Commodity Trade Matters

Thibault Fally and James Sayre*
UC Berkeley ARE

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Abstract

Primary commodities account for approximately 16 percent of world trade, yet they are used extensively as intermediate inputs into many production processes. We show that ignoring several key features of trade in commodities leads to a large understatement of aggregate gains from trade despite their relatively small share of world trade. We quantify the welfare gains from international trade when we account for specific characteristics of most primary commodities: i) a low price elasticity of demand as a result of difficulty in finding substitutes, ii) a low price elasticity of supply, and iii) a high concentration of natural resources and production among a few countries. For instance, copper is difficult to replace in the electronic equipment industry, the supply and demand for copper vary only slightly with changes in prices, a large share of its supply comes from Chile and copper accounts for half of Chilean total export revenues. We explicitly account for these features in a general-equilibrium model of consumption, production, and input-output linkages. In our simulations, we confirm that ignoring these specific features of commodities leads to a wide understatement of the aggregate gains from trade.

Keywords: Gains from trade, Primary commodities, Multi-stage Production
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*Thibault Fally: UC Berkeley, NBER and CEPR; James Sayre: UC Berkeley; We would like to thank Justin Caron, Ben Faber, Cecile Gaubert, John Loeser, Gordon Rausser, Andrés Rodríguez-Clare, Aaron Smith, Brian Wright and David Zilberman, as well as seminar participants at various venues for helpful comments and suggestions. We also thank May Lyn Cheah and Chengyao Sun for excellent research assistance. We gratefully acknowledge the financial support of the Giannini Foundation for this project. Contact: fally@berkeley.edu

1 Introduction

A continued concern associated with globalization is the access of countries to critical commodities in the world market. Such pressing issues as geopolitical instability combined with increased openness, depletion of the supply of natural resources, and a burgeoning demand for critical minerals used in key technologies have made studying the role of international commodity trade even more important today. Quantifying the interdependency of nations on trade in natural resources has crucial implications for international relationships, such as the economic risk countries face due to instability in access to global markets, as well as how much countries lose by imposing barriers to trade such as the creation of a tariff or cutting off of a key trading partner.

Despite recognition among academics of the importance of international trade, several recent papers have found that the welfare gains from international trade are modest: using a formula proposed by Arkolakis et al. (2012) that applies to a wide range of models, estimated gains from trade equal 1.4% of GDP for the US in 2000.[1] These models, however, make stark assumptions that do not fit stylized facts about key primary commodities. Many crucial commodities in production are characterized by several traits: low responsiveness of demand and supply to changes in price, substantial difficulties in substituting one input for another, and a high concentration of natural resources among a few countries (e.g. Chile for copper, South Africa for platinum, Congo for cobalt). As shown in previous work (see Gilbert, 2010, Wright, 2011), these features can explain the high volatility of prices of these commodities. But little research has yet been undertaken to examine the implications of these features for the quantification of the gains from trade.

To examine the gains from trade in commodities, we proceed in three steps. First, we assemble a rich dataset on trade, production, prices and price elasticities across 169 detailed commodities. We document several stylized facts on trade in primary commodities using these data. Next, we develop a general-equilibrium model of trade that accounts for these specific features and stylized facts regarding primary commodities. Finally, we use our model and data to simulate counterfactual equilibria with higher trade barriers and confirm that ignoring these specific features of commodities leads to a wide understatement of the gains from trade.

In order to assess the gains from trade, an essential step is to gather trade and production data at a disaggregated level. Current datasets of trade and production generally aggregate commodities into broad categories, such as "minerals". This level of aggregation is not able to account for the input-output linkages found in commodity trade. For instance, although many countries produce minerals, the supply of minerals tends to be highly specialized across

[1] Given an import penetration of 7% and an elasticity of trade to trade cost equal to 5.

