Modeling the Upstream-Downstream Effects of Trade Policy Changes with Multiple Country Markets

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Abstract

This paper presents a partial equilibrium model of two closely related industries: an intermediate good in the upstream and a final good in the downstream. Unlike other partial equilibrium models that focus on one specific country, such as a model of the U.S. market, this model allows for more than one country market. The model can be used to analyze how a tariff on intermediate imports can affect final good domestic production. It can also be used to analyze how the removal of trade barriers on intermediates between two countries can affect both imports and exports in intermediate and final goods markets.

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1 Introduction

In recent years, there have been several significant trade disruptions that have impacted global supply chains. Semiconductor shortages, the COVID-19 pandemic, the war in Ukraine, and many others are impacting the supply of intermediate goods used in the production of final goods. To analyze the impact of supply chain disruptions and trade policy changes on related products, we present a partial equilibrium (PE) modeling framework that links together upstream and downstream products to analyze how changes in one affect the other. Departing from the standard PE model set-up that only models the market of one specific country, the approach in this paper has flexibility to model multiple countries that are linked by trade. This means that the model can analyze the effect of trade policy changes on both imports and exports between two countries.

Section 2 describes the model, first as a many-market model with i origin countries and j destination countries, and second as a two-country model. Then, we describe the data inputs required for the model and potential sources. In section 2.4, we describe how the cost parameters in the model can be calibrated to available data. Section 3 then provides illustrative simulations to show how the model works. First, the model is run with a 10 percent tariff applied to one country's imports of another country. Second, tariff liberalization is illustrated by reducing a 10 percent tariff on trade in intermediates between two countries. Finally, section 4 concludes.

2 Model Description

This partial equilibrium model is intended to be applied to analyze trade policy changes on two closely related industries: an intermediate good in the upstream and a final good in the downstream. Unlike other partial equilibrium models that focus on one specific country,

such as a model of the U.S. market, this model allows for more than one country market.[1] The model can be used to analyze how a tariff or supply chain disruption on intermediate imports can affect final good domestic production. It can also be used to analyze how the removal of trade barriers on intermediates between two countries can affect both imports and exports in intermediate and final goods markets.

2.1 Many-Market Model

The index i refers to the origin country and j the destination market.[2] The price p_{ui} is the producer price of the upstream good that is produced in country i. The tariff factor, $1+\tau_{uij}$, is the tariff imposed by country j on upstream imports from country i. Equation (1) is the upstream price index in country j, z_j, where b_{uij} is a calibrated demand asymmetry parameter and σ_u the upstream constant elasticity of substitution.

$$z_j = \left(\sum_i \; b_{uij} \; (p_{uij}(1+\tau_{uij}))^{1-\sigma_u} \right)^{\frac{1}{1 \; - \; \sigma_u}} \tag{1}$$

Equation (2) shows the downstream price index, P_j, where p_{di} is the price of the downstream good produced in country i and consumed in country j and $1+\tau_{dij}$ is the tariff factor.

$$P_j = \left(\sum_i \; b_{dij} \; (p_{di} \; (1+\tau_{dij}))^{1-\sigma_d} \right)^{\frac{1}{1 \; - \; \sigma_d}} \tag{2}$$

The price of the downstream domestically-produced good is a function of the upstream prices it uses as inputs. Equation (3) represents the price of the downstream domestic product in country i. The parameter c_i is a calibrated cost parameter and w_i is the price of

[1] The equations presented in this section are first written in general terms. We then set the number of country markets equal to two in the illustrative simulation described later in this paper.

[2] We describe the location of production as the origin country and the location of consumption as the destination market. The destination market could also be called destination country.

all other production inputs, treated as exogenous in the model.[3] The upstream good and all other production inputs are consumed by the downstream in fixed proportions.

$$p_{di} = (w_i \ + \ c_i \ z_i) \tag{3}$$

Then the demand for the upstream good produced in country i by all destinations j, q_{ui}, is represented by Equation (4). This equation is a modified version of a constant elasticity of substitution (CES) demand equation that incorporates upstream and downstream prices. Demand for the downstream good produced in country i and consumed in j is represented by Equation (5).

$$q_{ui} \ = \sum_j \left(\frac{k_j \ c_j \ b_{uij}}{p_{ui} \ (1 + \tau_{uij})} \right) \left(\frac{p_{dj}}{P_j} \right)^{1-\sigma_d} \left(\frac{z_j}{p_{dj}} \right) \left(\frac{p_{ui} \ (1 + \tau_{uij})}{z_j} \right)^{1-\sigma_u} \tag{4}$$

$$q_{di} \ = \sum_j \ k_j \ b_{dij} \ P_j^{\sigma_d - 1} \ (p_{dj} \ (1 + \tau_{dij}))^{-\sigma_d} \tag{5}$$

