for policy analysis, by documenting all the necessary steps and making it available on many platforms, for economists from diverse backgrounds.

Despite being widely used for counterfactual policy analysis, simulation models based on theory are often only accessible to a small number of economists as they require special training. More popular methods, such as regression analysis, can inform us about the impact of past economic policies, but they are not informative of future policies. Nobel prize winner economist Robert Lucas famously stated the need for using structural models and deep parameters, instead of reduced-form statistical models, to study the impact of policy reforms because coefficients of regression equations can change after a policy shock, while deep parameters are always fixed. This important warning is known as "the Lucas critique" in the literature. Theory-based quantitative trade models are immune to this critique.

This paper provides a holistic discussion for an example trade model based on Eaton and Kortum, 2002, and presents a flexible mathematical solution method with solution code in four different programming languages along with processed data. There is also a browser-based tool available which allows experimentation with different counterfactual policy scenarios. Policymakers, researchers and students can use this paper to implement a practical trade model from scratch and add or change its components to address different policy questions.

It is often very difficult to calculate aggregate welfare impacts by econometrics alone. For this reason, there has been an increase in the popularity of trade models in the academic literature. Related policy tools, known as Computable General Equilibrium (CGE) models, are similar in some aspects because they also can generate numerical outcomes for proposed policies. But CGE models are often considered, sometimes unfairly, as opaque because it is difficult to uncover the economic mechanisms leading to their quantitative results. They are usually less relevant for academic research with some exceptions, as they tend to focus more on results instead of showing mechanisms transparently. Therefore, different from other policy tools, quantitative trade models fill in an important gap between policy analysis and research, and they can uniquely speak to both audiences. But they are subject to other setbacks, as their implementation usually takes impractically long time and often requires advanced training in multiple fields, such as econometrics, economic theory and computational methods.

More recently, another major challenge has emerged: It is very difficult to analyze new trade policies in a timely manner, such as new tariffs, due to their unpredictable nature. Major economies in the world can announce new trade policies, and change them after a few weeks, based on the current state of the negotiations and the political environment. This is a big setback for policymakers in developing countries, because it is not feasible to study a proposed trade policy on time due to their unpredictable and ever changing nature.

To partially remedy these challenges, this paper is proposing a quantitative trade model that features some of the recent advancements in the literature and presenting it in a way that will make it accessible and useful for all economists, independent of their technical training or time constraints. The model is designed with trade policy analysis for developing countries as its main focus.

The proposed model will have the following features: (1) Discrete choice import decisions similar to Eaton and Kortum, 2002, (2) discrete choice labor allocation like Artuc et al., 2010, (3) input output linkages similar to Caliendo and Parro, 2015, (4) exogenous trade imbalances, and (5) tariffs and iceberg transportation costs. The model will be transparent and fully tractable.

Then, we will provide an efficient and flexible mathematical solution algorithm utilizing hat algebra of Dekle et al., 2008 with a method that eliminates the need for double loops and complex substitutions. The simplicity of the solution makes the algorithm applicable to a wide range of problems. The steps of the solution method will have the exact same order as the presentation of the model's equations. Therefore, following the algorithm and matching it with the model will be easy and the steps will be very transparent. Then, we provide a detailed solution guide and toolkit for more advanced users, written in four programming languages: R, Python, MATLAB and Julia.[1] The toolkit can be used by economists with some background in trade theory to design their own variations.

Afterwards, the model will be calibrated with the most recent trade and tariff data available to us. We use the 2025 release of Inter-Country Input-Output (ICIO) tables provided by the Organisation for Economic Cooperation and Development (OECD) and World Trade Organization (WTO) Trade in Value Added (TiVA) database, which provides detailed bilateral trade and input-output linkages across 81 economies and 50 industries. This dataset includes many developing countries; therefore, it is a very good fit for our purpose. To match the model structure, we aggregate industries into 21 sectors and focus on 2022. Sector–country production parameters are constructed from these data, and import-weighted average tariffs are computed using the United Nations Conference on Trade and Development (UNCTAD) Trade Analysis and Information System (TRAINS) database, allowing for consistent cross country comparisons.[2]

Then, as a concrete illustration of our framework, we simulate a bilateral tariff shock between two country groups: High-income countries (H) and non-high-income countries (NH). The shock consists of a uniform 25 percentage-point increase in bilateral tariffs applied on top of baseline tariffs, affecting trade flows between the two groups while leaving intragroup tariffs unchanged. This scenario allows us to examine how trade policy changes propagate through international trade networks, impacting key macroeconomic outcomes such as disposable income, real GDP, exports, and imports. The results highlight heterogeneity across countries:

[1] For detailed references on the programming languages used here, see R Core Team, 2025, Harris et al., 2020, MathWorks, 2025 and Bezanson et al., 2017.

[2] See Guilhoto et al., 2022 and Constantinescu, 2025 for details on TiVA data and tariff data respectively.

while high-income countries experience moderate negative effects, non-high-income countries are more severely affected, reflecting differences in trade exposure, economic structure, and resilience to policy shocks. Unsurprisingly, the magnitude of negative impact on real disposable income is larger than that on real GDP, as tariffs are effectively a form of taxation, indicating that trade shocks disproportionately affect household welfare relative to the overall economic output.

Finally, we provide an online graphical user interface which allows the model to be executed in real time on the servers. This simulation tool can be used to replicate the simulation in this paper, as well as to study new tariff and trade cost scenarios both for practical policy analysis and for educational purposes.

To summarize, the outputs of this paper can facilitate both just-in-time trade policy analysis and development of specialized models and policy reports. Using the web-based tool, economists can study the impact of the most recently announced tariff policies by trade partners within minutes without the need for specialized training or expertise. This feature extends the audience of the model to researchers, students, policymakers, and government officials who are not necessarily familiar with the technical details. Using our tools, more advanced users can run the models locally with new data, or with modified mechanisms following relatively simple steps. Since we provide the code in many programming languages with very clear guidance, the model can be implemented easily on various platforms.

The rest of the paper is organized as follows: First, we present the classic Eaton and Kortum, 2002 model in section 2 along with a detailed discussion on its solution. Then, we introduce a generalized version of this model, that can be used for policy analysis, and its solution in section 3. In section 4, we give details about the data sources and our choice of parameter values. We discuss an example policy simulation exercise in section 5. Finally, we conclude in section 6. The replication package and two web-based simulation tools based on the extended model are available online. In the appendix, we provide user guides for the web-based tools, the full replication code in Python, Julia, Matlab and R; a discussion on differences between the programming languages for solution purposes; and other supplementary materials.

2 A simple textbook model

In this section, we provide the classic Eaton and Kortum, 2002 model and its solution to start with a relatively simple example, subject to some modifications in the notation for consistency with a more advanced version. Please refer to their paper for the full exposition, as we only discuss the most essential components.

The Eaton-Kortum model extends Dornbusch et al., 1977 to multiple countries without sacrificing tractability. It is one of the most influential international trade models along with Melitz, 2003, Armington, 1969 and Krugman, 1980. Arkolakis et al., 2012 provide an excellent discussion on welfare implications of these standard models. Since Eaton-Kortum model's quantification and numerical solution are very easy, it is a good starting point. Note that the equations needed for solving the Armington model are identical to this model, and the Krugman model is also very similar. Therefore, its solution can easily be extended to other models. Matching the equations in the solution and the model will be easy as we will lay out the model piece by piece in a specific order to facilitate this.

Consider N countries, indexed with either m or n, where consumers derive utility from varieties ω which can be traded internationally. Their utility function is defined as

$$U^m = \left[\int \left(Q^m(\omega)\right)^{\frac{\sigma-1}{\sigma}} d\omega \right]^{\frac{\sigma}{\sigma-1}},$$

where $Q^m(\omega)$ is the consumed quantity of variety ω and σ is an elasticity parameter.

Production: Production technology is Ricardian, where one worker can produce $A^m z^m(\omega)$ units of variety ω in an hour. The technology parameter A^m is country specific and reflects the overall productivity. Assume that the country-variety-specific productivity variable $z^m(\omega)$ is distributed Frechet with shape θ and scale $\left[\Gamma\left(1-\frac{1}{\theta}\right)\right]^{-1}$, where $\theta > 1$. Producers are perfectly competitive, and we do not need to model them explicitly. Workers' equilibrium hourly wage is equal to w^m in country m. Therefore, cost of producing one unit of ω is equal to $\tilde{c}^m(\omega) = \frac{w^m}{A^m z^m(\omega)}$.

Income: Assume that there are L^m workers in country m. Total nominal income (i.e. GDP) will be equal to $L^m w^m$, also equal to total expenditure.

Transportation costs: Consumers can source varieties locally if they are produced locally, or import them from abroad. Assume that transporting one unit of any variety to destination country m from origin country n requires shipping δ^{nm} units of goods. This simple transportation cost structure is called "iceberg transportation cost". We can think of this as a proportional cost equal to $\delta^{nm} - 1$ of the value. We assume $\delta_j^{nn} = 1$ if a good is sourced locally and ignore other types of trade costs, taxes and tariffs.

Prices: Consumers in country n will source each variety from the minimum cost origin, including the transportation cost, therefore the effective local price will be equal to

$$\tilde{p}^n(\omega) = \min_m \{\tilde{c}^m(\omega)\delta^{nm}\}.$$

If cost of producing the variety locally exceeds this effective price, i.e. $\tilde{c}^m(\omega) > \tilde{p}^m(\omega)$, the variety will not be produced locally. This expression means that each country will source a given variety from a single origin.

This structure leads to a very simple and convenient analytical solution. Let us define some price indices to streamline the equations. This will make the algorithm easy to follow as each of the following equations will refer to a step in the numerical solution.

The cost of producing $z^m(\omega)$ units of ω is defined as $c^m \equiv w^m/A^m$ and it is identical for all varieties. The price index reflecting the cost of importing from country n can be defined as $p^{nm} \equiv c^m \delta^{nm}$. We can think of c^m as the basic prices, and p^m as the prices with cost insurance and freight (CIF) arrangement. After combining the expressions for both, the price faced by consumers in n importing goods from m is given as

$$p^{nm} = \frac{w^m}{A^m}\delta^{nm}, \tag{1}$$

which will determine the number of varieties and hence the trade volume from a given origin destination pair. The price index reflecting the overall price levels relevant for consumers in n is equal to

$$\Phi^m = \left(\sum_n (p^{mn})^{-\theta} \right)^{-\frac{1}{\theta}}, \tag{2}$$

which follows from the distributional assumptions, and we are omitting the proof as it is available in many papers in the literature. The productivity draws need to be Frechet or Weibull for this equation to hold. Gumbel distribution also leads to a similar expression. It is crucial to emphasize the economic meaning of Φ^m: It can be used as the "consumer price index" to convert nominal variables to real.

International trade: The share of imports from n is equal to

$$\pi^{nm} = \left(\frac{p^{nm}}{\Phi^n} \right)^{-\theta}, \tag{3}$$

where p^{nm} is a price index representing the cost of varieties produced in m shipped to n, and Φ^n is a price index representing the overall cost of living. This expression, similar to equation 2, directly follows from the distributional assumptions. The shape parameter of the Frechet productivity variable determines the trade elasticity, $-\theta$, in this model, making it a constant elasticity of substitution system. This equation leads to the gravity equation discussed in Anderson, 1979 and Anderson and van Wincoop, 2003, therefore the quantified model fits the trade data exceptionally well.

Goods market clearing implies that exports from m to n, defined as X^{nm}, is equal to import demand

$$X^{nm} = \pi^{nm} w^n L^n, \tag{4}$$

where $w^n L^n$ is the total income of workers in n, which gives us the total demand for goods..

Factors market: Labor market clearing under perfect competition implies that total value of output (i.e., total exports including domestic absorption) should be equal to total cost of production (i.e., wage bill or total cost of all locally-owned production factors).

$$w^m L^m = \sum_n X^{nm}. \tag{5}$$

Welfare: Here, calculation of welfare is quite simple and can be defined as real income, equal to w^n/Φ^n.

Equilibrium: In this system, we can define the equilibrium as the vector of wages w^n and the matrix of imports X^{nm} such that markets clear following equations (4) and (5), and trade patterns follow equation (3) based on prices implied by wages and transportation costs, given by equations (1), and (2).

2.1 Solving the textbook model

The solution utilizes the hat-algebra approach of Dekle et al., 2008. We will solve the system using its contraction mapping features. It starts with guessed wages and updates them following the equation of the model until the code converges to a solution. This procedure is very efficient as long as the system is a contraction mapping.

The main idea is to write the equations in such an order that each equation will use variables implied by previous equations. In ideal conditions, there will be only one "guessed" variable needed in the first equation. We need to guess the right hand side variable in the first equation and update it slowly. The textbook model is a simple case with one "guessed" variable. More complex models will require guessing multiple variables. We can guess as many variables as needed, as long as the system as a whole is a contraction mapping. The choice of numeraire, i.e. the normalization process, is flexible and does not impact the results. In the upcoming sections, we will provide a more complex model that requires guessing multiple variables, where the choice of numeraire is also consequential.

To accommodate the solution, we need to define the crucial "hat" operator: Consider $\hat{x} = x_1/x_2$ as the ratio of any variable x in two states of the world, such as before a trade shock and after a trade shock. The idiosyncratic productivity variables, $z^m(\omega)$ are *not* necessarily redrawn after a proposed shock. They are already substituted out from the main equations, and we will not consider them further in the solution. Many of the unchanged variables and parameters will cancel out, which makes the implementation of this method very convenient. More specifically, we assume that $\hat{A}^m = 1$ and $\hat{L}^m = 1$, which will be omitted altogether from the equations. It is easy to plug these variables back into the equations, if the goal is to simulate change in population or productivity.

Note that neither the utility function, nor the utility function parameter σ, will appear in the solution as long as $\sigma < 1 + \theta$. This condition ensures well defined price indices and σ scales price indices in all countries exactly the same, which in turn can be ignored. See Eaton and Kortum, 2002 for details.

Imagine that we would like to calculate the impact of the change in transportation costs, hence $\hat{\delta}^{mn} \neq 1$ for some corridors. This shock is exogenous, thus $\widehat{\delta^{nm}}$ is given to us. There are no other changes or shocks in the system.

Algorithm

Intuition of the algorithm: We write equations of the system one by one, where we have a single variable on the left hand side and multiple variables, parameters and data on the right hand side. The right-hand-side variable(s) of the first equation must be guessed as they appear the first time. The right-hand-side variables of the following equations must be guessed if they do not appear in the previous equations' left-hand-side. The idea is to keep the guessed variables as few as possible, ideally just one. For this, we need to think about how to order the equations. Then write the system of equations as a function such that $\mathbf{x} = F(\mathbf{x}; \mathbf{\Theta})$, where $\mathbf{x}$ is the array of guessed variables, and $\mathbf{\Theta}$ is an array of data and parameters. Then we solve it by iteration, assuming that $F(.)$ is a contraction mapping. This is done by guessing $\mathbf{x}$, then updating it slowly using values implied by $F(.)$. We need to normalize nominal variables to prevent prices from reaching infinity or zero simultaneously.

We need to rewrite equations 1, 2, 3, 4, and 5 in hat format, and the solution steps will follow exactly this order (as we deliberately designed the exposition of the model as such to make the solution easy to follow). Since $\hat{A}^m = 1$ and $\hat{L}^m = 1$, these variables will drop from the equations. The solution method starts with an arbitrary guess of wages and then calculates each variable in hats one by one and ends up with implied wages. Then, it updates wages slowly and continues until a fixed point is reached. See Appendix A4 or the replication package for the code in Python, Julia, Matlab, and R. The equation numbers are also provided in the code for convenience.

Step 0→ Guess the wages $\widehat{w^m}$. A good starting point is to assume all equal to one.

Step 1→ Change in prices (including iceberg costs) $\widehat{p^{nm}} = \widehat{\delta^{nm}}\widehat{w^m}$, from equation (1). Note that $\widehat{\delta^{nm}}$ is the exogenous shock.

Step 2→ Price index for composites $\widehat{\Phi^n} = \left(\sum_m \overline{\pi^{nm}} \left(\widehat{p^{nm}}\right)^{-\theta}\right)^{-\frac{1}{\theta}}$, from equation (2).

Step 3→ Change trade (import) shares $\widehat{\pi^{nm}} = \frac{\left(\widehat{p^{nm}}\right)^{-\theta}}{\left(\widehat{\Phi^n}\right)^{-\theta}}$, from equation (3).

Step 4→ Expenditure is equal to income. The market clearing condition that makes imports equal to exports for all trade corridors is $\widehat{X^{nm}} = \widehat{\pi^{nm}}\widehat{w^n}$, from equation (4).

Step 5→ Calculate the change in wages $\widehat{w^{m*}} = \frac{\sum_n \widehat{X^{nm}}\overline{X^{nm}}}{\sum_n \overline{X^{nm}}}$, from equation (5).

Step 6→ First, calculate the implied change in numeraire, which is the world GDP in this example: $\vartheta = \frac{\sum_m \sum_n \widehat{X}^{nm}\overline{X^{nm}}}{\sum_m \sum_n \overline{X^{nm}}}$. Then, scale nominal variables as needed, such that $\widehat{w^{m**}} = \widehat{w^{m*}}/\vartheta$.

Step 7→ Calculate error $\xi_1 = \sum_m |\widehat{w^m} - \widehat{w^{m**}}|$ and update $\widehat{w^m} = \rho_1\widehat{w^{m**}} + (1-\rho_1)\widehat{w^m}$.

Step 8→ If $\xi_1 < 10^{-8}$ stop the loop, else go to step 1 and continue.

Most of the steps above are simple hat transformations of model equations. Note that, we will need the initial import shares $\overline{\pi^{mn}}$ and import values $\overline{X}^{mn}$ to calculate equations 2 and 5. We implicitly fix nominal world GDP by scaling all variables with it, which serves as the numeraire. Make sure that the code gives same result in real terms (when nominal variables are divided to the price index) irrespective of the starting point or the choice of numeraire.

Data requirements

See Section 4 to learn more about data processing. The data requirements are modest for the textbook model. The following parameters and data are needed:

- Trade elasticity parameter θ.
- Trade data $\overline{X^{nm}}$, providing value of imports of destination n from origin m. Note that this includes diagonals $\overline{X^{nn}}$, i.e. domestic production consumed locally or domestic absorption. Domestic absorption is usually not included in trade data sets, but there are special data sets that include them. For simplicity, we assume that trade is balanced in this example.