countries. To remain at this level of granularity, we use data on production at a detailed level in order to match the trade data available across 6-digit HS product categories (with some exceptions where aggregation is required). Production data are gathered from various sources since there is no readily-available dataset on production at the detailed level. Since most of the information on production is in quantity only, we also gather price data at a similar level of disaggregation in order to compute the total value of production. For downstream industries, we employ data from the World Bank and GTAP at a more aggregate level.[2] We combine our data with a meta-analysis of elasticities of demand and supply elasticities across many scattered sources.[3] In doing so, we document nine stylized facts that describe trade in commodities: the share of commodities in world trade, the concentration of trade and income in a few commodities and countries, the low elasticities of supply and demand, and the responsiveness of trade in commodities to trade barriers in gravity equations. These features help justify several assumptions of our model and explain the large gains from trade in commodities.

Our model includes multiple (traded) sectors, two stages of production (final goods and commodities) and different factors of production (labor and natural resources).[4] The production of final goods relies on labor and commodities, while the production of commodities relies on labor and natural resources. We depart from an otherwise standard model of trade (multi-sector Eaton Kortum 2002 framework) in several ways in order to account for trade in scarce commodities. First, on the supply side, the production of commodities requires natural resources and a common factor, labor, with potentially low elasticities of substitution between them. Many existing models of international trade explain production processes using just one factor (e.g. labor) or a few factors of production (e.g. capital, labor and land). In contrast, we assume that each commodity requires natural resources that are specific to each commodity. This setup reflects the production of minerals and fuel commodities and, to some extent, agricultural commodities that may be specific to certain climates or types of land. With these assumptions, our model can explain why the production of some commodities is highly concentrated across space.[5] Moreover, a low elasticity of substitution between inputs combined with the presence of a fixed factor generates a low price elasticity of supply, as typically observed for commodities.[6] Commodities do not directly enter final demand but are absorbed by downstream sectors.

[2] We also combine our data with commodity use by downstream industry across finely-defined commodities.

[3] A preliminary version of these harmonized production and trade data is provided here: http://are.berkeley.edu/ fally/data.html

[4] in our model, "labor" refers to a factor of production that is mobile across sectors. We do not explicitly differentiate labor from capital. A distinction between labor and capital would not play an important role here.

[5] For instance, uranium from South Africa and rare earth elements from China. See Table 8, stylized fact 9.

[6] See Table 2 for our review of elasticity estimates from the literature.

In turn, we assume that final good production requires both labor and commodities, allowing for a potentially low elasticity of substitution in order to generate a low price elasticity of demand for commodities. While commodities account for a small share of total costs in downstream sectors, those commodities would be very costly to replace if their supply drops.

The model can be calibrated using estimates of several key parameters such as supply, demand and trade elasticities, as well as moments that can be observed in the data, such as production, trade flows and input-output relationships. Moreover, we provide closed-form solutions for the gains from trade in a few specific cases to generalize Arkolakis et al. (2012) with commodity trade and highlight the role of substitution and trade elasticities and the patterns of production in the baseline equilibrium.

From this, we calibrate our model and simulate counterfactual equilibria with higher trade costs and complex input-output linkages, after matching our commodity dataset to the Global Trade Analysis Project (GTAP) dataset. Our baseline calibration assumes an elasticity of substitution equal to 0.4 on the demand and supply sides (a conservative choice given most estimates for primary commodities, see Table 6).

Comparing the baseline equilibrium to Autarky, we find vastly larger changes in welfare compared to models that would have either only one factor of production or higher elasticities of substitution. For large countries such as the US and China, gains from international trade double. For the median country, gains from trade are three times larger than in standard models. For small countries with few resources, the gains from trade are enormous. We find that the gains from trade are much more (negatively) correlated with market size if we account for natural resources and trade in commodities. Most of the gains from trade are captured by workers (common input across industries). In our baseline calibration, owners of natural resources on average lose from trade.

These results are greatly muted if we consider higher elasticities of substitution between natural resources and labor in the production of commodities, or between commodities and labor in downstream industries. Interestingly, gains from trade become positive for most natural resource owners when elasticities of substitution are higher. In contrast, considering a higher (double) elasticity of trade for commodities only moderately erodes the gains from trade and the distribution of the gains.