Equation (6) describes the supply curve for upstream imports and domestic production destined for all sources, where a_{ui} is a supply parameter and ϵ_{ui} is the constant elasticity of supply for upstream goods from country i.[4] Equation (7) is the supply curve for downstream imports from countries outside of the model.

$$q_{ui} \ = \ a_{ui} \ p_{ui}^{\ \epsilon_{ui}} \tag{6}$$

$$q_{di} \ = \ a_{di} \ p_{di}^{\ \epsilon_{di}} \tag{7}$$

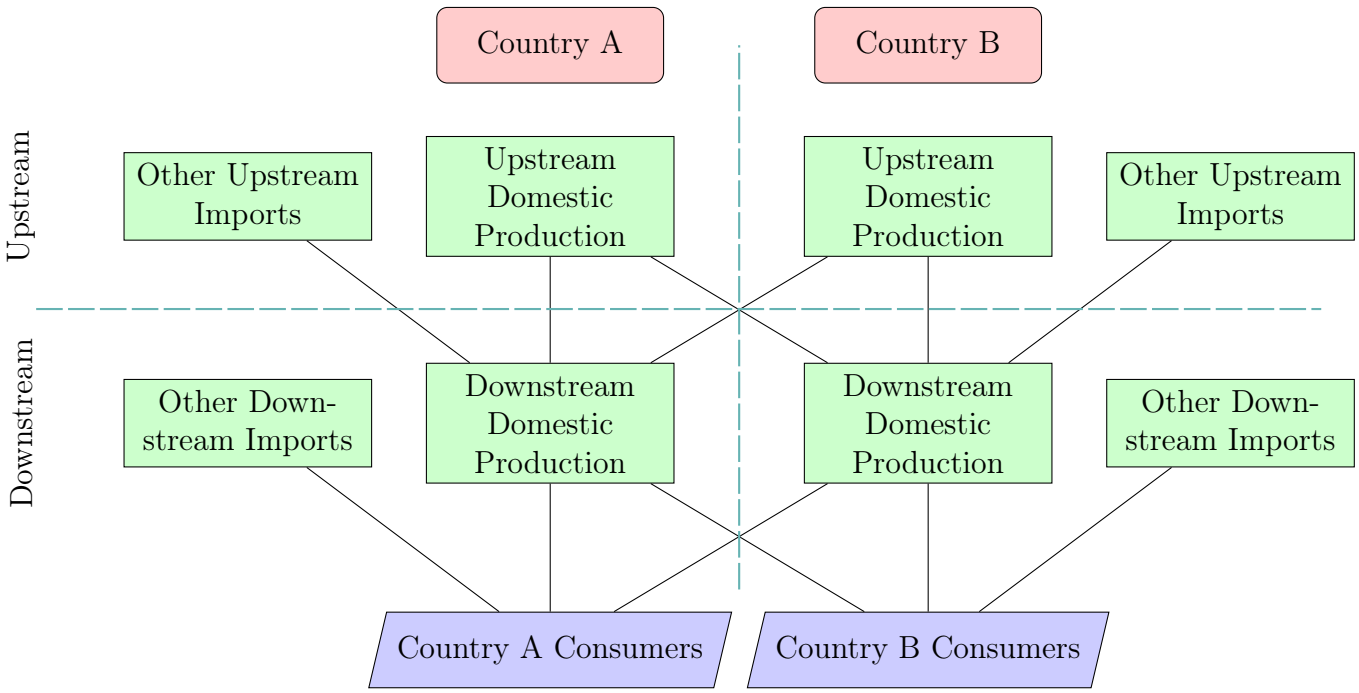
[3] This assumption is appropriate when the trade policy shock is small. If the policy change is expected to have large effects on the market, impacting the cost of labor and other production inputs, it might not be feasible to make this assumption.

[4] Note that $q_{ui} = \sum_j q_{uij}$.

2.2 Two-Market Model

In this section, we set j equal to two and present the model with two countries that are both destinations and origins. We run illustrative simulations with hypothetical countries A and B to show how the model works. Figure 1 illustrates the model design with two markets.

Figure 1: Multi-Country Supply Chain Model with 2 Markets



Equations (8) - (15) describe the price indices and equilibrium conditions for the two-market model.[5]

$$z_A = \left(p_{uA}^{1-\sigma_u} + b_{uBA}\ (p_{uB}(1+\tau_{uBA}))^{1-\sigma_u} + b_{uCA}\ (p_{uCA}(1+\tau_{uCA}))^{1-\sigma_u}\right)^{\frac{1}{1\ -\ \sigma_u}} \tag{8}$$

$$z_B = \left(p_{uB}^{1-\sigma_u} + b_{uAB}\ (p_{uA}(1+\tau_{uAB}))^{1-\sigma_u} + b_{uCB}\ (p_{uCB}(1+\tau_{uCB}))^{1-\sigma_u}\right)^{\frac{1}{1\ -\ \sigma_u}} \tag{9}$$

$$P_A = \left(p_{dA}^{1-\sigma_d} + b_{dBA}\ (p_{dB}(1+\tau_{dBA}))^{1-\sigma_d} + b_{dCA}\ (p_{dCA}(1+\tau_{dCA}))^{1-\sigma_d}\right)^{\frac{1}{1\ -\ \sigma_d}} \tag{10}$$