- Trade (import) shares are calculated from trade values as $\overline{\pi^{nm}} = \frac{\overline{X^{nm}}}{\sum_i \overline{X^{ni}}}$.
- Finally, we need to set the update speed, where $0 < \rho_1 < 1$. We arbitrarily take it equal to $\rho_1 = 0.2$. A large number can prevent convergence.

3 A generalized model

In this section, we modify the classic Eaton and Kortum, 2002 model discussed in the previous section to make it more realistic and relevant as a policy tool. First, we allow sectors which are effectively continua of differentiated goods. Second, we allow input output linkages. These two modifications make the framework similar to the influential Caliendo and Parro, 2015 model. In addition to these extensions, we assume that workers have differentiated productivity across sectors and they choose a sector based on that. This is a static version of the Artuc et al., 2010 model, which allows calibration for the entire world. As far as we are aware, the first static implementation of this idea in the trade literature was Redding, 2016. More recently, Galle et al., 2022 also implement a similar model with focus on heterogeneity. A full implementation of a dynamic version (along with the IO linkages) was introduced by Caliendo et al., 2019. Most of these models consider labor market frictions in only one country, with some exceptions like Lee, 2020, Artuc, Porto, and Rijkers, 2025 and Artuc and Sommer, 2024. Although not an international trade paper, Lagakos and Waugh, 2013 is particularly relevant and important as it was the first paper to look at labor market frictions on a global scale (as far as we know).

We will express the model with equations in a specific order that will match the order of equations used in the solution. The solution will be similar to the textbook model's solution utilizing simple hat algebra. Consider N countries, indexed with either m or n, where agents derive utility from consuming varieties ω_j categorized into J sectors. Different from the textbook model, allowing sectors in addition to varieties facilitates taking the model to more disaggregated data. The varieties are combined by agents in country n to produce sectoral composites, following the intuition of the textbook model:

$$Q_j^n \equiv \left[\int \left(Q^n(\omega_j) \right)^{\frac{\sigma-1}{\sigma}} d\omega_j \right]^{\frac{\sigma}{\sigma-1}},$$

where $Q^n(\omega_j)$ is the quantity of variety ω_j used, and σ is the elasticity parameter. The sectoral composites enter the utility of country n agents as

$$U^n = \prod_j \left(Q_j^n \right)^{\gamma_j^n},$$

where Q_j^n is the consumed quantity of sector j composite, and γ_j^n is the Cobb-Douglas share parameter.

Production: The production process requires combining intermediate inputs with labor input:

$$q^m(\omega_j) = A_j^m z^m(\omega_j) \left[\prod_k \left(Q_k^m(\omega_j) \right)^{\beta_{jk}^m} \right]^{\alpha_{jM}^m} \left[\widetilde{L^m}(\omega_j) \right]^{\alpha_{jL}^m},$$

where $Q_k^m(\omega_j)$ is the sector k composite and $\widetilde{L^m}(\omega_j)$ is the effective labor units (not headcount) used in ω_j production. Cobb-Douglas production function shares and material input shares add up to one, $\alpha_{jL}^m + \alpha_{jM}^m = 1$ and $\sum_k \beta_{jk}^m = 1$. The technology parameter A_j^m is country-sector specific and reflects the overall productivity. As usual, assume that the country-variety-specific productivity variable $z^m(\omega_j)$ is distributed Frechet with shape θ and scale $\left[\Gamma \left(1 - \frac{1}{\theta} \right) \right]^{-1}$, where $\theta > 1$. The cost of producing one unit of ω_j is equal to

$$\tilde{c}^m(\omega_j) = \varrho_j^m \frac{\left(c_{jM}^m \right)^{\alpha_{jM}^m} \left(w_j^m \right)^{\alpha_{jL}^m}}{A_j^m z^m(\omega_j)},$$

where $\varrho_j^m = (\alpha_{jM}^m)^{-\alpha_{jM}^m} (\alpha_{jL}^m)^{-\alpha_{jL}^m}$ is the constant cost multiplier which does not play any role in the solution, c_{jM}^m is the price of intermediate input and w_j^m is the sector-specific wage.

Tariffs and transportation costs: Consumers can source varieties locally if they are produced locally, or import them from abroad. Destination country n consumers must pay d_j^{nm} times the price when they purchase a variety from origin country m. The cost multiplier is defined as $d_j^{nm} \equiv \delta_j^{nm}(1 + \tau_j^{nm})$, where δ_j^{nm} is the iceberg transportation cost multiplier and τ_j^{nm} is the tariff imposed by n on sector j products from m. We assume $d_j^{nn} = 1$ if a good is sourced locally.

Prices: This part of the model is identical to the textbook model, but implemented for multiple sectors. Consumers in country n will source each variety from the minimum cost origin, including the transportation costs and tariffs, therefore the local price will be

$$\tilde{p}^n(\omega_j) = \min_m \{\tilde{c}^m(\omega_j) d_j^{nm}\}.$$

If the cost of producing the variety locally exceeds this effective price, i.e. $\tilde{c}^n(\omega_j) > \tilde{p}^n(\omega_j)$, the variety will not be produced locally. This expression means that each country will source a given variety from a single origin.

This structure leads to a very simple and convenient analytical solution. Let us define some price indices to streamline the equations. Similar to the previous example model, these definitions will make the solution easy to follow as each of the following equations will correspond to a step in the numerical solution.

The cost of producing $z^m(\omega_j)$ units of ω_j is defined as c_j^m and it is identical for all varieties

$$c_j^m \equiv \frac{\varrho_j^m}{A_j^m} \left(c_{jM}^m\right)^{\alpha_{jM}^m} \left(w_j^m\right)^{\alpha_{jL}^m}, \tag{6}$$

based on the previously provided expression for $\tilde{c}^m(\omega_j)$.

The price index reflecting the total cost of importing from country n is

$$p_j^{nm} = c_j^m d_j^{nm}, \tag{7}$$

which will determine the number of varieties and hence the trade volume from a given origin. Like the basic model, we can think of c_j^m as the basic prices and p^m as the prices with cost insurance and freight (CIF) plus tariffs.

The price index reflecting the overall price levels relevant for consumers in n is given as

$$\Phi_j^n = \left(\sum_m \left(p_j^{nm}\right)^{-\theta} \right)^{-\frac{1}{\theta}}, \tag{8}$$

which follows from the distributional assumptions. Φ_j^n is a key variable and can be used as the "consumer price index" to convert nominal variables to real.

Intermediate input prices: The unit price of the composite intermediate input used in sector j production can be expressed as

$$c_{jM}^m = \tilde{\varrho}_j^m \prod_k \left(\Phi_k^m\right)^{\beta_{jk}^m}, \tag{9}$$

where the constant cost multiplier is $\tilde{\varrho}_j^m = \prod_k \left(\beta_{jk}^m\right)^{-\beta_{jk}^m}$.

International trade: The share of imports from n is equal to

$$\pi_j^{nm} = \left(\frac{p_j^{nm}}{\Phi_j^n} \right)^{-\theta}, \tag{10}$$

where p_j^{nm} is a price index representing the cost of varieties produced in m shipped to n, and Φ_j^n is a price index representing the overall cost of living.

Labor allocation and income: We model the labor allocation problem as a static version of Artuc et al., 2010, similar to Lee, 2020 and Artuc and Sommer, 2024. Assume that there is a continuum of workers with measure L^m in country m. Each worker, indexed with l, draws a sector specific inverse-productivity shock ϵ_j^l. Since the model is static, the shocks are drawn once, not repeatedly. Therefore we can consider the vector that consists of ϵ_j^l as the worker type. This is similar to how Melitz, 2003 treats the firm-specific productivity shocks. In this case, it is the sector-specific worker productivity.

One effective unit of labor input translates into ϵ_j^l units of worker time. Therefore, the productivity adjusted wage is given as w_j^m/ϵ_j^l. Workers' productivity draws are specific to the sector and worker, but they do not depend on the specific variety or the producer. The shocks are Weibull distributed with scale $\Gamma\left(1+\frac{1}{\nu}\right)$ and shape ν. The distributional assumption facilitates the solution and produces simple expressions for the key variables in equilibrium.

The expected labor income is

$$W^m = \left[\sum_k (w_k^m)^\nu \right]^{\frac{1}{\nu}}, \tag{11}$$

and sectoral labor supply, i.e. the number (headcount) of workers allocated to production of j varieties, is

$$L_j^m = \left(\frac{w_j^m}{W^m} \right)^\nu L^m. \tag{12}$$

The headcount of workers in sector j is different from the effective units of labor input. The latter is given as $\widetilde{L_j^m} = \left(w_j^m / W^m\right)^{\nu-1} L^m$. Since there is only one factor of production (excluding the input materials), the total income is simply equal to $W^m L^m$.

Labor market clearing wages: Labor market clearing under perfect competition implies that the value of wage bill implied by firms' optimization problem should be equal to the total income of workers. In this case, Cobb-Douglas technology simply implies a constant share of the wage bill in total output, when the production is optimized.

Consider sectoral output,

$$Y_j^m = \sum_n X_j^{nm}. \tag{13}$$

where X_j^{nm} is the value of sector j flows from m to n. Then, the labor market clearing condition discussed above implies that

$$w_j^m \left(\frac{w_j^m}{W^m} \right)^{\nu-1} L^m = \alpha_j^m Y_j^m, \tag{14}$$

which simply forces the total wage income of all sector j workers characterized by the labor allocation problem to be equal to the wage bill paid by producers.

Market clearing: Total nominal income is equal to

$$I^n = W^n L^n + \sum_m \sum_j X_j^{nm} \tau_j^{nm}, \tag{15}$$

which is the sum of disposable income, $W^n L^n$, and tariff revenue of the government given by $\sum_m \sum_j X_j^{nm} \tau_j^{nm}$. The expenditure is

$$E^n = I^n - S^n, \tag{16}$$

where S^n is the savings, which is assumed to be fixed.

Then, goods market clearing implies that exports from m to n, defined as X_j^{nm}, is equal to import demand

$$X_j^{nm} = \left(\gamma_j^n E^n + \sum_k \alpha_{kM}^m \beta_{kj}^m Y_k^n \right) \frac{\pi_j^{nm}}{1 + \tau_j^{nm}}, \tag{17}$$

where E^n is the total expenditure in n, and Y_k^n is the sectoral output as defined before. The $\gamma_j^n E^n$ expression accounts for the demand by consumers and the $\sum_k \alpha_{kM}^m \beta_{kj}^m Y_k^n$ expression accounts for the demand by producers for intermediate inputs.

Welfare: We can define welfare as the real GDP, which is equal to $\frac{E^n}{\prod_j \left(\Phi_j^n\right)^{\gamma_j^n}}$. Alternatively, disposable income can be used as a measure of welfare if tariff revenue is not distributed to the public, given as $\frac{W^n}{\prod_j \left(\Phi_j^n\right)^{\gamma_j^n}}$. Note that workers have different productivity draws for each sector, which stay with them for life, therefore the welfare of workers will differ from each other and can be calculated as $\frac{1}{\prod_j \left(\Phi_j^n\right)^{\gamma_j^n}} E \max_j \frac{w_j^m}{\epsilon_j^l}$. Since there are infinitely many workers types, this calculation is not trivial. Despite its importance for policy analysis, we will not focus on distributional impacts of trade shocks in this paper.

Equilibrium: In this system, we can define the equilibrium as the matrix of wages w_j^n, the matrix of composite input prices c_{jM}^m and the array of imports X_j^{nm} such that markets clear following equations (14) and (17), and trade patterns follow equation (10) based on prices implied by wages, intermediate composite prices and transportation costs, given in equations (6), (7), (8), (9), (11), (12), (13), (15), and (16).

3.1 Solving the generalized model

This section describes the method used to solve our model. Assume that tariffs change, such that $\widehat{d_j^{nm}} = \frac{1+\tau_{j1}^{nm}}{1+\tau_{j0}^{nm}}$. We are interested in the impact of this shock on trade patterns and welfare. There are no other shocks or changes in the system.

Algorithm

Similar to the textbook model, we can write the crucial equations in hat format. The solution will follow exactly the same order as the equations of the model, so that it is easy to follow. The order of the equations in the solution is flexible. But it is a good idea to choose an order to minimize the number of guessed variables. The solution is based on a contraction mapping, where we guess initial variables and iterate the system until a fixed point is reached.

The main idea, as we discussed previously, is to write the equations in an order, such that each equation uses variables implied by previous equations. If a variable cannot be recovered from left hand side of previous equations, it should be treated as a "guessed" variable. In ideal conditions, there should be only one or a few "guessed" variables. There can be many data objects or parameters in the equations without creating any complications. In an initial step, which we call step zero, we need to guess the necessary variables and update them slowly as we iterate through the equations.

Different from the earlier example, it is not possible to substitute out all variables (except one) in the extended model. Fortunately, there is a lot of flexibility in choosing the "guessed" variables. This is a major strength of this method: Since we can have as many guessed variables as we like, we don't need to substitute out a variable if it makes the equations convoluted or the order of the equations unintuitive.

Here we chose to take the trade flow array X_j^{nm}, wage matrix w_j^m and input prices c_{Mj}^m as the "guessed" variables. Since the trade flow array is large, it is not the ideal choice, but makes the solution a bit simpler and easier to follow compared to alternatives. In the online version, we chose to guess the sectoral output, Y_j^m, to save memory in the server and to be able to accommodate multiple users simultaneously. As long as the equations are correct, and the contraction mapping character of the system is preserved, the choice of guessed variables or the initial guesses will not impact the final results (subject to some precision loss). This flexibility makes the core model and the solution easy to adapt to a wide range of extended models.

In this model, different from the previous one, the choice of numeraire matters as savings are fixed in the units of numeraire. If you change it, the results will change. See Appendix A5 or the replication package for the corresponding code in Python, Julia, Matlab, and R. The equation numbers are also provided in the code for quick reference.

Step 0→ Guess the changes in outsourced input price index $\widehat{c_{jM}^m}$, wages $\widehat{w_j^m}$, and trade flows $\widehat{X_j^{nm}}$. A good starting point is to take all elements of each array equal to one.

Step 1→ Calculate change in cost index defined as

$$\widehat{c_j^m} = \left(\widehat{w_j^m}\right)^{\alpha_{jL}^m} \left(\widehat{c_{jM}^m}\right)^{\alpha_{jM}^m},$$

from equation (6).

Step 2→ Change in prices $\widehat{p_j^{nm}} = \widehat{d_j^{nm}}\widehat{c_j^m}$, from equation (7).

Step 3→ Calculate change in price index for composites $\widehat{\Phi_j^n} = \left(\sum_m \overline{\pi_j^{nm}} \left(\widehat{p_j^{nm}}\right)^{-\theta}\right)^{-\frac{1}{\theta}}$, from equation (8).

Step 4→ Calculate change in price index for intermediate inputs $\widehat{c_{jM}^{m*}} = \prod_k \left(\widehat{\Phi_k^m}\right)^{\beta_{jk}^m}$, from equation (9).

Step 5→ Change in trade (import) shares $\widehat{\pi_j^{nm}} = \frac{\left(\widehat{p_j^{nm}}\right)^{-\theta}}{\left(\widehat{\Phi_j^n}\right)^{-\theta}}$, from equation (10).

Step 6→ Change in total disposable income given as $\widehat{W^n} = \left(\sum_j \overline{L_j^n} \left(\widehat{w_j^n}\right)^{\nu}\right)^{\frac{1}{\nu}}$, from equation (11).

Step 7→ Change in labor allocation $\widehat{L_j^n} = \frac{\left(\widehat{w_j^n}\right)^{\nu}}{\left(\widehat{W^n}\right)^{\nu}}$, from equation (12).

Step 8→ Calculate change in sectoral output

$$\widehat{Y_j^m} = \left(\sum_n \overline{\Xi_j^{nm}}\widehat{X_j^{nm}}\right),$$

from equation (13).

Step 9→ Calculate change in wages $\widehat{w_j^{m*}} = \left(\widehat{Y_j^m}\right)\left(\widehat{L_j^{nm}}\right)^{-\frac{\nu-1}{\nu}}$, from equation (14) after plugging in labor allocation.

Step 10→ Market clearing and demand (where τ_{j1}^{nm} is the new tariff array)

$$\widehat{I^n} = (1-\overline{\varsigma^n})\widehat{W^n} + \frac{\sum_j \sum_m \tau_{j1}^{nm} \widehat{X_j^{nm}} \overline{X_j^{nm}}}{\overline{I^n}},$$

$$\widehat{E^n} = (\widehat{I^n} - \overline{S^n})/(1-\overline{S^n}),$$

$$\widehat{X_k^{nm*}} = \overline{D_{Lk}^{nm}} \widehat{\pi_k^{nm}} \widehat{E^n} + \sum_j \overline{D_{jk}^{nm}} \widehat{\pi_k^{nm}} \widehat{Y_j^n},$$

from equations (15), (16), and (17).

Step 11→ Calculate the implied change in numeraire, which is the world output in this example: $\vartheta = \frac{\sum_m \sum_n \sum_j \widehat{X_j^{nm}} \overline{X_j^{nm}}}{\sum_m \sum_n \sum_j \overline{X_j^{nm}}}$. Then, scale nominal variables as needed, such that $\widehat{w_j^{m**}} = \widehat{w_j^{m*}}/\vartheta$, $\widehat{c_j^{m**}} = \widehat{c_j^{m*}}/\vartheta$, and $\widehat{X_j^{nm**}} = \widehat{X_j^{nm*}}/\vartheta$.

Step 12a→ Calculate $\xi_1 = \sum_n \sum_m \sum_k |\widehat{X_k^{nm}} - \widehat{X_k^{nm**}}|$, and update $\widehat{X_k^{nm}} = \rho_1 \widehat{X_k^{nm**}} + (1-\rho_1)\widehat{X_k^{nm}}$.

Step 12b→ Calculate $\xi_2 = \sum_m \sum_j |\widehat{c_{jM}^m} - \widehat{c_{jM}^{m**}}|$ and update $\widehat{c_{jM}^m} = \rho_2 \widehat{c_{jM}^{m**}} + (1-\rho_2)\widehat{c_{jM}^m}$.

Step 12c→ Calculate $\xi_3 = \sum_m \sum_j |\widehat{w_j^m} - \widehat{w_j^{m**}}|$ and update $\widehat{w_j^m} = \rho_3 \widehat{w_j^{m**}} + (1-\rho_3)\widehat{w_j^m}$.

Step 13→ If $\xi_i < 10^{-8}$ for all $i = \{1,2,3\}$ then stop the loop, else go to step 1 and continue.