We also examine intermediate trade costs changes and tariffs. With commodities, gains from trade are highly non-linear (much higher as we approach Autarky), but the difference with benchmark models without commodities or natural resources is non-negligible even for intermediate trade cost reductions. Interestingly, tariffs generate only tiny differences with the benchmark model given that the dead-weight loss is small with low elasticities of commodity demand and supply. Finally, we illustrate the role of critical suppliers in each commodity by simulating the effect of cutting off from trade the top export of each commodity on prices in other countries for that commodity. We find large effects on prices, mainly driven by the increase in production costs due to the increase in supply (combined with low price elasticities of supply).

Literature Although other papers have not accounted for the aforementioned specific features of primary commodities, our model and calibration approach is similar to a number of other recent papers in the field of international trade such as Dekle et al. (2008), Caliendo and Parro (2015), and Caron and Fally (2017), aimed at quantifying the effect of trade costs and trade policy changes on various economic outcomes. Dekle et al. (2008) introduce the "exact hat algebra" and show that trade shares, production shares and key elasticities are sufficient to solve for counterfactual changes in general equilibrium, without approximations. Caliendo and Parro (2015) apply these techniques to examine the effect of NAFTA on production and employment. Caron and Fally (2017) examine the effects of changes in income and consumption on CO2 emissions in a general equilibrium framework with trade.

More specifically, our paper relates to three subgroups of papers that examine the gains from trade with: i) input-output links between industries (Costinot and Rodríguez-Clare, 2015, Caliendo and Parro, 2015, Alexander, 2017, Antràs and de Gortari, 2017); ii) gains from trade with multiple factor of production (Galle et al., 2017); iii) gains from trade from the specialization of land and natural resources into exported products (Sotelo, 2017, Costinot and Donaldson, 2016, Farrokhi, 2016). We depart from the literature on multi-stage production by assuming a key role for natural resources that are unevenly allocated across countries, and difficult to substitute. These features generate much larger gains from trade than typical model with multiple-stage of production. Our approach is probably close to multi-factor models, although we consider many more factors of production (natural resources are specific to each commodity) and lower demand and supply elasticities than usually assumed for instance across different types of labor (Galle et al., 2017, Acemoglu, 2002).[7] Closer to our work is Farrokhi (2016) who develops a general equilibrium model to incorporate how changes in oil production affect downstream demand and trade flows, arguing that the gains from trade in a model considering oil are larger than more general, existing models.

Although the crucial role of mineral commodities and fuels as inputs to many industries may be well known, considering the importance of agricultural commodities is also necessary to fully understand the gains from commodity trade. Lagakos and Waugh (2013) examine

[7] Galle et al. (2017) and Sotelo (2017) assume a Roy model to examine the allocation of factors across industries, with Frechet productivity draws that are specific to each individual and industry. Our framework yields very similar outcomes, but allows us to obtain closed-form solution for the gains from trade (described in Proposition 1) that cannot be obtained with these alternative approaches.

the selection of unproductive workers into agriculture, arguing that subsistence requirements may hinder the agricultural sector in developing countries and prevent exports of agricultural commodities from those countries. Similarly, Gollin et al. (2013) examine the "agricultural productivity gap" in developing countries, and point out the large sectoral misallocation of workers in the agriculture. Further, Tombe (2015) finds that trade may increase such labor market distortions in agriculture by almost 40 percent compared to Autarky, finding that trade costs significantly lower welfare in developing countries, asserting that explicitly modeling agricultural is necessary to understand the channels through which developing countries benefit from trade. Additionally, the benefits and costs of agricultural exports depend highly on the types of agricultural products and features of various sectors in each country, arguing for a highly granular treatment of agriculture trade (Carter et al., 1996)[8].