[5]The demand equations for imports from other countries are also omitted for brevity but follow equation (4) and (5).

$$P_B = \left(p_{dB}^{1-\sigma_d} + b_{dAB}\ (p_{dA}(1+\tau_{dAB}))^{1-\sigma_d} + b_{dCB}\ (p_{dCB}(1+\tau_{dCB}))^{1-\sigma_d}\right)^{\frac{1}{1\ -\ \sigma_d}} \tag{11}$$

$$p_{dA} = (w_A\ +\ c_A\ z_A) \tag{12}$$

$$p_{dB} = (w_B\ +\ c_B\ z_B) \tag{13}$$

$$\begin{aligned} a_{uA}\ p_{uA}{}^{\ \epsilon_{uA}} \ = & \left(\frac{k_A\ c_A\ b_{uAA}}{p_{uA}}\right)\left(\frac{p_{dA}}{P_A}\right)^{1-\sigma_d}\left(\frac{z_A}{p_{dA}}\right)\left(\frac{p_{uA}}{z_A}\right)^{1-\sigma_u} + \\ & \left(\frac{k_B\ c_B\ b_{uAB}}{p_{uA}\ (1+\tau_{uAB})}\right)\left(\frac{p_{dB}}{P_B}\right)^{1-\sigma_d}\left(\frac{z_B}{p_{dB}}\right)\left(\frac{p_{uA}\ (1+\tau_{uAB})}{z_B}\right)^{1-\sigma_u} \end{aligned} \tag{14}$$

$$\begin{aligned} a_{uB}\ p_{uB}{}^{\ \epsilon_{uB}} \ = & \left(\frac{k_B\ c_B\ b_{uBB}}{p_{uB}}\right)\left(\frac{p_{dB}}{P_B}\right)^{1-\sigma_d}\left(\frac{z_B}{p_{dB}}\right)\left(\frac{p_{uB}}{z_B}\right)^{1-\sigma_u} + \\ & \left(\frac{k_A\ c_A\ b_{uBA}}{p_{uB}\ (1+\tau_{uBA})}\right)\left(\frac{p_{dA}}{P_A}\right)^{1-\sigma_d}\left(\frac{z_A}{p_{dA}}\right)\left(\frac{p_{uB}\ (1+\tau_{uBA})}{z_A}\right)^{1-\sigma_u} \end{aligned} \tag{15}$$

2.3 Data Inputs Required for the Model

This model specification requires domestic production and trade data to calibrate model equations. For the two-market model described above, the data inputs are:

- Total domestic production of upstream product produced in country A and B
- Total domestic production of downstream product produced in country A and B
- Country A imports of upstream product from country B, country B imports of upstream product from country A, country A imports of upstream product from all other countries, country B imports of upstream product from all other countries
- Country A imports of downstream product from country B, country B imports of downstream product from country A, country A imports of downstream product from all other countries, country B imports of downstream product from all other countries

- Share of total upstream domestic production and total imports used in downstream production in each country

In addition, this model specification also requires the following parameter estimates:

- Elasticity of substitution across upstream sources of supply
- Elasticity of substitution across downstream sources of supply
- Price elasticity of supply of upstream domestic production in both country A and B
- Price elasticity of supply of non-Country A and B upstream imports
- Price elasticity of supply of non-Country A and B downstream imports
- Policy change (e.g. pre- and post- tariff rates, change in quantity from supply disruption, etc.)

For the U.S. market, domestic production data by NAICS code can be obtained from the U.S. Census Annual Survey of Manufactures.[6] Import data can be obtained from the USITC's DataWeb.[7] The BEA's use tables and import matrices can be used to determine the share of production and imports that are used in the specific downstream industry modeled.[8] Elasticity estimates can be obtained from a number of sources (including Ahmad and Riker, 2020). Data for non-U.S. countries may be difficult to find depending on the country.