Data requirements

Section 4 discusses the construction of required data in detail. The following parameters and initial shares are required for solution:

- Trade and labor allocation elasticity parameters, θ, and ν.
- Production function parameters, α_{jM}^n, α_{jL}^n, and β_{jk}^n.
- Preference parameters, γ_j^n.
- Labor allocation shares, $\overline{L_j^n}$.

- Trade data, $\overline{X_j^{nm}}$, i.e. good j produced by country m and demanded by country n. Note that this includes diagonals, i.e. domestic production consumed locally, therefore output is also included. Note that tariffs and transportation costs are excluded.
- Tariff data, τ_{j0}^{nm}, (initial tariffs before any change in trade policy).
- Initial share variables, calculated using the trade and tariff data using parameters above: $\overline{\varsigma^n}$, $\overline{S^n}$, $\overline{\pi_j^{nm}}$, $\overline{\Xi_j^{nm}}$, $\overline{D_{jk}^{nm}}$, and $\overline{D_{Lk}^{nm}}$. See below for definitions and calculations.
- Speed update variables for the solution method: $0 < \rho_i < 1$, for $i = \{1, 2, 3\}$. We set them arbitrarily equal to 0.5. Setting these numbers to large values might impact convergence, therefore small numbers are recommended.
- Imputation of required share variables:

  Consider the array of initial trade values $\overline{X_j^{nm}}$ at basic prices (excluding transportation costs and tariffs), the array of initial tariffs τ_{j0}^{nm}, and parameters of the model (α_{jM}^n, α_{jL}^n, β_{jk}^n, and γ_j^n), then:

  - Sectoral output is $\overline{Y_j^m} = \sum_n \overline{X_j^{nm}}$.
  - Initial total income is $\overline{I^n} = \sum_j \alpha_{jL}^n \overline{Y_j^n} + \sum_j \sum_m \tau_{j0}^{nm} \overline{X_j^{nm}}$.
  - Initial total expenditure is $\overline{E^n} = \sum_j \sum_m \overline{X_j^{nm}}(1 + \tau_{j0}^{nm}) - \sum_j \alpha_{jM}^n \overline{Y_j^n}$.
  - Tariff revenue share in income is $\overline{\varsigma^n} = \frac{\sum_j \sum_m \tau_{j0}^{nm} \overline{X_j^{nm}}}{\overline{I^n}}$.
  - Initial savings rate is $\overline{S^n} = \frac{\sum_m \sum_j \overline{X_j^{mn}} - \sum_m \sum_j \overline{X_j^{nm}}}{\overline{I^n}}$.
  - Initial trade (import) shares are $\overline{\pi_j^{nm}} = \frac{\overline{X_j^{nm}}(1+\tau_{j0}^{nm})}{\sum_i \overline{X_j^{ni}}(1+\tau_{j0}^{ni})}$.
  - Initial trade (export) shares are $\overline{\Xi_{j0}^{nm}} = \frac{\overline{X_j^{nm}}}{\sum_i \overline{X_j^{im}}}$.
  - The demand for intermediate inputs is defined as $\overline{\varphi_{jk}^{nm}} \equiv \overline{Y_j^n} \alpha_{jM}^n \beta_{jk}^n \overline{\pi_k^{nm}}$, while the demand for final goods is defined as $\overline{\varphi_{Lk}^{nm}} \equiv \overline{E^n} \gamma_k^n \overline{\pi_k^{nm}}$. Then the demand shares are $\overline{D_{jk}^{nm}} = \frac{\overline{\varphi_{jk}^{nm}}}{\sum_j \overline{\varphi_{jk}^{nm}} + \overline{\varphi_{Lk}^{nm}}}$ and $\overline{D_{Lk}^{nm}} = \frac{\overline{\varphi_{Lk}^{nm}}}{\sum_j \overline{\varphi_{jk}^{nm}} + \overline{\varphi_{Lk}^{nm}}}$ respectively, for intermediate inputs and final goods.

A note for the version with only trade costs: Please note that construction of the share variables above requires tariff data, which are often unreliable and very difficult to consolidate. For a version with only iceberg costs and without any tariffs, simply set both initial and final tariffs equal to zero, $\tau_{j0}^{nm} = \tau_{j1}^{nm} = 0$. Then the income share of tariffs will also be zero, $\overline{\varsigma^m} = 0$, and some other expressions will be affected such as $\overline{\pi_j^{nm}} = \overline{X_j^{nm}} / \sum_i \overline{X_j^{ni}}$, $\overline{E^n} = \sum_j \sum_m \overline{X_j^{nm}} - \sum_j \alpha_{jM}^n \overline{Y_j^n}$ and $\overline{I^n} = \sum_j \alpha_{jL}^n \overline{Y_j^n}$. There are also some changes in the solution equations: The price change equation becomes $\widehat{p_j^{nm}} = \widehat{\delta_j^{nm}} \widehat{c_j^m}$, to capture iceberg cost changes, $\widehat{\delta_j^{nm}}$, instead of tariff changes, $\widehat{d_j^{nm}}$. The income change equation is now simply $\widehat{I^n} = \widehat{W^n}$. After these simple modifications, same code can be used for a version with transportation cost shocks.

4 Data

We use annual data from the Inter-Country Input-Output (ICIO) Tables (2025 release) produced by the OECD as part of the Trade in Value-Added (TiVA) statistics. Guilhoto et al., 2022 provide details about their methodology.

The OECD–WTO TiVA 2025 database is based on ICIO tables that describe production linkages across countries and industries. The dataset covers 81 economies (80 individual economies and a Rest of the World aggregate; see Table A1) and reports bilateral trade and production linkages across 50 industries (see Table A2), with historical series available for 1995–2022.

Our analysis focuses on 2022, the latest year available. To align the data with our model structure, we collapse the original 50 industries into 21 sectors, grouping all service activities into a single category, "All services," which is not subject to tariffs (see Table A3).

4.1 Trade and input-output linkage data

We construct bilateral sectoral trade values X_j^{nm} from the OECD TiVA 2025, restricted to 2022 and covering all countries. The trade values are reported at basic prices, excluding all taxes and transportation costs. For each destination country n and sector j, TiVA reports (i) the use of intermediate inputs by origin country–sector pairs and (ii) final demand by origin. Aggregating over origin sectors within each origin country m yields the value of sector-j sales from origin country m to destination n:

$$\overline{X_j^{nm}} \equiv \sum_k Z_j^{n,(m,k)} + \widetilde{FD}_j^{n,(m)}, \tag{18}$$

where $Z_j^{n,(m,k)}$ denotes expenditure by (n, j) on intermediate inputs sourced from origin country m, origin sector k, and $\widetilde{FD}_j^{n,(m)}$ denotes final demand in n for goods of sector j produced in m (both measured at producer prices). Equation (18) is applied for all (n, m, j), including $n = m$ (domestic absorption). Thus, gross sectoral output in country m satisfies $\overline{Y_j^m} = \sum_n \overline{X_j^{nm}}$, as implied by equation (13).

4.2 Construction of production parameters

We calibrate sector–country production parameters using as input the same database. The data report, for each destination country m and destination sector j, gross output and a detailed use of intermediate inputs by origin sectors k, alongside primary income components. We map these accounts to the generalized model in Section 3 to construct:

- α_{jL}^m: the labor/primary input share in sector j of country m (exponent on the labor input).
- α_{jM}^m: the intermediate-input share in sector j of country m (exponent on the intermediate composite), satisfying $\alpha_{jL}^m + \alpha_{jM}^m = 1$.
- β_{jk}^m: the composition of the intermediate-input bundle; the share of sector-k composite in sector-j production in country m, with $\sum_k \beta_{jk}^m = 1$.

In addition to the expenditure on intermediate inputs $Z_j^{n,(m,k)}$, TiVA reports taxes less subsidies on intermediate and final products (TLS_j^m), value added (VA_j^m).[3] We partition gross output into a primary-input block and an intermediate-input block consistent with our two-nest Cobb–Douglas structure:

[3] In practice, this means we exclude final demand columns (HFCE, NPISH, GGFC, GFCF, INVNT, DPABR), focusing only on intermediate use, when the goal is to calibrate production function parameters.

$$\text{IntermediateCost}_j^m = \sum_k \widetilde{Z}_{jk}^m \tag{19}$$

$$\equiv \overline{Y_j^m} - TLS_j^m - VA_j^m, \tag{20}$$

where $\widetilde{Z}_{jk}^m$ represents total expenditure by sector j in country m on inputs from sector k, irrespective of the country of origin (including both domestic and imported inputs). $Z_j^{m,(n,k)}$ denotes expenditure by destination country–sector (m, j) on inputs sourced from origin country n, origin sector k.

$$\widetilde{Z}_{jk}^m \equiv \sum_n Z_j^{m,(n,k)}. \tag{21}$$

$$\text{PrimaryCost}_j^m \equiv TLS_j^m + VA_j^m, \tag{22}$$

which imposes

$$\overline{Y_j^m} = \text{PrimaryCost}_j^m + \text{IntermediateCost}_j^m.$$

With this partition, "PrimaryCost" includes compensation of employees and the non-wage components of value added (operating surplus, net taxes on production), consistent with our single primary-factor nest.

The Cobb–Douglas cost shares are then:

$$\alpha_{jL}^m = \frac{\text{PrimaryCost}_j^m}{\overline{Y_j^m}} = \frac{TLS_j^m + VA_j^m}{\overline{Y_j^m}}, \tag{23}$$

$$\alpha_{jM}^m = \frac{\text{IntermediateCost}_j^m}{\overline{Y_j^m}} = \frac{\sum_k \widetilde{Z}_{jk}^m}{\overline{Y_j^m}} \equiv \frac{\overline{Y_j^m} - TLS_j^m - VA_j^m}{\overline{Y_j^m}}. \tag{24}$$

so that $\alpha_{jL}^m + \alpha_{jM}^m = 1$ by construction.

The composition of the intermediate composite is derived from the intermediate-use block.

Specifically, β_{jk}^m denotes the share of total intermediate expenditure by sector j in country m that is allocated to inputs sourced from sector k. The input-share parameter is defined as:

$$\beta_{jk}^m = \frac{\widetilde{Z}_{jk}^m}{\sum_{k'} \widetilde{Z}_{jk'}^m}, \tag{25}$$

with the denominator representing the sum of all intermediate inputs used by sector j in country m, which ensures $\sum k\beta_{jk}^m = 1$. These β_{jk}^m enter the composite intermediate price in equation (9).

4.3 Tariff data

For 2022, we use the panel tariff database compiled by Constantinescu, 2025, which enables consistent cross-country comparisons and forms the foundation of the empirical analysis. Please also refer to Teti, 2024, for an excellent analysis of the issues related to reporting tariffs and a solution to these issues. The underlying data are sourced from UNCTAD TRAINS via the World Integrated Trade Solution (WITS), covering all available countries (199 in total). The dataset reports both Most Favored Nation (MFN) and Applied Tariffs at the HS 6-digit level, including ad valorem and specific tariffs.[4]

We subsequently implemented additional procedures:

- **Selecting tariff type**: Applied tariffs (including specific tariffs) are prioritized; MFN rates are used as a fallback when applied tariffs are unavailable.
- **Capping extreme values**: Tariff rates exceeding 100% are truncated to 100%.[5]

Tariff rates are mapped from the HS-1 (HS 1996) 6-digit classification to ISIC Rev.3 4-digit industries using concordance tables from WITS. We then aggregate ISIC industries into the 21 sectors used in our TiVA-based model. Each sectoral tariff is applied to imports from

[4] Constantinescu, 2025 processed the data to ensure consistency, including but not limited to backfilling missing observations: (i.e.) when 2022 data were missing or incomplete, values from the closest preceding year were substituted.

[5] Exceptionally high values often result from converting specific tariffs into their ad-valorem equivalents (AVE), which can produce inflated percentages.

origin country m to destination country n, consistent with the definition of bilateral sectoral trade values X_j^{nm} in Section 4.1.

Finally, for each sector j and country pair (n, m), we compute import-weighted average tariffs:

$$\tau_{j0}^{nm} = \frac{\sum_{p \in j} \text{tariff}_p^{nm} \cdot \text{imports}_p^{nm}}{\sum_{p \in j} \text{imports}_p^{nm}}, \tag{26}$$

where p indexes products within sector j, and imports_p^{nm} are bilateral import values in USD (BACI, CEPII). Missing import values are replaced with a small constant to avoid division by zero. These τ_{j0}^{nm} represent the initial tariffs before any change in trade policy.

4.4 Elasticity parameters

Trade elasticity is probably the most crucial parameter in the model, which impacts the results significantly. But estimating the trade elasticity is not a straightforward task, and there are many excellent papers in the literature taking up the challenge. We use the estimate from Simonovska and Waugh, 2014 who report it as approximately equal to -4.0, meaning $\theta = 4.0$. They use model simulations to estimate the parameter structurally. Since we are also using a similar structural model, their estimation method is consistent with our implementation. Eaton and Kortum, 2002 estimate the dispersion parameter as $\theta = 8.0$, which implies trade elasticity equal to -8.0. We use a single elasticity parameter covering all sectors, which minimizes the moving parts in the model, and thus increases transparency of the results. Although this assumption is perfectly consistent with the underlying microstructure, many researchers use sector specific elasticities to improve the fit of the model. For example, Caliendo and Parro, 2015 report different elasticities for sectors, ranging between -0.37 and -51.08 with mean -4.45, who use a similar data, a similar model and comparable sectoral aggregations to this paper. Bagwell et al., 2021 report that the sectoral trade elasticities are between -1.73 and -10.12 with mean -5.24. Some authors consider much richer heterogeneity for trade elasticities: For example, Kee et al., 2008 estimate precisely 315,451 trade elasticity parameters at the six-digit HS level for 117 countries. They find that the average elasticity is equal to -1.67 across all countries in their sample and across all product groups. They find that the standard deviation is 2.47, hence there is a sizable dispersion. More recently, Boehm et al., 2023 argued that trade elasticities are different in the short and long runs, approximately equal to -0.76 in the former and -2.0 in the latter.

The other important elasticity parameter is the labor supply elasticity. Compared to trade elasticity, this parameter has a smaller impact on aggregate results. However, if we want to focus on distributional effects of policy shocks, this parameter becomes the key determinant. In this paper, we focus on the aggregate effects. The parameter ν usually corresponds to true elasticity or semi-elasticity depending on the model specification and distributional assumptions. Given the Weibull distribution of the productivity shock and linearity of the indirect utility function in income, it is a true elasticity in this model, just the trade part. Specification of the indirect utility function and assumptions on the dynamics can influence the estimated elasticity. Therefore, caution should be exercised when taking elasticity related parameters from other papers in the literature. We assume that $\nu = 2.0$, which is roughly equal to values estimated by Artuc, Bastos, and Lee, 2025 and Artuc, Porto, and Rijkers, 2025, who report them as 1.93 and 2.05 respectively. Lee, 2020 reports labor mobility elasticity as 1.35 for the lowest skill workers, and 1.15 for the highest skill workers on average. Artuc and McLaren, 2015 report a similar parameter (equivalent to semi-elasticity) as either 1.62 or 1.80, depending on the discount factor. However, Artuc et al., 2010 and Artuc et al., 2022 find much smaller semi-elasticity numbers for the United States and Argentina using data with earlier time periods, roughly equal to 0.53 and 0.39 respectively. Artuc, 2013 presents a simple method based on gravity equation and reports a low estimate of 0.96 and a high estimate of 3.67 with the US data.

5 Policy simulations

We simulate a bilateral tariff shock between two country groups: high-income countries (H) and non-high-income countries (NH). The definitions of high-income and non-high-income is based on World Bank groupings. There are 47 countries in the high-income group and 34 countries in the non-high-income group, the latter including the Rest of the World (ROW).

We consider a 25 percentage-point increase in bilateral tariffs, applied on top of these baseline tariffs τ_{j0}^{nm} defined in (26). Formally, the counterfactual tariffs are:

$$\tau_{j1}^{nm} = \begin{cases} \tau_{j0}^{nm} + 0.25 & \text{if } n \in H \text{ and } m \in NH, \\ \tau_{j0}^{nm} + 0.25 & \text{if } n \in NH \text{ and } m \in H, \\ \tau_{j0}^{nm} & \text{otherwise,} \end{cases} \tag{27}$$

where $\tau_{j1}^{nn} = \tau_{j0}^{nn} = 0$, which corresponds to consumption of domestically produced goods (domestic absorption). Also recall that the tariffs are set to zero for services at all times. Thus:

- Every importer in the high-income group increases tariffs on imports from the non-high-income group by 25 percentage points.
- Symmetrically, every importer in the non-high-income group increases tariffs on imports from the high-income group by 25 percentage points.
- Tariffs between countries within the same group remain at their baseline level τ_{j0}^{nm}.

Importantly, this does not imply that intra-group tariffs are zero, only that they do not change relative to the initial tariff structure.

Results at the country level allow understanding the implications of this scenario for key variables, including disposable income, real GDP, exports, and imports.

Figure 1 presents the five top and bottom performers after the shock, ranked by changes in disposable income. As shown in Table 1, all countries experience negative effects on disposable income. The top five performers, displayed in the left panel, are those with the smallest negative changes (i.e., least affected), while the right panel shows the bottom five performers, with the largest negative changes, along with the corresponding variations in the other key variables.

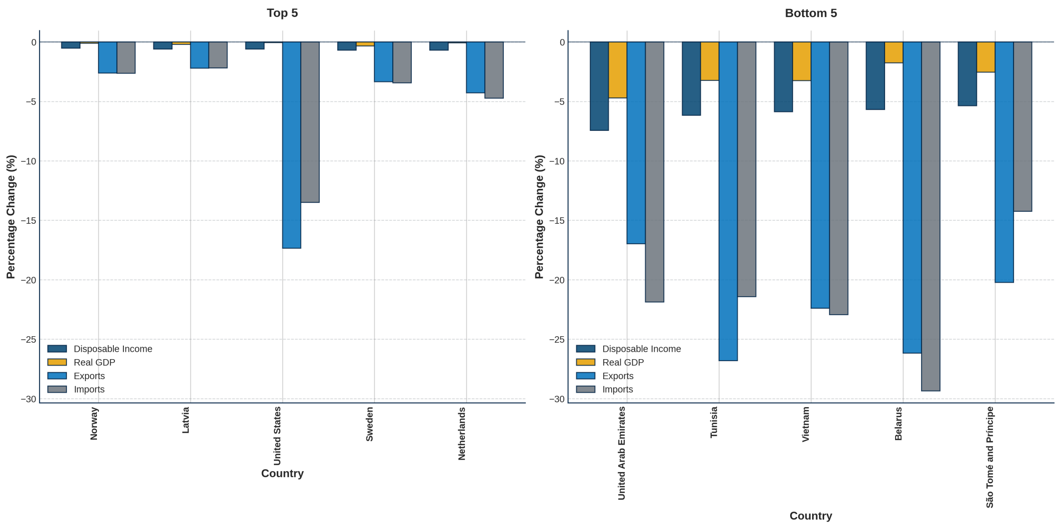

Figure 1: Top and Bottom Performers Analysis

Tables 1 and 2 present the estimated effects of the bilateral tariff shock on key economic outcomes for high-income and non-high-income countries, respectively.