Our analysis of the importance of commodity trade also relates to the literature on price volatility, how prices relate to commodity production, and the consequences for exporters, particularly developing countries where production is highly concentrated in only a few products. One prominent paper discussing this is Deaton and Laroque (1992), which argues that commodity prices are extremely volatile, and shows that a model of competitive storage where commodities are stored for relatively scarce times does not predict these price movements well. Additionally, Gilbert (2010) argues one of the main reasons for price booms is the low responsiveness of supply of agricultural products to sudden demand shocks not specific to one agricultural product, as seen for agricultural commodity prices in 2008, when prices of food commodities doubled in real terms from 2005. Similarly, Wright (2011) examines recent price spikes in grain and argues that features such as storage of grain and supply characteristics account for much of the spikes in prices. Williams and Wright (2005) analyze the importance of storage in commodity trade, and show its ability to temper price shocks for producers. In countries with heavy dependence on a few products, commodity price shocks can have negative consequences for development. Recently, Drechsel and Tenreyro (2017) show that for developing countries, commodity prices have been a large driver of growth (or the lack thereof), arguing that commodity price shocks account for about 38% of fluctuations in post-1950 growth in Argentina. Faber et al. (2017) suggest that price shocks in the world price of Cobalt may increase child labor and reduce education in communities dependent on mining income.

The remainder of the paper proceeds as follows; the second section describes the data and documents several stylized facts. The third section develops the model and theoretical findings. The fourth section documents the calibration of the baseline model. The fifth section examines

[8] We examine agricultural production and trade at disaggregated level, examining specific products, rather than simply "agriculture" or "grains", for example.

counterfactual equilibria using our calibrated model to illustrate the gains from trade with commodities.

2 Data and stylized facts

2.1 Data sources

We draw from a varied set of data sources for information on production, prices, trade, input-output linkages and price elasticities across commodities. In an online appendix, we provide information on the construction of our dataset, in addition to providing our data online.[9]

Production data. For minerals, the main source of production data is the British Geological Survey (2015), which provides mineral production data at the country level from 1913 to 2015. For agriculture, the main source of agricultural data is from the Food and Agriculture Organization of the United Nations (2017) (FAO), which provides data from 1960 to 2014 on the production of agricultural products at the country level, in addition to data from the US Department of Agriculture. Supplementally, we employ production data from the Global Trade Analysis Project, or GTAP (Aguiar et al., 2012) for downstream industries.

Trade data. For information on trade flows, we employ BACI data, constructed by CEPII and based on UN-Comtrade data (Gaulier and Zignago, 2010). These data are detailed at the 6-digit level of the Harmonized Commodity Description and Coding System (HS), of which we use the 1992 nomenclature. In order to match production and trade data, we further aggregate the trade data to match the level of granularity in the production data. These data cover the years 1995 to 2014.

Price data. We use the United States Geological Survey Historical Statistics for Mineral and Material Commodities in the United States for prices of mineral commodities (Kelly and Matos, 2014). This is the most comprehensive source of yearly price data but one shortcoming is that it does not cover mineral prices for countries other than the US. We complement this price data with the IMF Primary Commodity Price Series database for uranium prices (Commodities Team of the Research Department, IMF, 2017), the World Bank Commodity "Pink Sheets" for fuel petroleum and coal prices (World Bank Group, 2017), and U.S. Energy Information Association (2017) data on natural gas prices. For agricultural products, we use producer price

[9] A preliminary version of these harmonized production and trade data is provided here: http://are.berkeley.edu/ fally/data.html

data from the FAO at the country level when available, and use world agricultural prices for commodities when country level prices are unavailable.

Demand and supply elasticities. The Food and Agricultural Policy Research Institute (2017) provides price elasticity estimates of supply and demand for numerous agricultural commodities, in addition to an extensive literature, some of which is reviewed by Muhammad et al. (2011). For other commodities, especially minerals, many other scattered and diverse sources and journal articles provide elasticity estimates. Examples are Jenkins (2011) for 17 commodities produced in Latin America (4 minerals, oil and 12 agricultural products); Stuermer (2017) on 5 minerals over a century; Caldara et al. (2016) for oil; Russo et al. (2008) for 6 agricultural commodities produced in California; and Evans and Lewis (2002) for 14 metals. We refer to Table 6 in the Appendix for the current list of papers that we have surveyed along with their estimates. This review is not intended to be exhaustive, especially for elasticity estimates of agricultural and fuel commodities, but we have attempted to survey mineral elasticity estimates comprehensively, for which there is a smaller literature.