2.4 Calibration of Cost Parameters to Implicit Cost Shares

A number of model parameters can be calibrated to data inputs described above. The demand asymmetry parameters (b_{uij}, b_{dij}) and supply parameters (a_{ui}, a_{di}) can be calibrated to upstream domestic production and import data by using the demand and supply equations

[6]https://www.census.gov/programs-surveys/asm.html
[7]https://dataweb.usitc.gov/
[8]https://www.bea.gov/industry/input-output-accounts-data

specified in Section 2.1 and 2.2. The cost parameters (c_i) can be calibrated to available cost share data, assuming perfect competition in the downstream. In equations (16) and (17), the left-hand side represents the upstream share of downstream production costs by country implied by the data inputs. The right-hand side re-writes the cost share using the demand equations, which are a function of observable inputs, calibrated parameters, and elasticities. Then the cost parameters (c_A, c_B) can be solved for analytically by using the following equations[9]:

$$\frac{v_{uAA0} + v_{uBA0} + v_{uCA0}}{v_{dAA0} + v_{dAB0} + v_{dAC0}} =$$
$$\frac{1}{v_{dAA0} + v_{dAB0} + v_{dAC0}} \left(\left(p_{uAA0} \ \frac{k_A \ c_A}{p_{uAA0}} \right) \left(\frac{p_{dA0}}{P_{A0}} \right)^{1-\sigma_d} \left(\frac{z_{A0}}{p_{dA0}} \right) \left(\frac{p_{uAA0}}{z_{A0}} \right)^{1-\sigma_u} \right)$$
$$+ \left(\left(p_{uBA0}(1+\tau_{uBA0}) \ \frac{k_A \ c_A \ b_{uBA}}{p_{uBA0}(1+\tau_{uBA0})} \right) \left(\frac{p_{dA0}}{P_{A0}} \right)^{1-\sigma_d} \left(\frac{z_{A0}}{p_{dA0}} \right) \left(\frac{p_{uBA0}(1+\tau_{uBA0})}{z_{A0}} \right)^{1-\sigma_u} \right)$$
$$+ \left(\left(p_{uCA0}(1+\tau_{uCA0}) \ \frac{k_A \ c_A \ b_{uCA}}{p_{uCA0}(1+\tau_{uCA0})} \right) \left(\frac{p_{dA0}}{P_{A0}} \right)^{1-\sigma_d} \left(\frac{z_{A0}}{p_{dA0}} \right) \left(\frac{p_{uCA0}(1+\tau_{uCA0})}{z_{A0}} \right)^{1-\sigma_u} \right) \tag{16}$$

[9]The values variables v_{uij} and v_{dij} are data inputs. The prices $\{p_{uA}, p_{uB}, p_{uCA}, p_{uCB}\}$ can be normalized to 1 if the researcher only wishes to estimate percent changes. The other prices can be solved for with the equations listed above.

$$\frac{v_{uBB0}+v_{uAB0}+v_{uCB0}}{v_{dBB0}+v_{dBA0}+v_{dBC0}} =$$
$$\frac{1}{v_{dBB0}+v_{dBA0}+v_{dBC0}}\left(\left(p_{uBB0}\ \frac{k_B\ c_B}{p_{uBB0}}\right)\left(\frac{p_{dB0}}{P_{B0}}\right)^{1-\sigma_d}\left(\frac{z_{B0}}{p_{dB0}}\right)\left(\frac{p_{uBB0}}{z_{B0}}\right)^{1-\sigma_u}\right)$$
$$+\left(\left(p_{uAB0}(1+\tau_{uAB0})\ \frac{k_B\ c_B\ b_{uAB}}{p_{uAB0}(1+\tau_{uAB0})}\right)\left(\frac{p_{dB0}}{P_{B0}}\right)^{1-\sigma_d}\left(\frac{z_{B0}}{p_{dB0}}\right)\left(\frac{p_{uAB0}(1+\tau_{uAB0})}{z_{B0}}\right)^{1-\sigma_u}\right)$$
$$+\left(\left(p_{uCB0}(1+\tau_{uCB0})\ \frac{k_B\ c_B\ b_{uCB}}{p_{uCB0}(1+\tau_{uCB0})}\right)\left(\frac{p_{dB0}}{P_{B0}}\right)^{1-\sigma_d}\left(\frac{z_{B0}}{p_{dB0}}\right)\left(\frac{p_{uCB0}(1+\tau_{uCB0})}{z_{B0}}\right)^{1-\sigma_u}\right) \tag{17}$$

3 Illustrative Simulations

In the next section, we run illustrative simulations to describe how the model works. First, a unilateral 10 percent tariff is applied to Country A imports of upstream products from country B. Second, we simulate a tariff liberalization by removing a 10 percent tariff on intermediate imports for both countries. We consider two cases: one where the markets are the same size, and one where one market is larger.

Data and parameter inputs are held fixed throughout this section, with the exception of the last simulation that changes the market size for one of the countries. The elasticities of substitution and price elasticities of supply are all set to 5. Data inputs used are described in table 1.