For high-income countries (Table 1), the average decline in disposable income is 1.52%, with values ranging from -7.43% in the United Arab Emirates to -0.52% in Norway. Real GDP falls on average by 0.62%, with outcomes ranging from -4.71% to a small positive change of 0.17%. Exports and imports decrease on average by 7.52% and 8.10%, respectively. While most advanced economies experience relatively moderate contractions in trade flows, larger declines are observed in countries such as Chile, the Republic of Korea, and Singapore. Overall, dispersion remains relatively contained, with standard deviations of 1.32% for disposable income, 0.94% for GDP, 5.26% for exports, and 6.18% for imports.

In contrast, non-high-income countries (Table 2) experience larger average contractions. Disposable income declines by 2.59% on average, with values ranging from -6.16% in Tunisia to -0.78% in Argentina. Real GDP decreases by 1.30% on average, while exports and imports fall by 16.83% and 15.40%, respectively. The dispersion in trade outcomes is substantially larger than in high-income countries, with standard deviations of 6.50% for exports and

6.44% for imports and several economies experiencing very large contractions. For example, Mexico records an export decline of 33.08% and an import decline of 30.59%, while Morocco, Tunisia, and Belarus also exhibit particularly large reductions in trade flows.

Table 1: Results for High Income Countries

Country	**Income (%)**	**GDP (%)**	**Exports (%)**	**Imports (%)**
United Arab Emirates	-7.43	-4.71	-16.98	-21.88
Australia	-2.28	-1.42	-13.50	-17.29
Austria	-1.06	-0.10	-4.37	-4.40
Belgium	-0.78	-0.26	-2.95	-2.92
Bulgaria	-1.66	-0.33	-7.89	-8.01
Brunei Darussalam	-4.72	-2.58	-15.11	-22.79
Canada	-0.91	-0.14	-5.97	-5.98
Switzerland	-0.77	-0.31	-3.53	-4.00
Chile	-4.51	-2.31	-20.70	-19.03
Costa Rica	-1.81	-0.57	-10.74	-10.97
Cyprus	-1.23	-0.68	-2.43	-2.42
Czechia	-0.99	0.17	-4.74	-4.77
Germany	-1.01	-0.24	-6.33	-6.48
Denmark	-0.73	-0.40	-2.67	-2.88
Spain	-1.19	-0.08	-8.49	-8.64
Estonia	-0.80	0.08	-1.98	-1.98
Finland	-0.80	-0.30	-5.83	-5.57
France	-0.73	-0.29	-4.97	-4.66
United Kingdom	-0.83	-0.19	-5.98	-5.66
Greece	-1.55	0.11	-10.09	-8.65
Hong Kong SAR, China	-0.73	-0.12	-5.40	-5.89
Croatia	-1.32	-0.52	-5.51	-5.04
Hungary	-0.98	-0.07	-3.50	-3.44
Ireland	-1.57	-1.24	-2.79	-3.13
Iceland	-0.91	-0.17	-3.65	-3.65
Israel	-0.91	-0.42	-7.28	-7.87
Italy	-1.00	0.01	-8.45	-8.19
Japan	-1.00	-0.16	-17.64	-15.08
Korea, Rep.	-2.37	-0.98	-20.09	-19.85
Lithuania	-0.73	-0.10	-3.00	-2.97
Luxembourg	-0.76	-0.56	-1.29	-1.18
Latvia	-0.59	-0.21	-2.21	-2.19
Malta	-1.28	-0.75	-2.64	-2.72
Netherlands	-0.69	-0.07	-4.28	-4.72
Norway	-0.52	-0.12	-2.62	-2.63
New Zealand	-1.65	-0.76	-14.35	-11.93

Country	Income (%)	GDP (%)	Exports (%)	Imports (%)
Poland	-1.08	0.11	-5.35	-5.39
Portugal	-1.10	-0.04	-5.66	-5.46
Romania	-0.78	-0.11	-5.58	-5.13
Russian Federation	-1.55	-1.09	-12.84	-21.56
Saudi Arabia	-2.78	-2.29	-9.49	-16.95
Singapore	-3.98	-2.34	-8.86	-11.46
Slovak Republic	-1.13	0.04	-5.28	-5.14
Slovenia	-1.34	-0.13	-4.57	-4.60
Sweden	-0.68	-0.32	-3.34	-3.44
Taiwan, China	-3.40	-2.21	-15.14	-18.82
United States	-0.60	-0.05	-17.35	-13.49
Summary				
Mean	-1.52	-0.62	-7.52	-8.10
Median	-1.01	-0.26	-5.58	-5.46
Std Dev	1.32	0.94	5.26	6.18
Min	-7.43	-4.71	-20.70	-22.79
Max	-0.52	0.17	-1.29	-1.18

Notes: Table shows percent change in disposable income, total output, exports and imports after the trade shock. All results are presented in real terms after deflating by the price index.

Table 2: Results for Non-High Income Countries

Country	Income (%)	GDP (%)	Exports (%)	Imports (%)
Angola	-1.88	-1.66	-5.82	-18.58
Argentina	-0.78	-0.54	-11.71	-12.67
Bangladesh	-0.97	-0.70	-16.45	-10.21
Belarus	-5.67	-1.75	-26.17	-29.35
Brazil	-1.27	-0.76	-15.86	-16.33
China	-1.17	-0.59	-23.86	-28.61
Côte d'Ivoire	-1.63	-1.20	-14.11	-12.42
Cameroon	-1.59	-1.19	-11.99	-11.34
Congo, Dem. Rep.	-2.73	-1.33	-7.34	-7.12
Colombia	-1.47	-0.64	-18.52	-13.79
Egypt, Arab Rep.	-0.99	-0.24	-20.70	-14.84
Indonesia	-1.15	-0.66	-13.92	-16.26
India	-1.15	-0.40	-16.69	-14.43
Jordan	-2.51	0.03	-17.27	-12.25
Kazakhstan	-3.58	-2.12	-13.83	-20.35
Cambodia	-4.22	-3.37	-8.82	-6.53
Lao PDR	-1.71	-1.46	-3.57	-4.38
Morocco	-4.46	-1.31	-26.33	-21.59
Mexico	-4.42	-2.39	-33.08	-30.59

Country	Income (%)	GDP (%)	Exports (%)	Imports (%)
Myanmar	-0.96	-0.58	-7.49	-7.27
Malaysia	-3.09	-1.43	-17.84	-20.21
Nigeria	-1.42	-1.15	-12.61	-11.01
Pakistan	-0.78	-0.40	-16.97	-8.44
Peru	-1.90	-1.20	-14.40	-14.39
Philippines	-2.25	-0.66	-18.13	-12.25
Senegal	-2.34	-0.81	-14.15	-8.54
São Tomé and Príncipe	-5.37	-2.54	-20.22	-14.25
Thailand	-3.89	-1.88	-18.24	-17.41
Tunisia	-6.16	-3.22	-26.81	-21.43
Türkiye	-3.23	-1.17	-23.78	-21.21
Ukraine	-3.26	-1.25	-22.62	-15.37
Vietnam	-5.88	-3.24	-22.39	-22.94
South Africa	-1.81	-0.91	-13.52	-14.22
Rest of the World	-2.28	-1.46	-17.05	-13.13
Summary				
Mean	-2.59	-1.30	-16.83	-15.40
Median	-2.07	-1.20	-16.83	-14.32
Std Dev	1.59	0.86	6.50	6.44
Min	-6.16	-3.37	-33.08	-30.59
Max	-0.78	0.03	-3.57	-4.38

Notes: Table shows percent change in disposable income, total output, exports and imports after the trade shock. All results are presented in real terms after deflating by the price index.

Taken together, these results suggest that the tariff shock is associated with larger average declines in income, output, and trade flows among non-high-income countries. In addition, the greater dispersion of outcomes within this group indicates higher heterogeneity in economic exposure and adjustment capacity relative to high-income economies.

Figure 2 relates the change in real GDP to the change in disposable income by income level. All countries lie below the 45-degree line, indicating that the shock affects disposable income more negatively and disproportionately compared to GDP. This is consistent with prior findings, as tariff revenues collected by governments are partially offset by government spending, subject to some deadweight loss. There are a few high-income countries that show negligibly small but positive GDP growth after the shock.

As shown in Tables 1 and 2, the largest negative variations are concentrated in non-high-income countries. Nonetheless, there are some high-income countries experiencing substantial negative changes. In fact, as shown in Figure 1, the bottom performer in terms of disposable income was a high-income country.

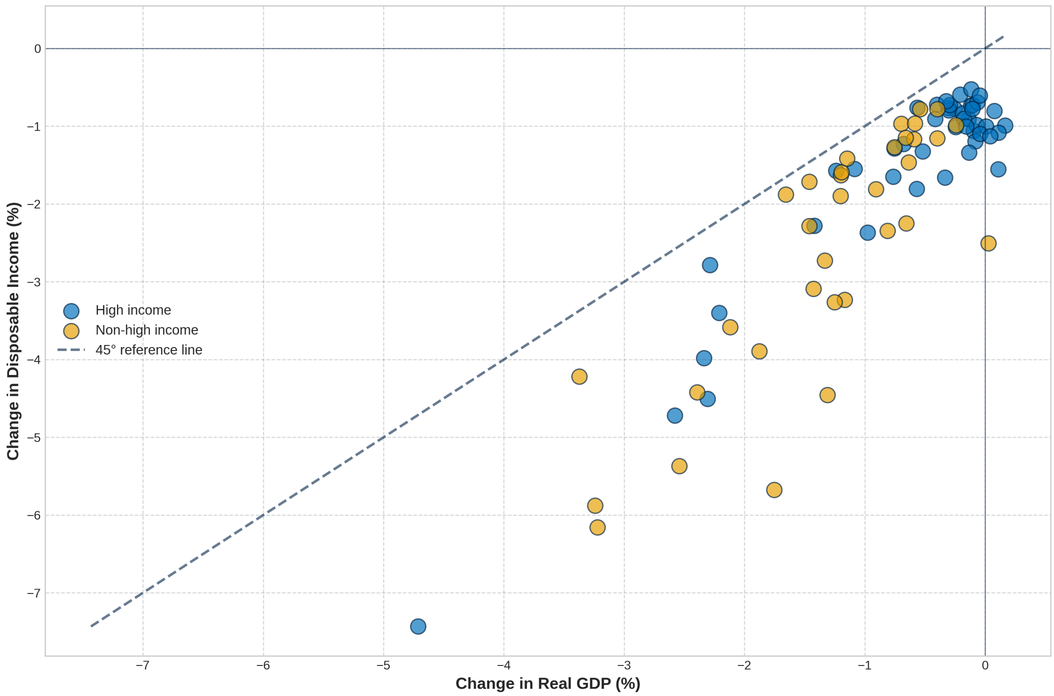

Figure 2: Real GDP vs. Disposable Income by Income Level

The mean effects of the bilateral tariff shock across different outcomes are reported in Panels A–D of Figure 5. Disposable income (Panel A) declines on average by 1.97%, ranging from -7.4% to -0.52%, with most values concentrated around -1%. Real GDP (Panel B) falls on average by 0.91%, ranging from -4.7% to 0.17%, with values clustering slightly below 0%. Exports (Panel C) decrease on average by 11.43%, ranging from -33.1% to -1.29%, with the most frequent effects between -5% and 0%, and noticeable clustering near -1% and -15%. Imports (Panel D) decline on average by 11.17%, ranging from -30.59% to -1.18%, following a pattern similar to that of exports, with the most frequent values concentrated between -5% and 0%.

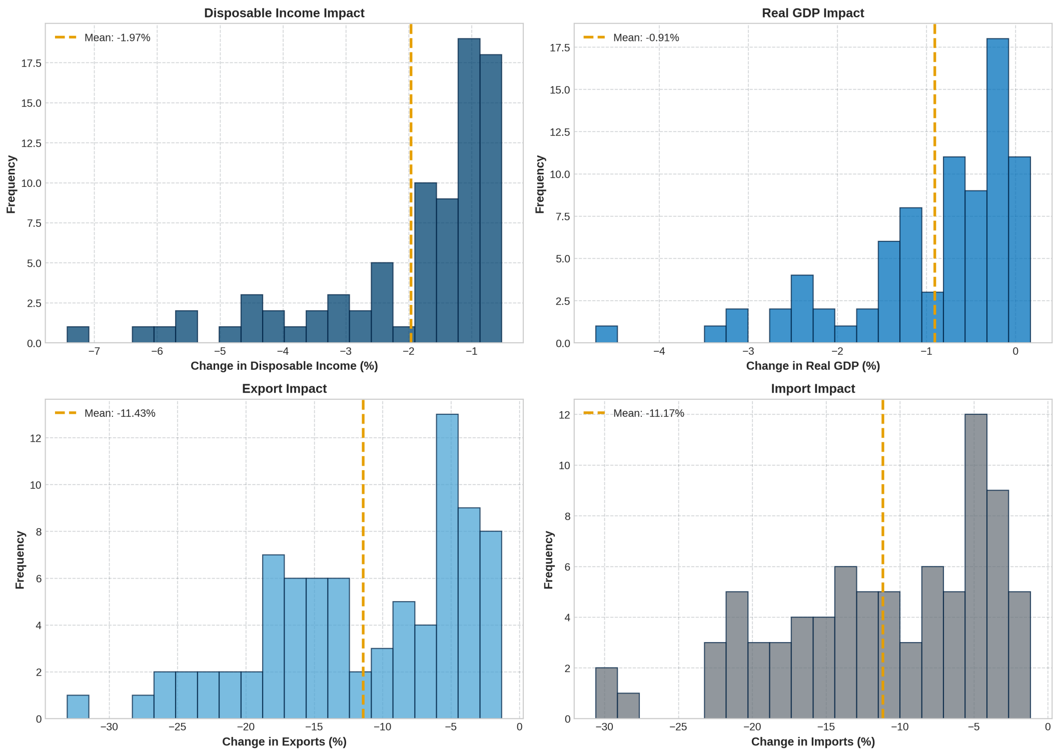

Figure 3: Distributions of Economic Impacts

Figures 4 and 5 present the distribution of the effects of the shock on disposable income and GDP, respectively, across regions. The regional composition is as follows: Europe & Central Asia (35 countries), East Asia & Pacific (17 countries), Middle East, North Africa, Afghanistan & Pakistan (9 countries), Sub-Saharan Africa (8 countries), Latin America & Caribbean (7 countries), South Asia (2 countries), and North America (2 countries).[6]

Figure 4 shows a common pattern across all regions: the distribution of the effect on disposable income lies entirely on the negative side of the axis. Dispersion is mechanically limited in North America and South Asia, as each region includes only two countries. In all regions where there is meaningful variation, the median lies above the mean. Consistent with the observed dispersion in several regions, this indicates that the mean is pulled downward by a number of particularly large negative realizations. The region with the most negative average effect on disposable income is Middle East, North Africa, Afghanistan & Pakistan, with a mean of approximately −3.0% and a median of −2.5%, and it also exhibits the largest

[6] We exclude Rest of the World from the violin graph on purpose, as it contains a single aggregate category and therefore exhibits no within-group variation.

variance.

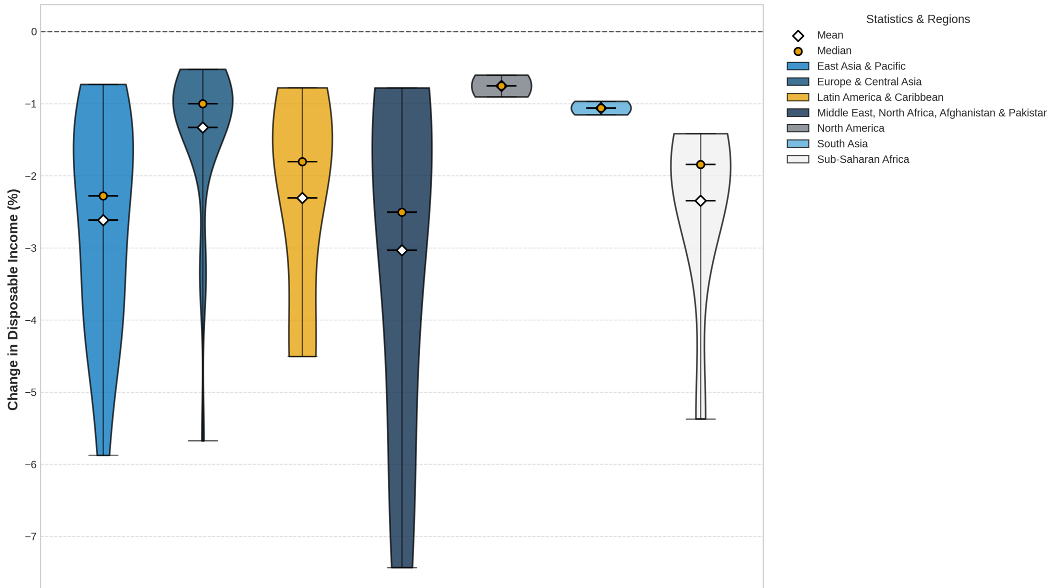

Figure 4: Distribution of Disposable Income Changes by Region

Figure 5 displays similar patterns for GDP. However, in contrast to disposable income, the distribution for Europe & Central Asia extends partially into positive territory, indicating that some countries experience gains in terms of economic growth, consistent with Figure 2. As before, in regions with variation the median generally lies above the mean. The gap between the two statistics narrows in East Asia & Pacific and Europe & Central Asia, while it remains wider in Latin America & Caribbean and Middle East, North Africa, Afghanistan & Pakistan. Sub-Saharan Africa shows relatively limited changes in dispersion patterns.

For GDP, the most negative mean effect is again observed in Middle East, North Africa, Afghanistan & Pakistan (approximately −1.5%). In terms of medians, East Asia & Pacific exhibits the most negative outcome (around −1.4%), compared to roughly −0.75% for Middle East, North Africa, Afghanistan & Pakistan.