Commodity end use. A few sources report figures for commodity consumption by downstream sectors. GTAP data provide input-output linkages between several categories of primary commodities[10] and broad secondary and tertiary industrial sectors, which we use for agricultural commodities and fuel products. However, mineral commodities are more highly aggregated by the GTAP classification (grouped into only 2 categories), despite their relatively complex downstream usage compared to agricultural commodities. To rectify this, we employ USGS end usage data (Barry et al., 2015) for each mineral commodity across downstream NAICS industry codes at the 3 or 6-digit level. Where possible, we match each NAICS code to the GTAP classification coding system to determine the relative use of a given mineral by each downstream GTAP industrial sector.

2.2 Stylized facts

Before turning to the setup of our model, we document a series of stylized facts on the specific patterns of commodity trade to motivate the key assumptions of the model and help explain the large gains from trade in commodities.

Fact 1: Commodities account for a modest share of World trade. As a percentage of total trade, commodities account for a modest share, approximately 16 percent of the value

[10] The GTAP classification leaves Rice, Wheat, Sugar, Coal, Natural Gas, and Oil disaggregated.

of world trade in 2014. However, this amount has not been constant over time. Table 1 (under column "Primary Commodities") and Figure 1 exhibit the trends in commodity trade both from the period of 1962 to 1995 (panel a) and from 1995 to 2014 (panel b). We find that the share of world trade in all commodities has experienced a decline since 1962, but has leveled off from the period of 1995 to 2014. Recently, the share of fuels has increased, making up for some of losses in commodities in world trade. Our study examines both commodities and some of the their directly-related intermediate products at a slightly more processed stage, such as steel and processed metals (see Appendix E for the list of primary commodities in our study). Hence, the products in our study (the first three columns of Table 1) encompass a slightly larger share of world trade, up to 27 percent of world trade in 2014 and 23 percent on average.

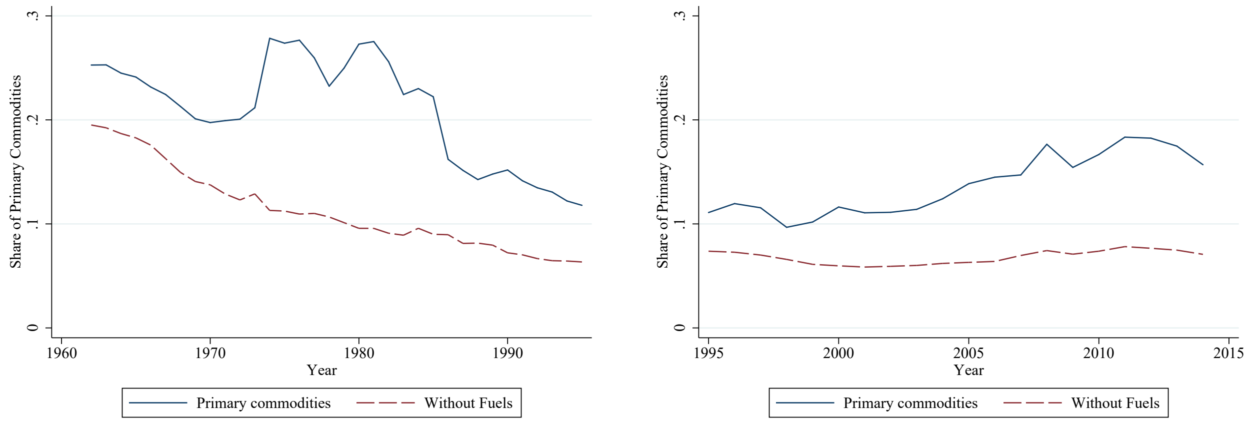
Table 1: Share of Products in World Trade