A tariff on intermediate goods affects the downstream industries that use the intermediate as a production input. The magnitude of the economic effects depends on the cost share of that intermediate input in domestic production, as well as the share of intermediates that are sourced from imports. Another important determinant is the amount of trade that is diverted to and from the other country in the model. Additionally, the elasticity of substitution parameter between intermediate sources is another important determinant; the easier it is to shift sourcing after a relative price change of inputs, the greater the economic

Table 1: Illustrative Data Inputs

Upstream:	
Country A production used in Country A downstream	200
Country A production used in Country B downstream	200
Country A production exported to other countries excluding B	200
Country A imports from other countries excluding B	200
Country B production used in Country B downstream	200
Country B production used in Country A downstream	200
Country B production exported to other countries excluding A	200
Country B imports from other countries excluding A	200
Downstream:	
Country A production consumed in Country A	2,000
Country A production exported to Country B	2,000
Country A production exported to countries other than B	2,000
Country A imports from other countries excluding B	1,000
Country B production consumed in Country B	2,000
Country B production exported to Country A	2,000
Country B production exported to countries other than A	2,000
Country B imports from other countries excluding A	1,000

effects.

3.1 Effects of a Unilateral Upstream Tariff

In this first simulation, we apply a 10 percent tariff to intermediate inputs originating in Country B and used in the downstream production in Country A (figure 2). Note that the current model specification estimates the effects of a tariff on intermediate goods on the downstream industry modeled, not the effects of the tariff on total upstream production. This means that the model does not estimate the effects of a tariff on intermediates sent to other downstream industries. The model could be extended to include all upstream production and imports of the intermediate product, and additional downstream industries that use the intermediate good as an input.

Economic effects are reported in figure 3 and table 2. Country A adds a 10 percent

Figure 2: Unilateral 10 percent tariffs on intermediate goods

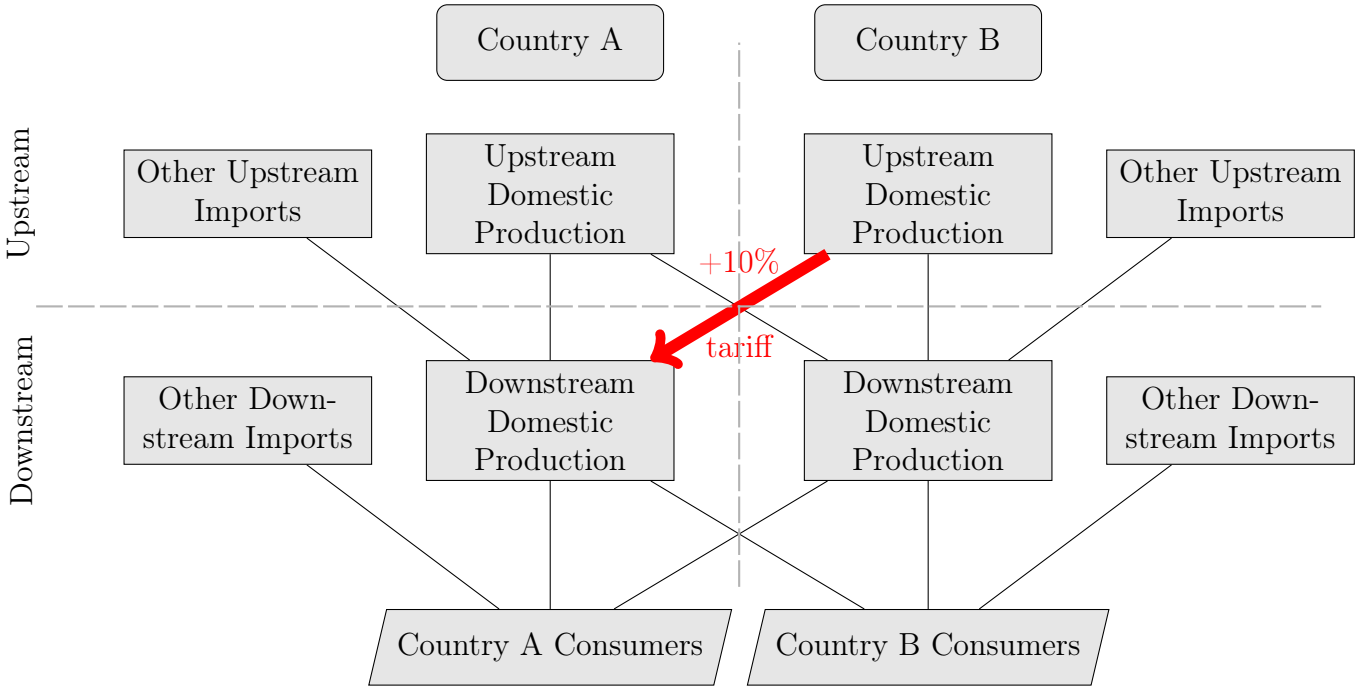
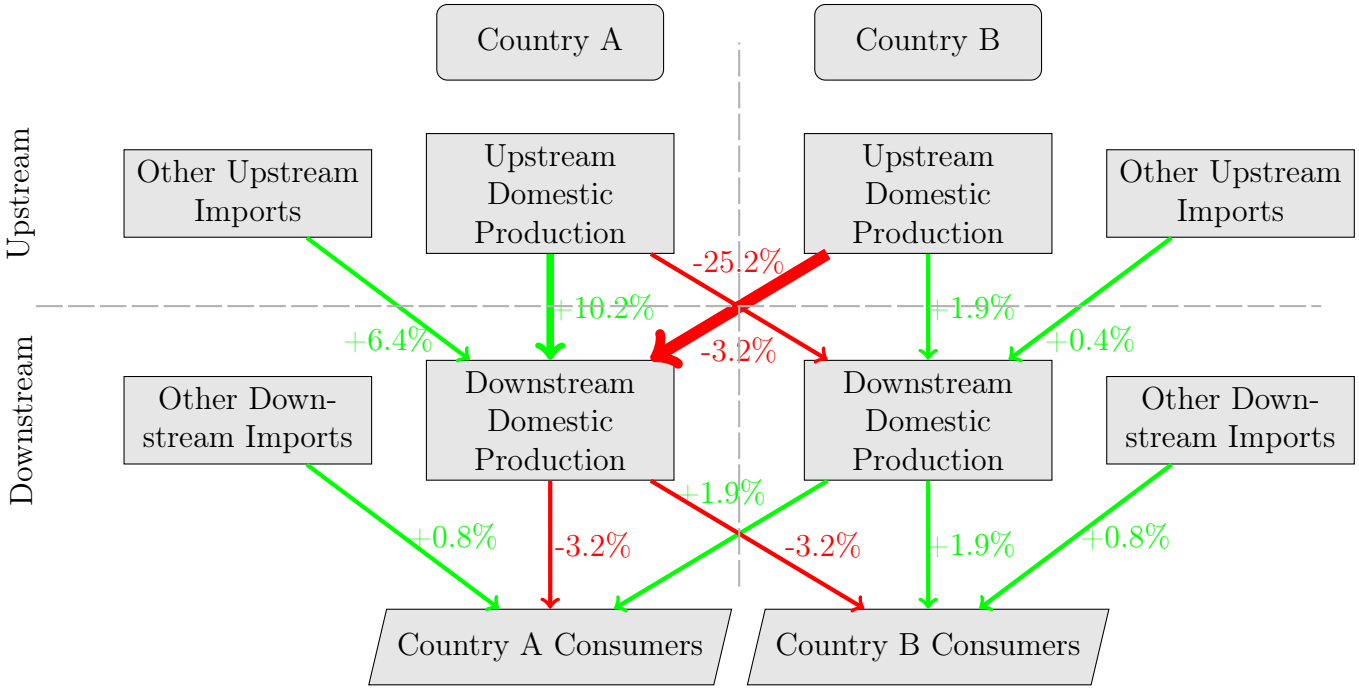