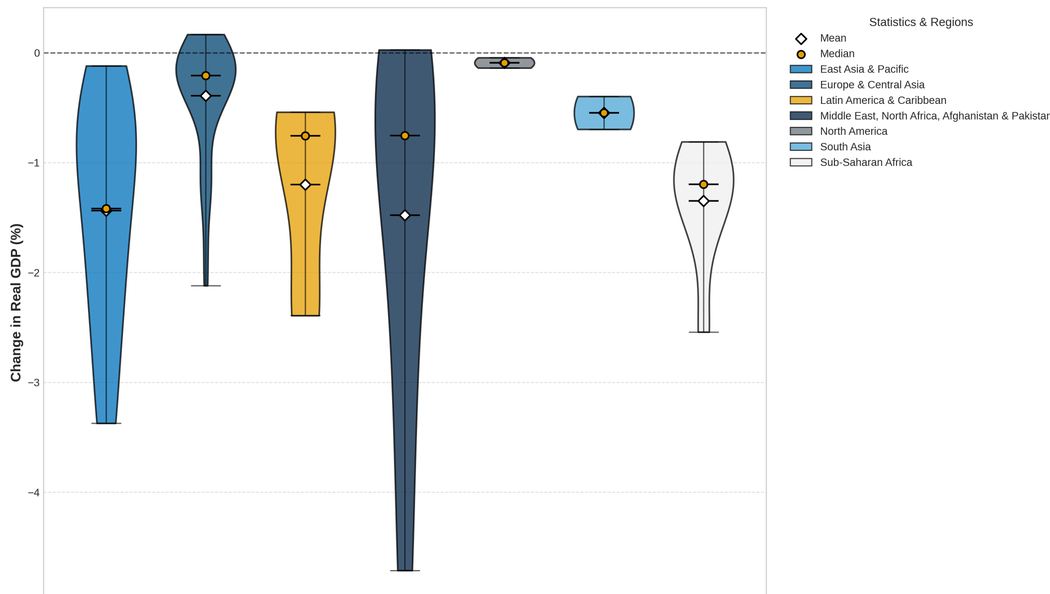

Figure 5: Distribution of GDP Changes by Region

6 Conclusion

This paper provides a holistic discussion of two example trade models with a flexible mathematical solution method, solution code in four different programming languages, processed data and a browser-based tool to experiment with different policy scenarios.

A counterfactual simulation of a bilateral 25 percentage point increase in tariffs between high-income countries and non-high-income countries shows large negative effects on consumer welfare. The results indicate a large heterogeneity with impacts on disposable income ranging between -0.5% and -7.4%. This simulation allowed us to examine how trade policy changes propagate through international trade networks, impacting key macroeconomic outcomes such as disposable income, real GDP, exports, and imports.

Outputs of this paper can facilitate both just-in-time trade policy analysis and development of specialized models and policy reports. Using the web-based tool, economists and policymakers can study the impact of the most recently announced tariff policy by developed country partners within minutes without the need for specialized training or expertise. Using our tools, more advanced users can also run the models locally with new data, or with modified mechanisms.

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Appendix

Erhan Artuc & Johan Ortega

A1 User Guide - Trade Policy Simulator: Tariffs

Website

Trade Policy Simulator: Tariffs

https://www.worldbank.org/en/data/interactive/2025/12/15/trade-simulator-tariffs

Overview

This dashboard provides an accessible, customizable, and transparent interface for conducting quantitative simulations of tariff shocks. Unlike many public and commercial platforms, this tool does not require the installation of additional software; it is fully web-based and freely available to researchers, policymakers, practitioners, and educators. Conceived as a public good, it lowers the barriers to performing model-based trade policy analysis while ensuring broad usability.

A tariff shock is modeled as a change in **percentage points (pp)** applied to baseline tariff rates. For example, a 50 pp increase means the final tariff equals the initial tariff plus 50 pp, and a 100 pp increase means adding 100 pp to the baseline rate. Reductions work analogously, but tariffs are subject to a non-negativity constraint. For instance, if the baseline tariff is 15 pp and a reduction of 20 pp is applied, the final tariff is set to zero.

Unlike the Iceberg Trade Cost Dashboard, this tool **does not apply tariffs to services sectors**, reflecting the typical treatment of services in trade agreements and policy analysis.

Key Features

While most data visualization platforms rely on a limited set of predefined scenarios, this tool run solves the model live on the server. Following features are available for users:

- Specify up to two simultaneous tariff shocks.
- Select the specific countries or country groups that impose and/or face these tariff changes.
- Determine the aggregation level used for country selection (country, region, or income level).

Using the Dashboard

The main control panel is divided into two parts.

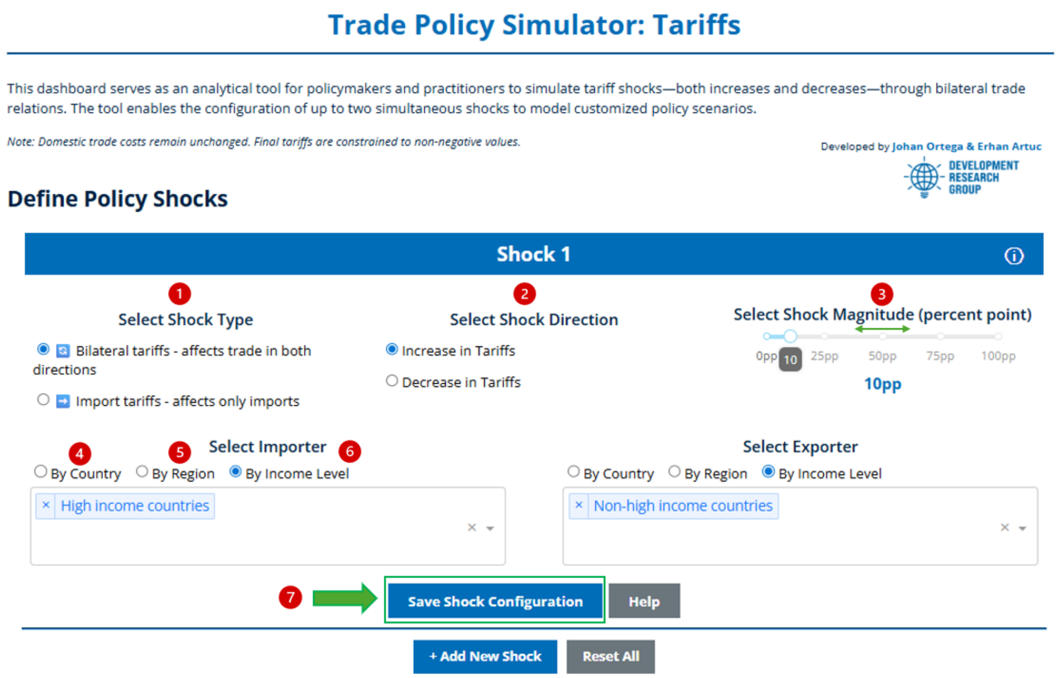

Figure A1: Panel 1

Part 1: Defining the Shock

1 Shock Type:

- **Bilateral Tariffs:** Simulates a reciprocal change in tariffs between two selected countries/groups (e.g., a tariff increase of Z pp between Country X and Country Y).
- **Import-side Tariffs:** Simulates a unilateral tariff shock imposed by a selected importer country/group on a selected exporter country/group.

Note: When the same entities are selected as both importers and exporters in a bilateral shock, the results are equivalent regardless of the selection here. Domestic (within-country) tariffs are not modeled.

2 Shock Direction:

- **Increase in Tariffs:** Simulates an increase in tariff barriers, raising trade costs.
- **Decrease in Tariffs:** Simulates a reduction in tariff barriers, lowering trade costs and facilitating trade.

3 **Shock Magnitude:**

- Use the slider to select a custom shock magnitude in percentage points (pp), ranging from 0 pp to 100 pp.

Important: Reductions are subject to a non-negativity constraint. If a reduction would result in a negative tariff, the final tariff is set to zero.

Part 2: Selecting Countries

The second part allows users to define the actors involved in the shock. Selections can be made using one of the following filters, and each filter allows multiple selections.

4 **By Country:** Select one, several, or "All countries".[7]

5 **By Region:** Select from the following regions or "All regions":

- East Asia & Pacific
- Europe & Central Asia
- Latin America & Caribbean
- Middle East, North Africa, Afghanistan & Pakistan
- North America
- South Asia
- Sub-Saharan Africa
- Rest of the World

6 **By Income Level:** Select "High income countries", "Non-High income countries", or "All income levels".[8]

7 **Save Shock Configuration:** Once the user customizes the shock and selects importers and exporters, the shock configuration **should** be saved.

[7] Note: Individual EU member states cannot be selected separately; the European Union must be selected as a single entity.

[8] Countries classified as "Rest of the World" are included in the "Non-High income" group. Regional and income classifications follow the World Bank categories. For details, see: https://datahelpdesk.worldbank.org/knowledgebase/articles/378834-how-does-the-world-bank-classify-countries

Adding a second shock (if needed)

The "+ Add New Shock" button allows users to include a second, simultaneous trade cost shock. Once clicked, a new panel—identical to the main one—becomes available to set up the second shock.

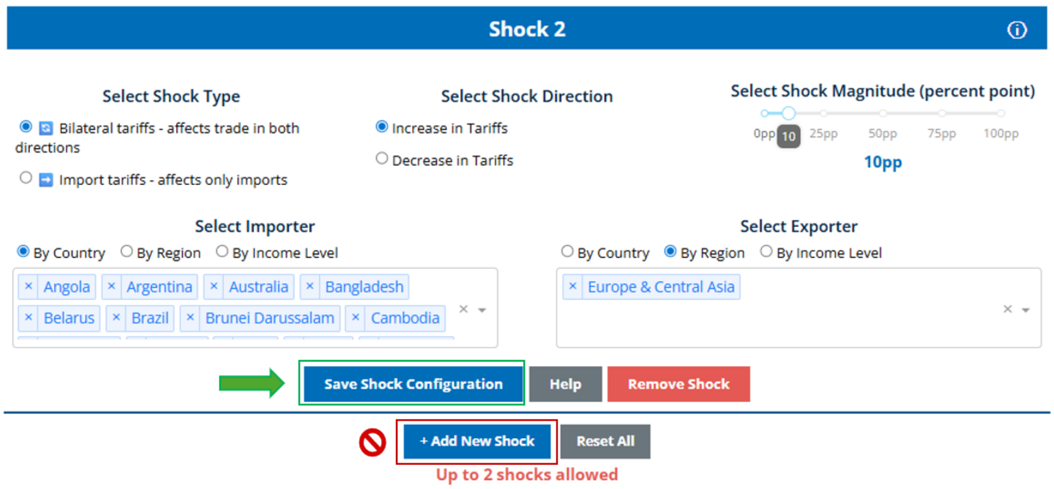

Figure A2: Panel 2

Figure A8 shows an example of a possible configuration for the second shock. Once the user defines the shock, the shock configuration should be saved.

Note: Once two shocks have been added, the "+ Add New Shock" button will no longer add a new shock panel and will display the red message: "Up to 2 shocks allowed."

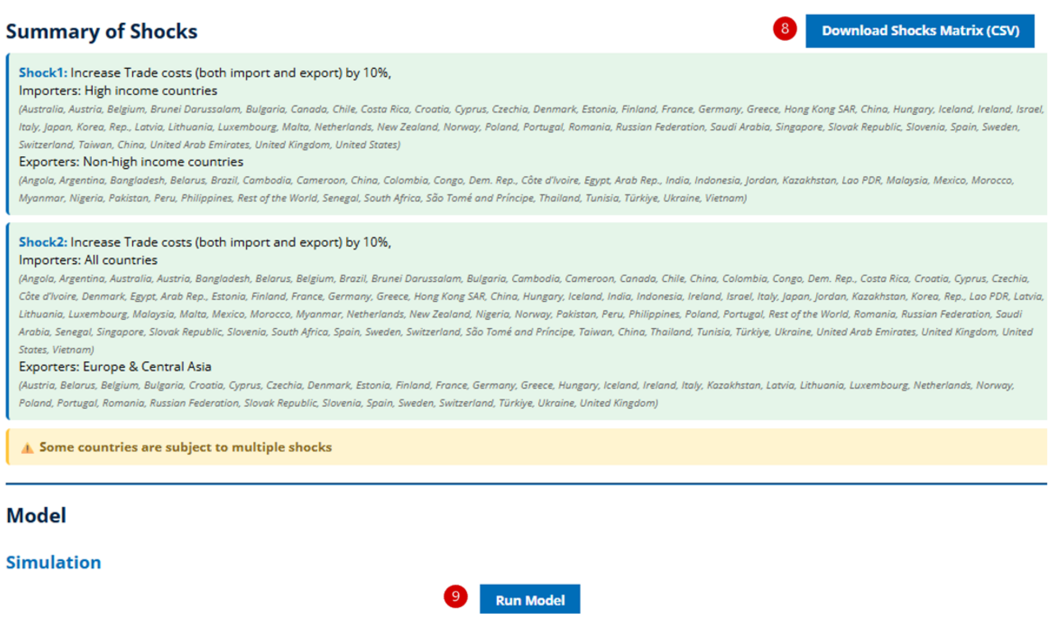

Figure A3: Panel 3

As Figure A9 shows, the dashboard includes a summary panel that displays the applied and saved shocks, as well as the countries involved.

Formally, tariff rates are stored in a three-dimensional array τ_j^{nm}, where n indexes the importing country, m indexes the exporting country, and j indexes sectors. Tariff shocks apply only to goods sectors (services are excluded from the tariff module).

The baseline tariff rates correspond to τ_{j0}^{nm}. A tariff shock of $\Delta\tau$ (expressed in percentage points) modifies the applied tariff as:

$$\tau_{j1}^{nm} = \max\left(0,\ \tau_{j0}^{nm} + \Delta\tau\right).$$

For example, if country n increases tariffs on imports from country m by 10 percentage points in all goods sectors:

$$\tau_{j1}^{nm} = \tau_{j0}^{nm} + 0.1 \quad \forall j \in \text{goods sectors}.$$

If the baseline tariff is 5 percentage points and a reduction of 10 percentage points is applied:

$$\tau_{j1}^{nm} = \max(0,\ 0.05 - 0.1) = 0.$$

When multiple shocks apply to the same country pair and sector, they are aggregated additively before imposing the non-negativity constraint:

$$\tau_{j1}^{nm} = \max\left(0,\ \tau_{j0}^{nm} + \sum_{s=1}^{S} \Delta\tau^{(s)}\right).$$

For instance, a +10 percentage point shock followed by a -5 percentage point shock results in:

$$\tau_{j1}^{nm} = \tau_{j0}^{nm} + 0.1 - 0.05, = \tau_{j0}^{nm} + 0.05.$$

Two consecutive +10 percentage point shocks yield:

$$\tau_{j1}^{nm} = \tau_{j0}^{nm} + 0.1 + 0.1 = \tau_{j0}^{nm} + 0.2.$$

Connection to the model solution.

In the quantitative algorithm, tariffs enter through bilateral trade costs:

$$d_j^{nm} = \delta_j^{nm}\left(1 + \tau_j^{nm}\right).$$

Hence, the relevant object in hat-algebra form is:

$$\widehat{d_j^{nm}} = \frac{d_{j1}^{nm}}{d_{j0}^{nm}} = \frac{1+\tau_{j1}^{nm}}{1+\tau_{j0}^{nm}},$$

since iceberg costs δ_j^{nm} remain unchanged. Therefore, the tariff shocks selected in the dashboard directly determine the trade cost shock that enters the equilibrium system through $\widehat{d_j^{nm}}$.

8 **Download Tariffs Matrix:** This button allows downloading a CSV file identifying importer country, exporter country (along with the ISO code), the 21 goods sectors, baseline tariff (%), final tariff (%), and change in tariff (pp).[9]

9 **Run Model:** Once the user verifies that the shocks reflect the desired scenario, the next step is to run the model

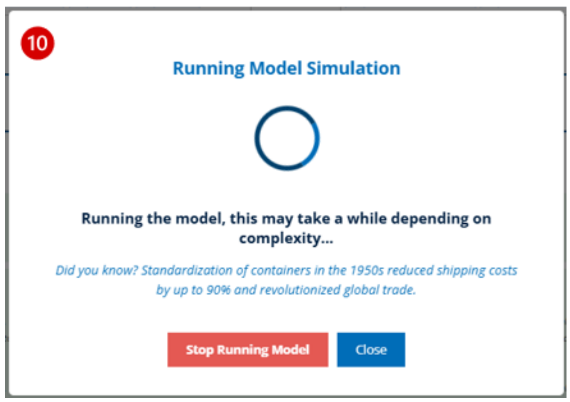

Figure A4: Running Model

10 **Model execution:** Once the user clicks on *Run Model*, a message is displayed while the model is running. During execution, the user can stop the simulation to make changes or simply close the pop-up message and continue using the interface while the model runs in the background.

Results

This panel summarizes the time elapsed during model execution and the number of iterations required for convergence. After completion, the tool generates a figure to analyze the top and bottom performers based on the included shock(s). The outcomes provided by the dashboard are

- Disposable income: The percent change real income excluding the tariff revenue of the government. If the disposable income doubles it will be presented as 100%. Real

[9]Note: Tariffs on services sectors are set to 0.

disposable income is calculated by dividing the nominal total value added minus tariff paid by consumers (or nominal total income of all agents minus the tariff paid) to the price index.

- GDP: The percent change real income including the tariff revenue of the government. Real GDP is calculated by dividing the nominal total value added (or nominal total income of all agents) to the price index.
- Exports: The percent change in real exports to all partners, calculated by dividing the nominal value of exports to the price index.
- Imports: The percent change in real imports from all partners, calculated by dividing the nominal value of imports to the price index.

Top performers are the countries with the largest positive changes (or, when applicable, the smallest negative changes) in the variable of interest, while bottom performers are those with the largest negative changes (or, when applicable, the smallest positive changes).

11 **Sort countries by:** This interactive plot allows users to sort countries by the percentage change in Real Income, Exports, or Imports.

12 **Number of countries:** The interface allows users to select how many countries to display (top/bottom 3, 5, or 10), enhancing comparative analysis.