Year	Minerals	Agriculture	Fuels	Primary Commodities
1995	0.079	0.039	0.067	0.111
1996	0.072	0.039	0.082	0.120
1997	0.072	0.037	0.081	0.116
1998	0.072	0.036	0.059	0.097
1999	0.065	0.033	0.074	0.102
2000	0.067	0.027	0.099	0.116
2001	0.064	0.028	0.093	0.111
2002	0.065	0.029	0.092	0.111
2003	0.066	0.029	0.096	0.114
2004	0.074	0.027	0.111	0.124
2005	0.079	0.024	0.133	0.139
2006	0.086	0.023	0.143	0.145
2007	0.098	0.025	0.140	0.147
2008	0.095	0.028	0.178	0.177
2009	0.078	0.031	0.146	0.154
2010	0.085	0.029	0.161	0.167
2011	0.087	0.031	0.183	0.183
2012	0.080	0.030	0.188	0.182
2013	0.077	0.030	0.180	0.175
2014	0.079	0.031	0.160	0.157

Notes: BACI-COMTRADE international trade data.

Fact 2: Commodities face low supply and demand elasticities. We conduct a meta-analysis of price elasticity estimates in the literature over the past decades. Since price elasticities matter greatly for examining the patterns of commodity prices, hundreds of papers have estimated price or demand elasticities for the specific commodities in our study, often with an

Figure 1: Evolution of the share of primary commodities in world trade



(a) 1962-1995 (Feenstra data)

(b) 1995-2014 (BACI data)

emphasis on demand elasticities. We list all the papers and price elasticity estimates that we have reviewed so far in Appendix Table 6. Further, Table 2 provides summary statistics for these elasticity estimates; in cases where there are mutliple elasticity estimates we do not take a stance on providing one value but instead provide a range of coefficient estimates.

Appendix figures 18 and 19 plot the empirical distributions of the elasticity estimates we have surveyed. Most estimates fall within the 0.1 and 0.5 range (in absolute values), both on the supply side and demand side. The modal estimate for both distributions appears to be somewhat less than 0.2 (in absolute value); assuming demand and supply elasticites of 0.4-0.5, as we do in our simulations in Section 4, is quite conservative. A majority of these estimates are short-run elasticities, i.e. examining supply and demand responses within a year. Several papers also estimate long-run elasticities for commodities (see Appendix Table 6), which leads to slightly higher elasticities, but these figures remain very low[11]. In comparison, most estimates of the elasticity of substitution between skilled and unskilled workers lie between 1.5 and 2 (Acemoglu, 2002) (Autor et al., 1998), with a few exceptions as low as 1 and as high as 4.

Fact 3: Commodity prices are volatile. As part of the consequences of low demand and supply elasticities, the fluctuations in commodity prices can be very large. Table 3 presents historical price volatility of commodities, broken down by agriculture, fuels, and minerals. We measure volatility as the standard deviation of log price changes (rather than the standard

[11]Scott (2014) argues that static analyses of long-run supply elasticities may generate lower elasticity estimates, although a dynamic model incorporating farmer choices to plant crops still suggests that overall crop supply has an elasticity around 0.3, which is still fairly low.