Figure 3: Change in Quantity after Unilateral 10% Tariff



tariff on the intermediate goods imported from Country B. The consumer price of Country B-originating imports increases by 8.6 percent after the tariff application, decreasing intermediate imports from Country B by 25.2 percent. Downstream production in Country A demand more upstream production in Country A as the relative price of imports increases after the tariff. This raises the price of domestically produced intermediates by half a percent, and increases the use of domestic intermediates in the downstream by 10.2 percent. Intermediate imports in Country A from countries not subject to the tariff also increase by 6.4 percent.

The increase in prices in the upstream translates to an increase in costs per unit of production in the downstream of Country A. This lowers Country A output of the final good modeled. The consumer price of downstream production increases by just less than one percent, and domestic production of the final good decreases by 3.2 percent.

Table 2: Effects of a Unilateral 10% Tariff

	% Change
Upstream results:	
Producer price, country A domestic production	0.54
Delivered price, country B imports of country A	0.54
Producer price, country B domestic production	-1.23
Delivered price, country A imports of country B	8.64
Quantity, produced and consumed in country A	10.16
Quantity, produced and consumed in country B	7.19
Quantity, country A imports of country B	-25.23
Quantity, country B imports of country A	-1.94
Total quantity of country A domestic production	2.74
Total quantity of country B domestic production	-6.01
Downstream results:	
Price, country A domestic production	0.95
Price, country B domestic production	-0.07
Quantity, country A domestic production	-3.17
Quantity, country B domestic production	1.86

As described in the previous paragraph, the amount of intermediates exported from

Country B to Country A decreased after the Country A tariff. The producer price of the Country B intermediate good decreased by 1.2 percent. The relatively lower price of Country B intermediates leads Country B downstream purchasers to buy more domestic intermediates. In other words, the intermediates sent to Country A are now being used in Country B downstream production. This leads to an increase of domestic intermediates in Country B of 7.2 percent, and an increase in quantity of downstream production by 1.9 percent.