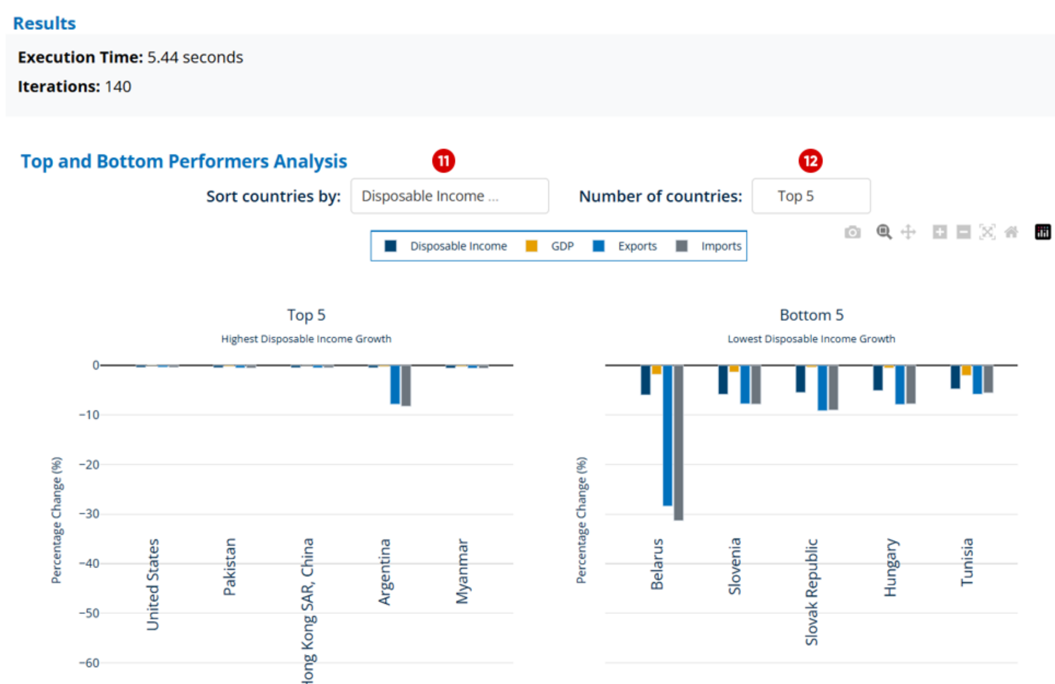

Figure A5: Panel 4

However, the user may not be interested only in this set of countries, but instead in specific countries or in all countries. Figure A12 shows how users can access the data through an interactive table.

13 **Download Results as CSV:** Users can access country-level results for Real Income, Exports, and Imports (percentage changes after the shocks), along with ISO codes, using this button, enabling further analysis, plot replication, and the construction of additional figures and tables.

Detailed Results - All Countries

Download Results as CSV 13

Country	Disposable Income Change (%)	GDP Change (%)	Export Change (%)	Import Change (%)
filter data...				
United States	−0.40	0.09	−0.36	−0.40
Pakistan	−0.47	−0.21	−0.50	−0.52
Hong Kong SAR, China	−0.47	0.01	−0.49	−0.47
Argentina	−0.48	−0.27	−7.83	−8.26
Myanmar	−0.55	−0.26	−0.58	−0.58
Japan	−0.57	0.15	−0.69	−0.71
Bangladesh	−0.64	−0.40	−11.35	−7.31
Indonesia	−0.64	−0.26	−0.70	−0.70
China	−0.66	−0.18	−14.77	−17.31
Canada	−0.67	0.05	−5.09	−5.11

« ‹ 1 / 9 › »

Figure A6: Panel 5

Input Data

The dashboard relies on the latest global trade data from the OECD, with the OECD Trade in Value Added (TiVA) 2025 database as the primary source Organisation for Economic Co-operation and Development, 2025. This database is based on a multi-regional input–output (MRIO) framework that traces value added along global production networks and decomposes gross exports into domestic and foreign components.

The data set covers 81 economies (80 individual countries plus a Rest of the World aggregate) and 50 industries, with annual data available for 1995–2022. Our analysis focuses on 2022, the most recent available year. To match the model structure, we aggregated the original 50 industries into 21 sectors, grouping all service activities into a single category, “All services.”

The model is solved within a general equilibrium framework that accounts for bilateral trade flows, sectoral trade composition, and constant elasticity of substitution.

For 2022, we rely on the panel tariff database compiled by Constantinescu, 2025, based on UNCTAD TRAINS data accessed through WITS, which provides comprehensive and comparable tariff information across countries. We focus on applied tariffs at the HS 6-digit level, using MFN rates when applied tariffs are unavailable, and cap extreme tariff values at 100 percent. Tariff data are mapped from HS products to ISIC industries and subsequently to TiVA sectors using standard concordances. Finally, tariffs are aggregated to the industry level for TiVA countries using import-weighted averages based on BACI (CEPII) trade data, with non-TiVA economies grouped into a Rest of the World category.

A2 User Guide - Trade Policy Simulator: Trade Costs

Website

Trade Policy Simulator: Trade Costs

https://www.worldbank.org/en/data/interactive/2025/12/15/trade-simulator-trade-costs

Overview

This dashboard provides an accessible, customizable, and transparent interface for conducting quantitative simulations of trade cost shocks. Unlike many public and commercial platforms, this tool does not require the installation of additional software; it is fully web-based and freely available to researchers, policymakers, practitioners, and educators. Conceived as a public good, it lowers the barriers to performing model-based trade policy analysis while ensuring broad usability.

A trade cost shock is modeled as an *Iceberg Trade Cost*. In simple terms, this represents the change in proportion of value of traded goods that is implicitly lost due to an increase (or decrease) in trade costs. These costs are broad and can represent a wide range of possible trade barriers. Consequently, the tool allows the shock to be applied to **all sectors**, including services. This differs from our other tool, the Tariff Dashboard, which assumes services are not subject to tariffs.

Key Features

While most data visualization platforms rely on a limited set of predefined scenarios, this tool solves the model live on the server. Following features are available for users:

- Specify up to two simultaneous trade cost shocks.
- Select the specific countries or country groups that impose and/or face these cost changes.
- Determine the aggregation level used for country selection (country, region, or income level).

Using the Dashboard

The main control panel is divided into two parts.

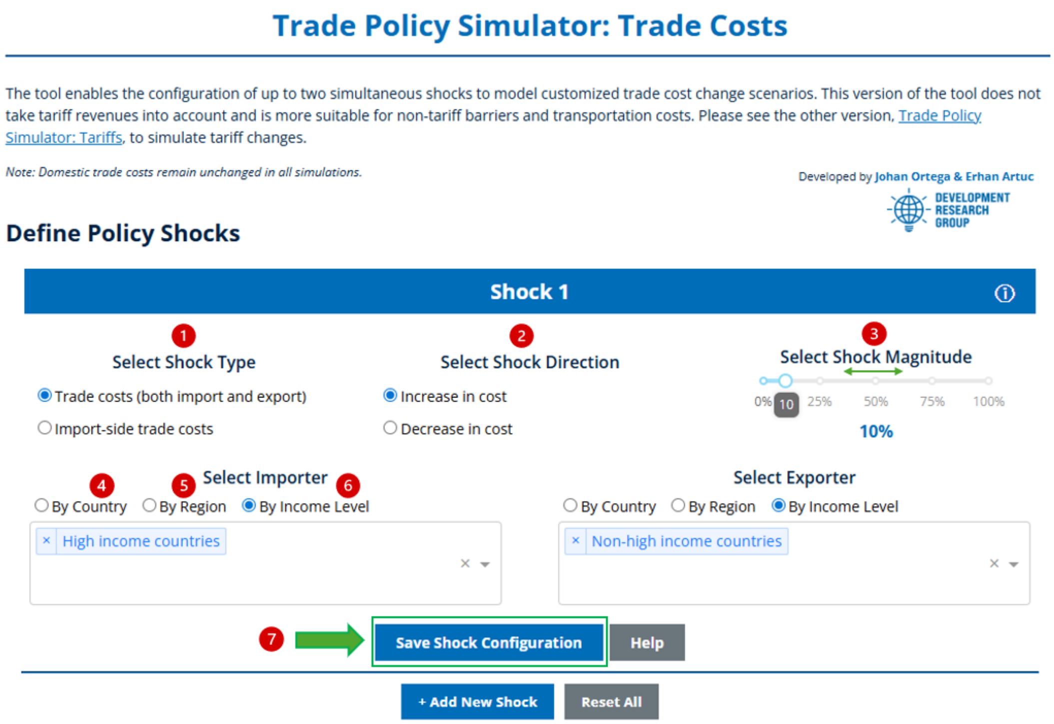

Figure A7: Panel 1

Part 1: Defining the Shock

1 Shock Type:

- **Bilateral Trade Costs:** Simulates a reciprocal change in trade costs between two selected countries/groups (e.g., a cost increase of Z% between Country X and Country Y).
- **Import-side Trade Costs:** Simulates a unilateral shock imposed by a selected importer country/group on a selected exporter country/group.

Note: When the same entities are selected as both importers and exporters in a bilateral shock, the results are equivalent regardless of the selection here. Domestic (within-country) trade costs are not modeled.

2 Shock Direction:

- **Increase in Cost:** Simulates an increase in trade barriers, raising trade costs.
- **Decrease in Cost:** Simulates a reduction in trade barriers, lowering trade costs and facilitating trade.

3 Shock Magnitude:

- Use the slider to select a custom shock magnitude, ranging from 0% to 100%.

Part 2: Selecting Countries

The second part allows users to define the actors involved in the shock. Selections can be made using one of the following filters, and each filter allows multiple selections.

4 **By Country:** Select one, several, or "All countries".[10]

5 **By Region:** Select from the following regions or "All regions":

- East Asia & Pacific
- Europe & Central Asia
- Latin America & Caribbean
- Middle East, North Africa, Afghanistan & Pakistan
- North America
- South Asia
- Sub-Saharan Africa
- Rest of the World

6 **By Income Level:** Select "High income countries", "Non-High income countries", or "All income levels".[11]

7 **Save Shock Configuration:** Once the user customizes the shock and selects importers and exporters, the shock configuration **should** be saved.

Adding a second shock (if needed)

The "+ Add New Shock" button allows users to include a second, simultaneous trade cost shock. Once clicked, a new panel—identical to the main one—becomes available to set up the second shock.

[10] Note: Individual EU member states cannot be selected separately; the European Union must be selected as a single entity.

[11] Countries classified as "Rest of the World" are included in the "Non-High income" group. Regional and income classifications follow the World Bank categories. For details, see: https://datahelpdesk.worldbank.org/knowledgebase/articles/378834-how-does-the-world-bank-classify-countries

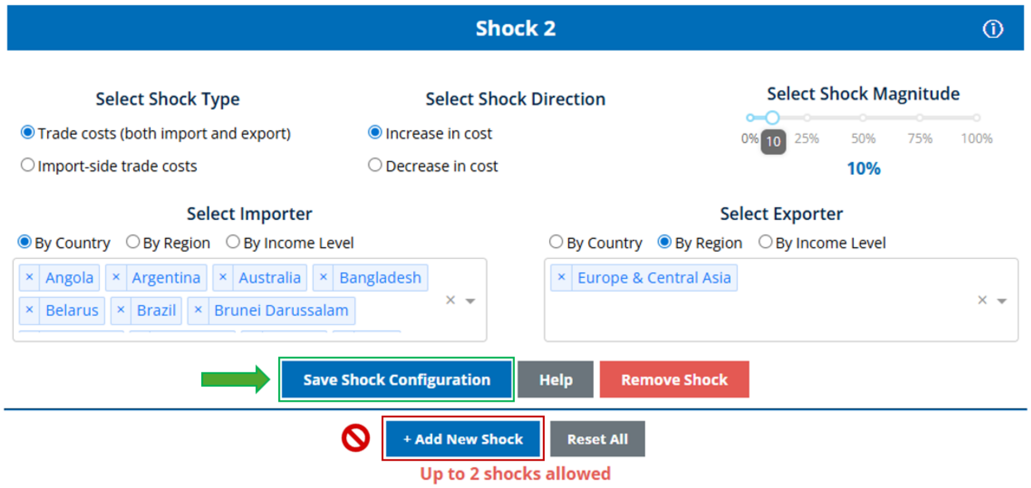

Figure A8: Panel 2

Figure A8 shows an example of a possible configuration for the second shock. Once the user defines the shock, the shock configuration should be saved.

Note: Once two shocks have been added, the "+ Add New Shock" button will no longer add a new shock panel and will display the red message: "Up to 2 shocks allowed."

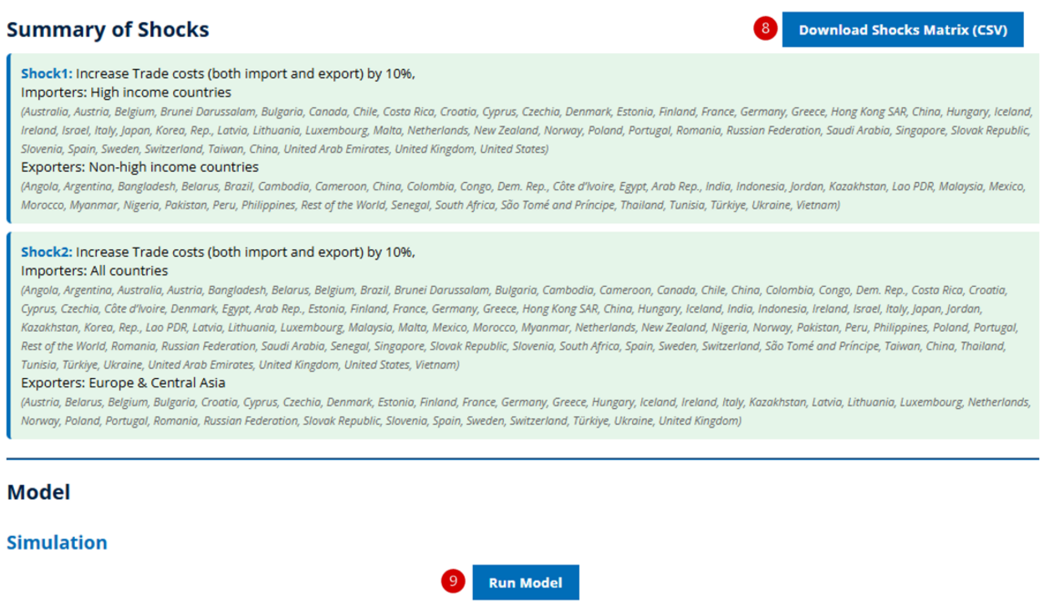

Figure A9: Panel 3

As Figure A9 shows, the dashboard includes a summary panel that displays the applied and saved shocks, as well as the countries involved.

Formally, iceberg trade costs are stored in a three-dimensional array δ_j^{nm}, where n indexes the importing country, m indexes the exporting country, and j indexes sectors.

An iceberg cost equal to 1 implies no additional international trade costs and applies to domestic trade ($n = m$). A 50% increase in trade costs corresponds to $\delta_j^{nm} = 1.5$, while a 100% increase corresponds to $\delta_j^{nm} = 2$. When $\delta_j^{nm} = 2$, the total trade cost equals the value of the shipped product.

Initially:

$$\delta_{j0}^{nm} \geq 1 \quad \forall n, m, j. \tag{28}$$

Shocks are applied by directly updating entries of δ_j^{nm}. For example, if country n increases import costs from country m by 10% in all sectors:

$$\delta_{j1}^{nm} = 1.1\delta_{j0}^{nm} \quad \forall j. \tag{29}$$

The user can apply multiple shocks sequentially. The second shock may involve the same country pair, a subset of countries, or entirely different ones. When multiple shocks apply to the same country pair and sector, they are aggregated multiplicatively:

$$\delta_{j1}^{nm} = \delta_{j0}^{nm} \prod_{s=1}^{S} \left(1 + \Delta^{(s)}\right),$$

where $\Delta^{(s)}$ denotes the proportional change applied in shock s.

For example, for a 10% first shock and a -10% second shock, we have $\Delta^{(1)} = 0.1$ and $\Delta^{(2)} = -0.1$. The shocks are multiplicatively aggregated, thus a +10% shock increases the iceberg cost from 1 to 1.1, and a subsequent -10% shock reduces it to

$$1.1 \times 0.9 = 0.99,$$

rather than returning it to 1. Similarly, two consecutive +10% shocks yield:

$$1.1 \times 1.1 = 1.21.$$

Connection to the model solution.

In the equilibrium system, iceberg trade costs enter directly through the hat-algebra object:

$$\widehat{\delta_j^{nm}} = \frac{\delta_{j1}^{nm}}{\delta_{j0}^{nm}} = \prod_{s=1}^{S} \left(1 + \Delta^{(s)}\right).$$

Therefore, the shocks selected in the dashboard map one-to-one into the trade cost shocks that enter the system of equilibrium equations via $\widehat{\delta_j^{nm}}$.

8 **Download Shocks Matrix:** This button allows to download a csv file identifying importer country, exporter country (along with the iso code), the 21 sectors, Final change in cost (%) and "deltahat". [12]

9 **Run Model:** Once the user verifies that the shocks reflect the desired scenario, the next step is to run the model

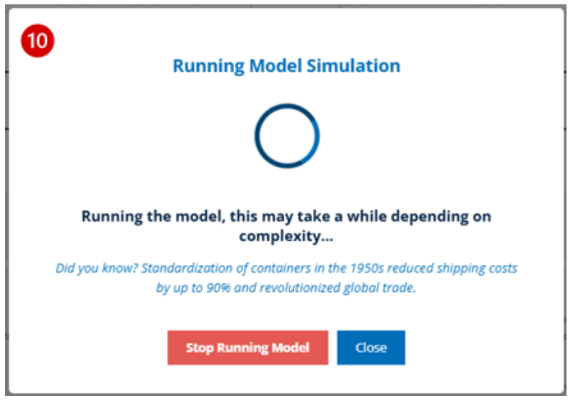

Figure A10: Running Model

10 **Model execution:** Once the user clicks on *Run Model*, a message is displayed while the model is running. During execution, the user can stop the simulation to make changes or simply close the pop-up message and continue using the interface while the model runs in the background.

Results

This panel summarizes the time elapsed during model execution and the number of iterations required for convergence. After completion, the tool generates a figure to analyze the top and bottom performers based on the included shock(s). The outcomes provided by the dashboard are

- Income: The percent change real income. If the income doubles it will be presented as 100%. Real income is calculated by dividing the nominal total value added (or nominal total income of all agents) to the price index.
- Exports: The percent change in real exports to all partners, calculated by dividing the nominal value of exports to the price index.
- Imports: The percent change in real imports from all partners, calculated by dividing the nominal value of imports to the price index.

Top performers are the countries with the largest positive changes (or, when applicable, the smallest negative changes) in the variable of interest, while bottom performers are those

[12] "deltahat" is the final multiplicative change in iceberg costs.

with the largest negative changes (or, when applicable, the smallest positive changes).

11 **Sort countries by:** This interactive plot allows users to sort countries by the percentage change in Real Income, Exports, or Imports.

12 **Number of countries:** The interface allows users to select how many countries to display (top/bottom 3, 5, or 10), enhancing comparative analysis.

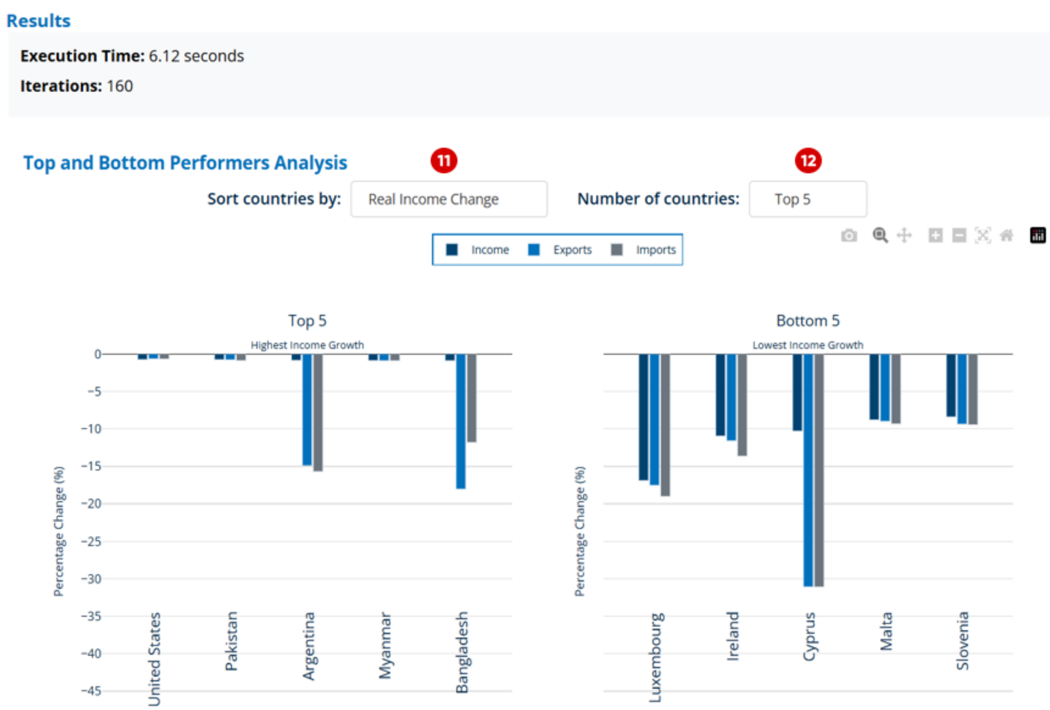

Figure A11: Panel 4

However, the user may not be interested only in this set of countries, but instead in specific countries or in all countries. Figure A12 shows how users can access the data through an interactive table.

13 **Download Results as CSV:** Users can access country-level results for Real Income, Exports, and Imports (percentage changes after the shocks), along with ISO codes, using this button, enabling further analysis, plot replication, and the construction of additional figures and tables.

Country	Real Income Change (%)	Export Change (%)	Import Change (%)
Angola	-2.95	-5.39	-25.90
United Arab Emirates	-9.67	-19.11	-24.53
Argentina	-1.30	-18.46	-20.60
Australia	-2.39	-13.94	-19.08
Austria	-8.94	-45.17	-46.10
Belgium	-10.49	-46.88	-45.73
Bangladesh	-1.48	-26.27	-16.63
Bulgaria	-12.08	-44.30	-44.63
Belarus	-13.23	-54.01	-58.66
Brazil	-1.95	-22.34	-23.68

Figure A12: Panel 5

Input Data

The dashboard relies on the latest global trade data from the OECD, with the OECD Trade in Value Added (TiVA) 2025 database as the primary source Organisation for Economic Co-operation and Development, 2025. This database is based on a multi-regional input–output (MRIO) framework that traces value added along global production networks and decomposes gross exports into domestic and foreign components.

The data set covers 81 economies (80 individual countries plus a Rest of the World aggregate) and 50 industries, with annual data available for 1995–2022. Our analysis focuses on 2022, the most recent available year. To match the model structure, we aggregated the original 50 industries into 21 sectors, grouping all service activities into a single category, "All services."

The model is solved within a general equilibrium framework that accounts for bilateral trade flows, sectoral trade composition, and constant elasticity of substitution.

A3 Notes on using Python, Julia, Matlab, and R for matrix operations

There are many obscure differences across programming languages when dealing with multidimensional arrays. Therefore, it is probably not a good idea to use AI for matrix manipulations, especially for the core equations of the model (including paid AI tools as of 2025[13]). In the extended model, only ten equations characterize the equilibrium conditions, which are also used to solve the model. In the basic model, there are five equations for the equilibrium. It is important to understand the economic intuition of these equations and they are not labor intensive to program. Using AI to code these equations or convert them to other languages, without fully understanding the idea behind these equations, will most likely result in error, and the code will eventually become a black box. Despite this, AI tools are very useful for mechanical and time consuming operations, like loading data, copying variables into dictionaries, and plotting results. AI tools definitely accelerate the speed of coding and can also help tremendously in learning new programming languages. Therefore, the warning applies only to the core code for equilibrium conditions that will be presented in the next section.

Here we list some differences across programming languages that can be relevant for solving quantitative models:

- For our use case and on our test systems, R is significantly slower than Julia and Python. Matlab is often faster than all three, but not significantly so compared to Julia and Python. As of 2025, only Matlab can use parallel processing automatically without explicitly declaring parallelization, this feature boosts its speed. The speed of the programming language also depends on the underlying Basic Linear Algebra Subprograms (BLAS), such as Math Kernel Library, OpenBLAS, Apple Accelerate, cuBLAS, etc. The performance of the language depends significantly on the underlying linear algebra library.
- The biggest speed gains are achieved by moving the array operations to GPU. The solution code can easily be moved to GPU after some minor changes and the general

[13] We wrote most of this code in late 2024 and early 2025. Since then, AI tools seem to be more aware of the particularities of matrix operations, and the dimensions of arrays, but they often generate extremely convoluted code even when the algebra is correct.

idea remains the same. Since the libraries are platform dependent, we do not include GPU-specific code in the replication package. See Hannun et al., 2023, Paszke et al., 2019 or Okuta et al., 2017 for more information about array operations on GPUs depending on your preferred platform. But, some of the speed gains are due to narrower data types used in GPUs. If you use 32-bit float arrays, instead of 64 bit double, the speed will increase a bit even on the CPU.

- We did not see any improvements in the speed of Julia, when we devectorized the code and used loops. Since Julia is a compiled language, it should be theoretically possible to increase its speed by using loops with a more Fortran-like code. Python seemed to be surprisingly fast, despite being a general purpose interpreted language, not specifically designed for mathematical or statistical programming.

- In Python, indexing starts from 0, and it starts from 1 in Matlab, Julia and R. Muscle memory with a certain programming language can cause typos in others.

- By default, Julia and Matlab keep matrix shape after operations like summation. Python and R drop the dimension after summation over that dimension. In Python, you can choose to keep all dimensions by passing it as an option.

- In Python and Julia, B=A[:,1,:] returns an NxM matrix and stores it in B, but in Matlab it will be an Nx1xM matrix. Matlab does not drop singleton dimensions. To achieve the same output in all three without ambiguity, we can use B=[:,1:1,:]. These subtle differences between languages can create bugs that are extremely difficult to catch.

- In Python, Julia and Matlab, we specify the dimensions to sum over them. In R, the logic is completely the opposite, and we need to specify the dimensions to keep using the "apply sum" function.

- Julia is a compiled language, but compilation takes place in the first run, which can create confusion for first time users. Julia's scoping system is logical but very complex. We need to define variables in advance, if we need to access them outside a loop. Its behavior with scripts and functions is different. These oddities make Julia more difficult to use for new starters, but it a very powerful and rewarding language, with a lot of sophisticated features like meta programming.

- There is no vector data type in Matlab, (almost) everything is an array. This simplicity makes Matlab convenient to use for computational purposes, as the programmer does not need to pay attention to complex data types, and thus can focus on the algebra.
- There is no broadcasting in R. This omission makes R very difficult to use for computational programming. Broadcasting is element-wise multiplication of a singleton dimension in one array with a non-singleton dimension in the other array. Two non-singleton dimensions can never be element-wise multiplied, unless they are the same size.
- In Python/Numpy, if you broadcast a size N vector over a 3 dimensional array (with 3 singleton dimensions), the result has the shape 1x1xN. In Julia, if you broadcast a size N vector over a 3 dimensional array (with 3 singleton dimensions), the result has the shape Nx1x1.
- In Julia element-wise multiplication always starts from the first dimension of both arrays. So first dimensions are aligned. But Python/NumPy starts from the last and goes towards first. Last dimensions are always aligned.
- For element-wise operations or to broadcast, we can use "." notation like ".*" or "./" in Julia and Matlab. In Python, arrays are automatically operated element-wise and broadcast, there is no "." notation
- In Matlab, you need to define operations with element-wise format inside a function. Broadcasting in Matlab is less flexible than Julia. Earlier versions of Matlab, prior to release 2016b, do not support broadcasting at all.
- In Python and Julia, we can use dictionaries to pass many variables to functions, but the functionality is limited. For example, when a vector of dictionaries is defined, it is not easy to add elements dynamically. We need to "push" new elements in Julia. In Python, you need to use "append" function. This is significantly different in Matlab, where flexible structures are used.
- In Python, we need to write "numpy." or an alias like "np." in front of Numpy functions, which are needed for matrix operations. We could use "from numpy import *" to call functions from current namespace, but it is not recommended as it might cause conflict. This makes Python code a bit more convoluted compared to Matlab and Julia.

A4 Code for solving the textbook model

Please refer to the replication package for the full solution code, here we only show the equilibrium conditions which constitute the core of the algorithm. Latest version of the code is available at GitHub https://github.com/eartuc/tradeguide. Corresponding equation numbers from the model, Section 2, are indicated in parentheses.

A4.1 Python code

```python
# Step 1: price including iceberg trade costs (Eq.1)
costhat_nm = wagehat[np.newaxis, :]
pnmhat = deltahat * costhat_nm

# Step 2: price index (Eq.2)
Phihat = np.sum(pibar * (pnmhat ** (-theta)), axis=1, keepdims=True) ** (-1/theta)

# Step 3: trade flows (Eq.3)
pihat = (pnmhat / Phihat) ** (-theta)

# Step 4: market clearing and demand (Eq.4)
incomehat = np.tile(wagehat[:,np.newaxis], (1, DC))
Xhat = incomehat * pihat

# Step 5: new wages (Eq.5)
wagehat_star = np.sum(Xbar * Xhat, axis=0) / np.sum(Xbar, axis=0)

# Step 6: scale - need to scale guessed nominal variable
scale = np.sum(Xhat * Xbar, axis=(0,1)) / np.sum(Xbar, axis=(0,1))
wagehat_star = wagehat_star / scale

# Step 7: error computation then update variables
err = np.sum(np.abs(wagehat_star - wagehat))
wagehat = rho1 * wagehat_star + (1 - rho1) * wagehat

# Step 8: check convergence
if iter_count % 20 == 0:
    err_big = err > err_tol
    print(f"Iteration {iter_count}, Errors: {err}")
```

A4.2 Julia code

```julia
# Step 1: price including iceberg trade costs (Eq.1)
costhat_nm = permutedims(wagehat, [2, 1])
pnmhat = deltahat .* costhat_nm

# Step 2: price index (Eq.2)
Phihat = sum(pibar .* (pnmhat .^ (-theta)), dims=2) .^ (-1/theta)
```

```
# Step 3: trade flows (Eq.3)
pihat = (pnmhat ./ Phihat) .^ (-theta)

# Step 4: market clearing and demand (Eq.4)
incomehat = repeat(wagehat, 1, DC)
Xhat = incomehat .* pihat

# Step 5: new wages (Eq.5)
wagehat_star = reshape(sum(Xbar.*Xhat,dims=1)./sum(Xbar,dims=1),(DC,1))

# Step 6: scale - need to scale guessed nominal variable
scale = sum(Xhat[:].*Xbar[:])/sum(Xbar[:])
wagehat_star = wagehat_star/scale

# Step 7: error computation then update variables
err = sum(abs.(wagehat_star - wagehat))
wagehat = rho1 * wagehat_star + (1 - rho1) * wagehat

# Step 8: check convergence
if iter_count % 20 == 0
    err_big = err > err_tol
    @printf("Iteration %d, Errors: %s\n", iter_count, err)
end
```

A4.3 Matlab code

```
% Step 1: price including iceberg trade costs (Eq.1)
costhat_nm = permute(wagehat,[2,1]);
pnmhat = deltahat.*costhat_nm;

% Step 2: price index (Eq.2)
Phihat = ( sum( pibar.*(pnmhat.^(-theta)) , 2 ) ).^(-(1/theta));

% Step 3: trade flows (Eq.3)
pihat = ( pnmhat./Phihat ).^(-theta);

% Step 4: market clearing and demand (Eq.4)
incomehat = repmat(wagehat,1,DC);
Xhat = incomehat.*pihat;

% Step 5: new wages (Eq.5)
wagehat_star = reshape(sum(Xbar.*Xhat,1)./sum(Xbar,1),[DC,1]);

% Step 6: scale - need to scale guessed nominal variable
scale = sum(Xhat(:).*Xbar(:))/sum(Xbar(:));
wagehat_star = wagehat_star./scale;
```

```
% Step 7: error computation then update variables
err= sum( abs(wagehat_star(:) - wagehat(:)) );
wagehat = rho1*wagehat_star + (1-rho1)*wagehat;

% Step 8: check convergence
if mod(iter,20)==0
    err_big=(err > err_tol );
    disp(err)
end
```

A4.4 R code

```
# Step 1: price including iceberg trade costs (Eq.1)
costhat_nm <- aperm( replicate(DC, wagehat), c(2, 1) )
pnmhat <- deltahat * costhat_nm

# Step 2: price index (Eq.2)
Phihat <- (apply( pibar * (pnmhat^(-theta)), 1, sum))^(-1/theta)
Phihat_nm <- replicate(DC, Phihat)

# Step 3: trade flows (Eq.3)
pihat <- (pnmhat / Phihat_nm)^(-theta)

# Step 4: market clearing and demand (Eq.4)
incomehat <- replicate(DC, wagehat)
Xhat <- incomehat * pihat

# Step 5: new wages (Eq.5)
wagehat_star <- apply(Xbar*Xhat, 2, sum)/apply(Xbar, 2, sum)

# Step 6: scale - need to scale guessed nominal variable
scale <- sum(Xhat*Xbar)/sum(Xbar)
wagehat_star <- wagehat_star / scale

# Step 7: error computation then update variables
err <- sum(abs(wagehat_star - wagehat))
wagehat <- rho1 * wagehat_star + (1 - rho1) * wagehat

# Step 8: check convergence
if (iter_count %% 20 == 0) {
  err_big <- (err > err_tol)
  print(err)
}
```

A5 Code for solving the generalized model

Please refer to the replication package for the full solution code. Latest version of the code is available at GitHub https://github.com/eartuc/tradeguide. Corresponding equation numbers from the model, Section 3, are indicated in parentheses.

A5.1 Python code

```
#Step 1: production cost (Eq.6) - in different shapes
costhat = (wagehat ** alphabarL_) * (costMhat ** alphabarM_)
costhat_ = costhat[np.newaxis, :, :]

#Step 2: price including tariffs (Eq.7)
pnmjhat = dhat * costhat_

#Step 3: price index (Eq.8) - in different shapes
Phihat = np.sum(pibar * (pnmjhat ** (-theta)), axis=1) ** (-1/theta)
Phihat_nmj = Phihat[:, np.newaxis, :]

#Step 4: new intermediate input costs (Eq.9)
costMhat_star = np.prod( Phihat_nmj**betaM , axis=2)

#Step 5: trade flows (Eq.10)
pihat = (pnmjhat / Phihat_nmj) ** (-theta)

#Step 6: labor income (Eq.11)
What = np.sum(Lbar * (wagehat ** nu), axis=1) ** (1/nu)

#Step 7: labor allocation (Eq.12)
Lhat = (wagehat / What[:,np.newaxis]) ** nu

#Step 8: sectoral output (Eq.13)
Ymj_hat = np.sum(Xibar * Xhat, axis=0)

#Step 9: new wages (Eq.14)
wagehat_star = Ymj_hat * (Lhat ** (-(nu - 1)/nu))

#Step 10: market clearing and demand (Eqs.15,16,17)
incomehat = What*(1.0-taurevshare)+(np.sum( Xhat*Xbar*taunew,axis=(1,2))/incomebar)
expenditurehat = (incomehat - savings) / (1 - savings)

pihat_ = pihat[:, :, np.newaxis,:] #alternative shape
expenditurehat_ = expenditurehat[:,np.newaxis,np.newaxis] #alternative shape

cont_C = DbarL * expenditurehat_ * pihat #demand by consumers
cont_Y = Ymj_hat[:, np.newaxis, :, np.newaxis] #alternative shape
cont_I = np.sum(Dbar * pihat_ * cont_Y, axis=2) #demand by producers

Xhat_star = (cont_C + cont_I )/dhat #change in demand corridor by corridor
```

```
#Step 11: scale - all guessed nominal variables
scale=np.sum(Xhat*Xbar, axis=(0,1,2))/np.sum(Xbar, axis=(0,1,2))
Xhat_star=Xhat_star/scale
costMhat_star=costMhat_star/scale
wagehat_star=wagehat_star/scale

# Step 12: error computation then update variables
err1 = np.sum(np.abs(Xhat_star - Xhat))
err2 = np.sum(np.abs(costMhat_star - costMhat))
err3 = np.sum(np.abs(wagehat_star - wagehat))
err = [err1, err2, err3]

Xhat = rho1 * Xhat_star + (1 - rho1) * Xhat
costMhat = rho2 * costMhat_star + (1 - rho2) * costMhat
wagehat = rho3 * wagehat_star + (1 - rho3) * wagehat

# Step 13: check convergence
if iter_count % 20 == 0:
    err_big = err1 > err_tol or err2 > err_tol or err3 > err_tol
    print(f"Iteration {iter_count}, Errors: {err}")
```