The pass-through of upstream tariffs into downstream prices depends on the cost share of the intermediate good in production and the fraction of intermediates that are imported. The cost share of the intermediate in downstream production of Country A is 10 percent. Of that 10 percent, one third originates in country B that is subject to the policy change. Quantifying the pass-through into the downstream, a 10 percent tariff in the upstream on Country B translates to about a 1 percent increase in the price of Country A domestic production and about a 3 percent decline in production quantity.

3.2 Effects of Bilateral Tariff Liberalization

In this next set of simulations, tariff rates are reduced between the two closely-related countries. This illustration is akin to tariff liberalization following a new free-trade agreement. In the simulations, Country A removes a 10 percent tariff on intermediate imports from Country B, and Country B removes a 10 percent tariff on intermediate imports from Country A. Figure 4 illustrates the import flows with the tariff reductions.

Model results are shown in figure 5 and table 3. In the second column, country A and B are symmetric so economic effects are symmetric. In the third column, country A intermediate production is three times larger than country B intermediate production so economic effects differ by country. Consumer prices of the intermediate good decrease when the tariff is reduced in both Country A and B. There is a shift in use of domestic production of the intermediate good, as the price of exporting becomes relatively more advantageous for

Figure 4: Bilateral 10 percent tariff reduction on intermediate goods

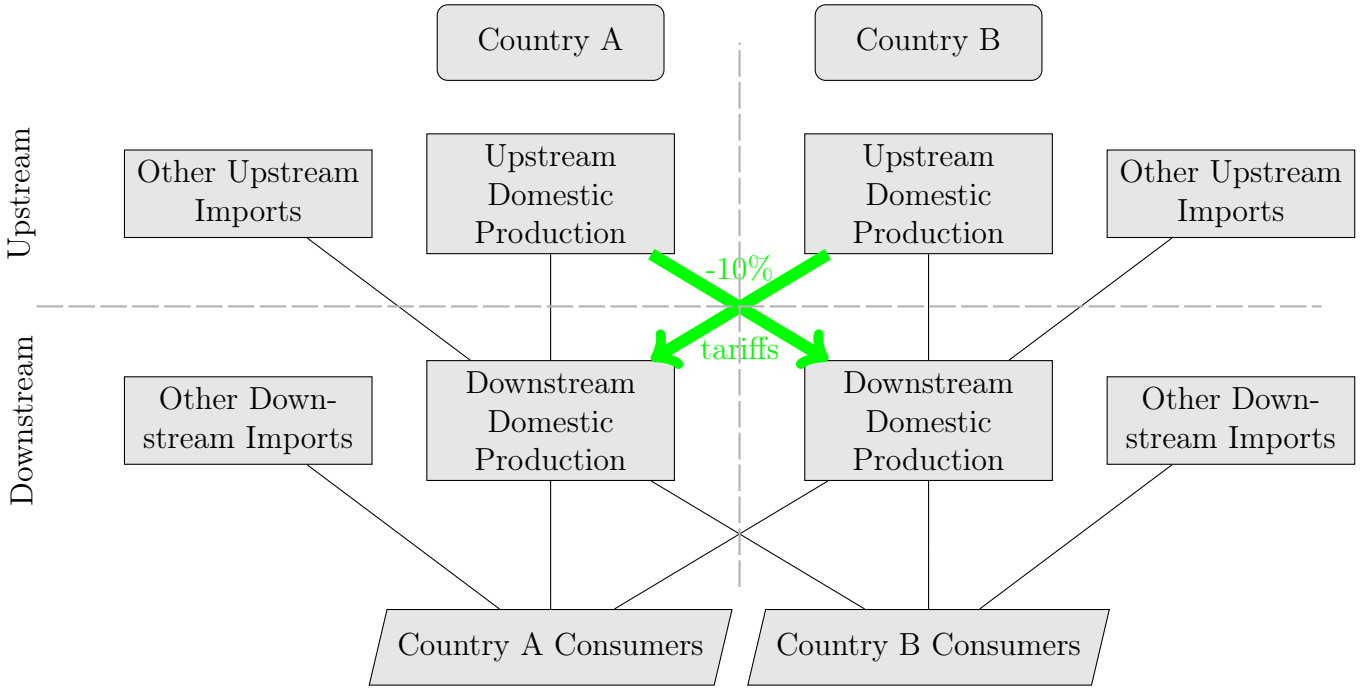
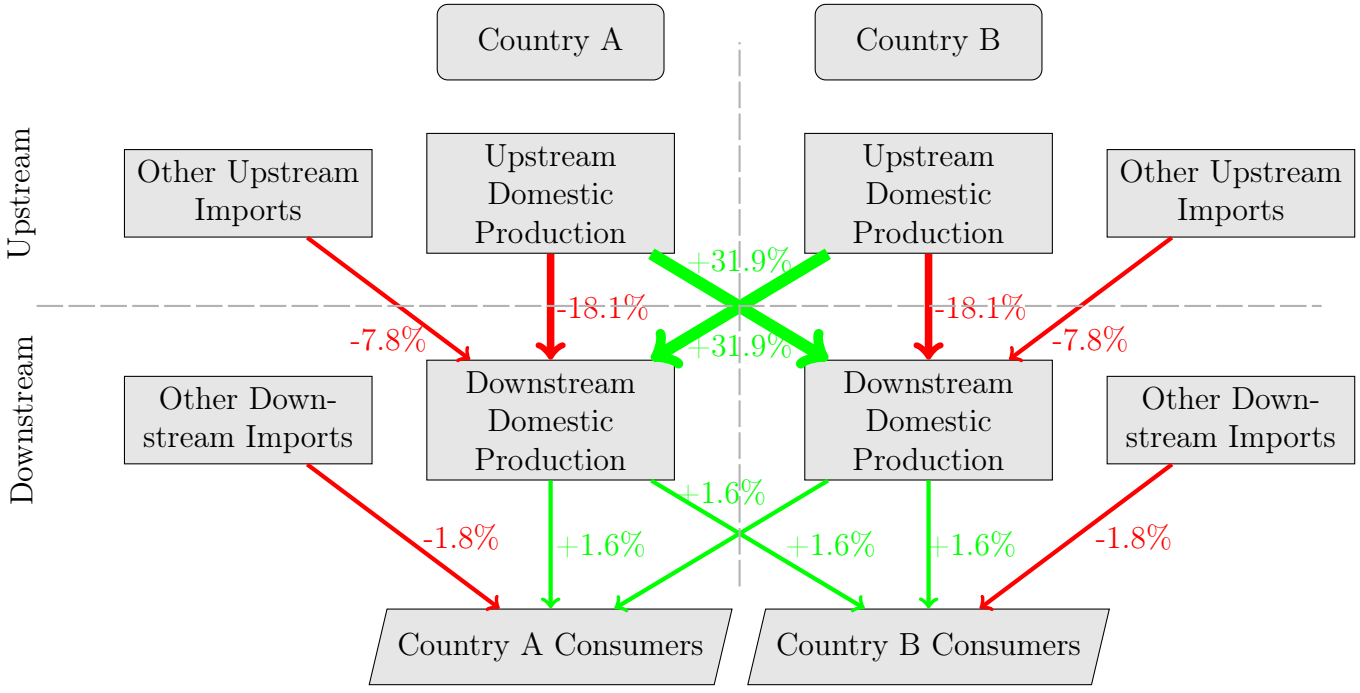