A5.2 Julia code

```
#Step 1: production cost (Eq.6) - in different shapes
costhat = (wagehat .^ alphabarL_) .* (costMhat .^ alphabarM_)
costhat_nmj = permutedims(repeat(costhat, 1, 1, DC), [3, 1, 2])

#Step 2: price including tariffs (Eq.7)
pnmjhat = dhat .* costhat_nmj

#Step 3: price index (Eq.8) - in different shapes
Phihat_nmj = sum(pibar .* (pnmjhat .^ (-theta)), dims=2) .^ (-1/theta)
Phihat = reshape(Phihat_nmj, (DC, DJ))

#Step 4: new intemediate input costs (Eq.9)
costMhat_star = dropdims(prod( Phihat_nmj.^ betaM, dims=3), dims=3)


#Step 5: trade flows (Eq.10)
pihat = (pnmjhat ./ Phihat_nmj) .^ (-theta)

#Step 6: labor income (Eq.11)
What = sum(Lbar .* (wagehat .^ nu), dims=2) .^ (1/nu)

#Step 7: labor allocation (Eq.12)
Lhat = (wagehat ./ What) .^ nu
```

```
#Step 8: sectoral output (Eq.13)
Ymj_hat = dropdims( sum(Xibar .* Xhat, dims=1), dims=1)

#Step 9: new wages (Eq.14)
wagehat_star = Ymj_hat .* (Lhat .^ (-(nu - 1)/nu))

#Step 10: market clearing and demand (Eqs.15,16,17)
incomehat=What.*(1.0.-taurevshare)+(sum(Xhat.*Xbar.*taunew,dims=(2,3))./incomebar)
expenditurehat = (incomehat - savings) ./ (1.0 .- savings)

pihat_ = permutedims(repeat(pihat, 1,1,1,DJ), (1,2,4,3)) #alternative shape

cont_C = DbarL .* expenditurehat .* pihat #demand by consumers
cont_Y = permutedims(reshape(Ymj_hat,(DC,DJ,1)), [1,3,2] ) #alternative shape
cont_I = dropdims(sum(Dbar.*pihat_.*cont_Y,dims=3),dims=3) #demand by producers

Xhat_star = (cont_C + cont_I)./dhat #demand corridor by corridor

#Step 11: scale - all guessed nominal variables
scale=sum(Xhat[:].*Xbar[:])/sum(Xbar[:])
Xhat_star=Xhat_star./scale
costMhat_star=costMhat_star./scale
wagehat_star=wagehat_star./scale

#Step 12: compute errors then update variables
err1 = sum(abs.(Xhat_star - Xhat) )
err2 = sum(abs.(costMhat_star - costMhat))
err3 = sum(abs.(wagehat_star - wagehat))
err = [err1, err2, err3]

Xhat = rho1 * Xhat_star + (1 - rho1) * Xhat
costMhat = rho2 * costMhat_star + (1 - rho2) * costMhat
wagehat = rho3 * wagehat_star + (1 - rho3) * wagehat

#Step 13: check convergence
if iter_count % 20 == 0
    err_big = err1 > err_tol || err2 > err_tol || err3 > err_tol
    @printf("Iteration %d, Errors: %s\n", iter_count, err)
end
```

A5.3 Matlab code

```
%Step 1: production cost (Eq.6) - in different shapes
costhat = ( wagehat.^(alphabarL_) ).*(costMhat.^(alphabarM_));
costhat_nmj = permute(costhat ,[3,1,2]);

%Step 2: price including tariffs (Eq.7)
pnmjhat= dhat.*costhat_nmj;

%Step 3: price index (Eq.8) - in different shapes
Phihat_nmj = ( sum( pibar.*(pnmjhat.^(-theta)) , 2 ) ).^(-(1/theta));
Phihat = permute(Phihat_nmj,[1,3,2]);

%Step 4: new intermediate input costs (Eq.9)
costMhat_star = prod( Phihat_nmj.^betaM,3);

%Step 5: trade flows (Eq.10)
pihat = ( pnmjhat./Phihat_nmj ).^(-theta);

%Step 6: labor income (Eq.11)
What = ( sum( Lbar.*(wagehat.^nu),2 ) ).^(1/nu);

%Step 7: labor allocation (Eq.12)
Lhat= (wagehat./What).^(nu);

%Step 8: sectoral output (Eq.13)
Ymj_hat=permute(sum(Xibar.*Xhat,1),[2,3,1]);

%Step 9: new wages (Eq.14)
wagehat_star=Ymj_hat.*( Lhat.^(-(nu-1)./nu));

%Step 10: market clearing and demand (Eqs.15,16,17)
incomehat = What.*(1-taurevshare)+(sum(Xhat.*Xbar.*taunew,[2,3])./incomebar);
expenditurehat = (incomehat - savings)./(1-savings);

pihat_ = permute(repmat(pihat,1,1,1,DJ),[1,2,4,3]); %alternative shape

cont_C = DbarL.*expenditurehat.*pihat; %demand by consumers
cont_Y = permute(Ymj_hat,[1,3,2]); %need alternative shape
cont_I = permute( sum( Dbar.*pihat_.*cont_Y , 3), [1, 2, 4, 3]); %by producers

Xhat_star = (cont_C + cont_I)./dhat; %demand corridor by corridor

%Step 11: scale - guessed variables in nominal terms
scale=sum(Xhat(:).*Xbar(:))/sum(Xbar(:));
Xhat_star=Xhat_star./scale;
costMhat_star=costMhat_star./scale;
wagehat_star=wagehat_star./scale;
```

```
%Step 12: calculate errors then update variables
err1= sum( abs(Xhat_star(:) - Xhat(:)));
err2= sum( abs(costMhat_star(:) - costMhat(:)) );
err3= sum( abs(wagehat_star(:) - wagehat(:)) );
err=[err1 err2 err3 ];

Xhat = rho1*Xhat_star + (1-rho1)*Xhat;
costMhat = rho2*costMhat_star + (1-rho2)*costMhat;
wagehat = rho3*wagehat_star + (1-rho3)*wagehat;

%Step 13: check convergence
if mod(iter,20)==0
    err_big=(err1 > err_tol || err2 > err_tol || err3 > err_tol );
    disp(err)
end
```

A5.4 R code

```
#Step 1: production cost (Eq.6) - in different shapes
costhat <- (wagehat^alphabarL_) * (costMhat^alphabarM_)
costhat_nmj <- aperm( replicate(DC, costhat), c(3, 1, 2) )

#Step 2: price including tariffs (Eq.7)
pnmjhat <- dhat * costhat_nmj

#Step 3: price index (Eq.8) - in different shapes
Phihat <- (apply( pibar * (pnmjhat^(-theta)), c(1,3), sum))^(-1/theta)
Phihat_nmj <- aperm( replicate(DC, Phihat), c(1, 3, 2))

#Step 4: new intermediate input costs (Eq.9)
costMhat_star <- apply((aperm(replicate(DJ, Phihat),c(1,3,2)))^betaM,c(1,2),prod)

#Step 5: trade flows (Eq.10)
pihat <- (pnmjhat / Phihat_nmj)^(-theta)

#Step 6: labor income (Eq.11)
What <- (rowSums(Lbar * (wagehat^nu)))^(1/nu)

#Step 7: labor allocation (Eq.12)
Lhat <- (wagehat / replicate(DJ, What))^(nu)

#step 8: sectoral output (Eq.13)
Ymj_hat <- apply(Xibar * Xhat, c(2, 3), sum)

#step 9: new wages (Eq.14)
wagehat_star <- Ymj_hat * (Lhat^(-(nu - 1)/nu))
```

```
#step 10: market clearing and demand (Eq.15,16,17)
incomehat <- What*(1.0-taurevshare)+(apply(Xhat*Xbar*taunew,1,sum)/incomebar)
expenditurehat <- (incomehat - savings) / (1 - savings)

pihat_ <- aperm(replicate(DJ,pihat),c(1, 2, 4, 3) ) #alt shape
expenditurehat_ <- replicate(DJ,replicate(DC,expenditurehat)) #alt shape

cont_C <- DbarL * expenditurehat_ * pihat #demand by consumers
cont_Y <- aperm(replicate(DC, Ymj_hat ),c(1, 3, 2)) #alternative shape
cont_Y <- replicate(DJ, cont_Y) #final needed shape
cont_I <- apply(Dbar * pihat_ * cont_Y, c(1, 2, 4), sum) #demand by producers

Xhat_star <- (cont_C + cont_I)/dhat #demand corridor by corridor

#Step 11: scale - all guessed nominal vars
scale <- sum(Xhat*Xbar)/sum(Xbar)
Xhat_star <- Xhat_star/scale
costMhat_star <- costMhat_star/scale
wagehat_star <- wagehat_star/scale

#step 12: computer errors then update variables
err1 <- sum(abs(Xhat_star - Xhat) )
err2 <- sum(abs(costMhat_star - costMhat))
err3 <- sum(abs(wagehat_star - wagehat))
err <- c(err1, err2, err3)

Xhat <- rho1 * Xhat_star + (1 - rho1) * Xhat
costMhat <- rho2 * costMhat_star + (1 - rho2) * costMhat
wagehat <- rho3 * wagehat_star + (1 - rho3) * wagehat

#step 13: check convergence
if (iter %% 20 == 0) {
  err_big <- (err1 > err_tol || err2 > err_tol || err3 > err_tol)
  print(err)
}
```

A6 Additional Tables

Table A1: List of Countries in the TiVA 2025 Database

	Code	Country		Code	Country
1	AGO	Angola	41	JOR	Jordan
2	ARE	United Arab Emirates	42	JPN	Japan
3	ARG	Argentina	43	KAZ	Kazakhstan
4	AUS	Australia	44	KHM	Cambodia
5	AUT	Austria	45	KOR	Korea, Rep.
6	BEL	Belgium	46	LAO	Lao PDR
7	BGD	Bangladesh	47	LTU	Lithuania
8	BGR	Bulgaria	48	LUX	Luxembourg
9	BLR	Belarus	49	LVA	Latvia
10	BRA	Brazil	50	MAR	Morocco
11	BRN	Brunei Darussalam	51	MEX	Mexico
12	CAN	Canada	52	MLT	Malta
13	CHE	Switzerland	53	MMR	Myanmar
14	CHL	Chile	54	MYS	Malaysia
15	CHN	China	55	NGA	Nigeria
16	CIV	Côte d'Ivoire	56	NLD	Netherlands
17	CMR	Cameroon	57	NOR	Norway
18	COD	Congo, Dem. Rep.	58	NZL	New Zealand
19	COL	Colombia	59	PAK	Pakistan
20	CRI	Costa Rica	60	PER	Peru
21	CYP	Cyprus	61	PHL	Philippines
22	CZE	Czechia	62	POL	Poland
23	DEU	Germany	63	PRT	Portugal
24	DNK	Denmark	64	ROU	Romania
25	EGY	Egypt, Arab Rep.	65	RUS	Russian Federation
26	ESP	Spain	66	SAU	Saudi Arabia
27	EST	Estonia	67	SEN	Senegal
28	FIN	Finland	68	SGP	Singapore
29	FRA	France	69	STP	São Tomé and Príncipe
30	GBR	United Kingdom	70	SVK	Slovak Republic
31	GRC	Greece	71	SVN	Slovenia
32	HKG	Hong Kong SAR, China	72	SWE	Sweden
33	HRV	Croatia	73	THA	Thailand
34	HUN	Hungary	74	TUN	Tunisia
35	IDN	Indonesia	75	TUR	Türkiye
36	IND	India	76	TWN	Taiwan, China
37	IRL	Ireland	77	UKR	Ukraine
38	ISL	Iceland	78	USA	United States
39	ISR	Israel	79	VNM	Viet Nam
40	ITA	Italy	80	ZAF	South Africa
			81	ROW	Rest of the World

Table A2: Industry Classification (TiVA 2025)

	Code	Industry
1	A01	Agriculture and hunting
2	A02	Forestry and logging
3	A03	Fishing and aquaculture
4	B05	Mining of coal and lignite
5	B06	Extraction of crude petroleum and natural gas
6	B07	Mining of metal ores
7	B08	Other mining and quarrying
8	B09	Mining support service activities
9	C10T12	Manufacture of food products; beverages and tobacco products
10	C13T15	Manufacture of textiles, wearing apparel, leather and related products
11	C16	Manufacture of wood and of products of wood and cork
12	C17_18	Manufacture of paper and paper products; Printing and reproduction of recorded media
13	C19	Manufacture of coke and refined petroleum products
14	C20	Manufacture of chemicals and chemical products
15	C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
16	C22	Manufacture of rubber and plastic products
17	C23	Manufacture of other non-metallic mineral products
18	C24A	Manufacture of basic iron and steel
19	C24B	Manufacture of basic precious and other non-ferrous metals
20	C25	Manufacture of fabricated metal products
21	C26	Manufacture of computer, electronic and optical products
22	C27	Manufacture of electrical equipment
23	C28	Manufacture of machinery and equipment n.e.c.
24	C29	Manufacture of motor vehicles, trailers and semi-trailers
25	C301	Building of ships and boats
26	C302T309	Manufacture of other transport equipment
27	C31T33	Manufacture of furniture; other manufacturing; repair and installation of machinery and equipment
28	D	Electricity, gas, steam and air conditioning supply

	Code	Industry
29	E	Water supply; sewerage, waste management and remediation activities
30	F	Construction
31	G	Wholesale and retail trade; repair of motor vehicles and motorcycles
32	H49	Land transport and transport via pipelines
33	H50	Water transport
34	H51	Air transport
35	H52	Warehousing and support activities for transportation
36	H53	Postal and courier activities
37	I	Accommodation and food service activities
38	J58T60	Publishing, Motion picture, video, television programme production and broadcasting activities
39	J61	Telecommunications
40	J62_63	Computer programming and information service activities
41	K	Financial and insurance activities
42	L	Real estate activities
43	M	Professional, scientific and technical activities
44	N	Administrative and support service activities
45	O	Public administration and defence; compulsory social security
46	P	Education
47	Q	Human health and social work activities
48	R	Arts, entertainment and recreation activities
49	S	Other service activities
50	T	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use

Table A3: Industry Concordance (TiVA 2025)

Code	Industry TIVA25	ISIC Rev 3	Sector	Industry
A01	Agriculture and hunting	A01	1	Agriculture, forestry, and fishing
A02	Forestry and logging	A02	1	Agriculture, forestry, and fishing
A03	Fishing and aquaculture	B	1	Agriculture, forestry, and fishing
B05	Mining of coal and lignite	C10	2	Coal, oil and gas extraction
B06	Extraction of crude petroleum and natural gas	C11, Exc C112	2	Coal, oil and gas extraction
B07	Mining of metal ores	C13	3	Metal ores and other mining activities
B08	Other mining and quarrying	C14, C12	3	Metal ores and other mining activities
C10T12	Manufacture of food products; beverages and tobacco products	D15–D16	4	Manufacture of food products; beverages and tobacco products
C13T15	Manufacture of textiles, wearing apparel, leather and related products	D17–D19	5	Manufacture of textiles, wearing apparel, leather and related products
C16	Manufacture of wood and of products of wood and cork	D20	6	Wood, paper and printing industries
C17_18	Manufacture of paper and paper products; Printing and reproduction of recorded media	D21–D22	6	Wood, paper and printing industries
C19	Manufacture of coke and refined petroleum products	D23	7	Manufacture of coke and refined petroleum products
C20	Manufacture of chemicals and chemical products	D24, Exc D2423	8	Manufacture of chemicals and chemical products
C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	D2423	9	Manufacture of basic pharmaceutical products and pharmaceutical preparations
C22	Manufacture of rubber and plastic products	D25	10	Manufacture of rubber and plastic products
C23	Manufacture of other non-metallic mineral products	D26	11	Manufacture of other non-metallic mineral products
C24A	Manufacture of basic iron and steel	D271, D2731	12	Manufacture of basic iron and steel

Code	Industry TIVA25	ISIC Rev 3	Sector	Industry
C24B	Manufacture of basic precious and other non-ferrous metals	D272, D2732	13	Manufacture of basic precious and other non-ferrous metals
C25	Manufacture of fabricated metal products	D28	14	Manufacture of fabricated metal products
C26	Manufacture of computer, electronic and optical products	D30, D32–D33	15	Manufacture of computer, electronic and optical products
C27	Manufacture of electrical equipment	D31	16	Manufacture of electrical equipment
C28	Manufacture of machinery and equipment n.e.c.	D29	17	Manufacture of machinery and equipment n.e.c.
C29	Manufacture of motor vehicles, trailers and semi-trailers	D34	18	Manufacture of motor vehicles, trailers and semi-trailers
C301	Building of ships and boats	D351	19	Shipbuilding and other transport equipment
C302T309	Manufacture of other transport equipment	D352, D353, D359	19	Shipbuilding and other transport equipment
C31T33	Manufacture of furniture; other manufacturing; repair and installation of machinery and equipment	36, 37	20	Manufacture of furniture; other manufacturing; repair and installation of machinery and equipment
B09	Mining support service activities	C112	21	All Services
D	Electricity, gas, steam and air conditioning supply	All Services	21	All Services
E	Water supply; sewerage, waste management and remediation activities	All Services	21	All Services
F	Construction	All Services	21	All Services
G	Wholesale and retail trade; repair of motor vehicles and motorcycles	All Services	21	All Services
H49	Land transport and transport via pipelines	All Services	21	All Services
H50	Water transport	All Services	21	All Services
H51	Air transport	All Services	21	All Services
H52	Warehousing and support activities for transportation	All Services	21	All Services

Code	Industry TIVA25	ISIC Rev 3	Sector	Industry
H53	Postal and courier activities	All Services	21	All Services
I	Accommodation and food service activities	All Services	21	All Services
J58T60	Publishing, Motion picture, video, television programme production and broadcasting activities	All Services	21	All Services
J61	Telecommunications	All Services	21	All Services
J62_63	Computer programming and information service activities	All Services	21	All Services
K	Financial and insurance activities	All Services	21	All Services
L	Real estate activities	All Services	21	All Services
M	Professional, scientific and technical activities	All Services	21	All Services
N	Administrative and support service activities	All Services	21	All Services
O	Public administration and defence; compulsory social security	All Services	21	All Services
P	Education	All Services	21	All Services
Q	Human health and social work activities	All Services	21	All Services
R	Arts, entertainment and recreation activities	All Services	21	All Services
S	Other service activities	All Services	21	All Services
T	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	All Services	21	All Services