Figure 5: Change in Quantity after Bilateral 10% Tariff Liberalization with Symmetric Markets



upstream producers than shipping their products to downstream domestic producers. The total quantity of domestic production increases after the tariff reduction.

The downstream results differ based on whether the markets are symmetric or asymmetric. In the symmetric markets case, where Country A and B are the same size in terms of domestic production of the intermediate, the lower tariff on intermediates lowers production costs and downstream production increases by about 1.6 percent. In the asymmetric markets case, downstream production increases in Country B but decreases in Country A. This is because there are multiple opposing effects. Country B subject imports from Country A are larger, so removing a tariff will have a larger positive impact on Country B production. Because more of Country A intermediates are being sent to the downstream in Country B, Country A benefits less from the tariff liberalization. Additionally, Country A consumers are purchasing relatively more from Country B and less from Country A domestic production because downstream domestic production in B is now relatively cheaper.

4 Conclusion

This paper presents a model that analyzes the supply chain effects of a new trade policy between closely-related countries. It can be used to analyze how a tariff change on intermediates may affect downstream industries. It can also be used to estimate the effects of tariff liberalization on imports, exports, and domestic production in both upstream and downstream industries. The model specification is designed for narrowly-defined industries. It is not suitable for aggregate industries or industries with complex supply chain linkages. The model analyzes a specific upstream-downstream linkage and does not compute general equilibrium effects.

Table 3: Effects of Tariff Liberalization on Intermediate Inputs

	Symmetric Markets, % Change	Asymmetric Markets, % Change
Upstream results:		
Producer price, country A domestic production	0.75	1.89
Consumer price, country B imports of country A	-8.41	-7.37
Producer price, country B domestic production	0.75	1.80
Consumer price, country A imports of country B	-8.41	-7.45
Quantity, produced and consumed in country A	-18.05	-13.81
Quantity, produced and consumed in country B	-18.05	-8.59
Quantity, country A imports of country B	31.98	39.38
Quantity, country B imports of country A	31.98	46.61
Total quantity of country A domestic production	3.79	9.81
Total quantity of country B domestic production	3.79	9.35
Downstream results:		
Price, country A domestic production	-1.05	-0.23
Quantity, country A domestic production	1.61	-1.57
Price, country B domestic production	-1.05	-1.33
Quantity, country B domestic production	1.61	4.02

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