Table 2: Selected estimates of supply and demand elasticities for commodities

Commodity	Price Elasticity of Demand	Price Elasticity of Supply	Commodity	Price Elasticity of Demand	Price Elasticity of Supply
Alfalfa	-0.107	0.44	Niobium	-0.3	
Almonds	-0.48 to -0.35	0.19	Peanuts	(-0 to -0.4)	(0.04 to 0.5)
Aluminium	(-0.07 to -0.7)	(0.17 to 0.4)	Petroleum	(-0.34 to -0.07)	(0.09 to 0.85)
Bananas	(-0.424 to -0.128)	(0.2 to 0.4)	Platinum	(-0.7 to -0.2)	
Barley	(-0.11 to -0.435)	(0.11 to 0.45)	Rapeseed	(-0.117 to -0.17)	(0.26 to 0.36)
Chromium	(-0.5 to -0.1)	(5 to 10)	Rice	(-0.01 to -0.55)	(0.01 to 0.57)
Coal	(-0.7 to -0.3)	0.05	Silver	-0.0423	
Cobalt	-0.5	< 1	Sorghum	(-0.06 to -0.49)	(0.16 to 0.53)
Cocoa	(-.14 to -.01)	(0.03 to 0.38)	Soybeans	(-0.05 to -0.175)	(0.32 to 0.45)
Coffee	-0.2	(0.1 to 0.28)	Sugar	(-0.06 to -0.17)	(0.055 to 0.21)
Copper	(-0.2 to -0.42)	(0.1 to .453)	Sunflower	(-0.083 to -0.15)	(0.15 to 0.41)
Corn	(-0.1 to -0.39)	(0.08 to 0.7)	Tin	(-0.097 to -0.55)	(0.3 to 1.11)
Cotton	-0.684	0.497	Titanium	-0.16	
Crude Oil	-0.13	(0.1 to 0.25)	Tomatoes	-0.32	0.27
Gold	-0.4115	1.426	Tungsten	(-0.5 to -0.15)	(0.11 to 0.15)
Iron ore	-0.087	(0.25 to 0.589)	Uranium	(-1.5 to -0.1)	(2.35 to 11.4)
Lead	(-0.111 to -0.22)	(0.1 to 0.81)	Vanadium	(-0.3 to -0.254)	
Manganese	-0.1	> 1	Walnuts	(-0.267 to -0.251)	0.02
Natural Gas	(-0.95 to -0.053)	0.37	Wheat	(-0.09 to -0.395)	(0.08 to 0.43)
Nickel	-0.037	(0.23 to 1.04)	Zinc	-0.064	(0.1 to 0.25)

Notes: The full lists of estimates and references are provided in Appendix Table 6. The parentheses indicate the ranges of estimates when more than one estimate is available, or when the author only offers an estimate of the range.

deviation of log prices, the latter being less robust to small trends). On average, the yearly volatility of commodity prices is around 20%. Over a longer term horizon, price fluctuations can also be very large and cumulative, since many commodities have price evolution patterns with very low mean reversion (Cashin et al., 2000, Cohen et al., 2006). The consequences of this volatility can be large, especially for exporters and importers for whom a commodity represents a large share of trade (see Fact 8).

Fact 4: Trade elasticities are not significantly higher for Commodities. Table 4 reports the results of our estimations of gravity equations for the products in our sample. Gravity equations are estimated separately for each commodity with the Poisson-PML estimator, including exporter and importer fixed effects to account for multilateral resistance terms (Fally, 2015). Table 4 column (1) is estimated using aggregate trade flows and reports the coefficient for each trade proxy and its estimated standard error. Columns (2) to (5) report the average of the coefficients for each trade proxy as well as the the standard deviation of these coefficients across commodities within each categories (in parentheses).

Primary commodities do not seem to have starkly higher distance elasticities than trade on

Table 3: Commodity Price Volatility, 1971-2014

	Agriculture	Minerals	Fuels
1971 to 1975	0.113	0.207	0.291
1976 to 1980	0.214	0.189	0.169
1981 to 1985	0.308	0.164	0.133
1986 to 1990	0.306	0.164	0.221
1991 to 1995	0.352	0.164	0.129
1996 to 2000	0.158	0.142	0.225
2001 to 2005	0.172	0.260	0.281
2006 to 2010	0.165	0.287	0.394
2011 to 2014	0.122	0.195	0.251
All years	0.213	0.197	0.233

Source: Authors' calculations, on price data from the FAO, IMF, World Bank, EIA, and USGS. Volatility is defined as the standard deviation of yearly changes in logged prices.

aggregate. However, there is some heterogeneity in these estimates, as shown by the standard deviations of the coefficients. Additionally, some commodities seem to have higher distance elasticities than others, for instance trade is more elastic for fuels than for minerals with respect to distance.

Also crucial is the elasticity of trade with respect to trade costs and tariffs, which differs from the distance elasticity documented above (the distance coefficient is the product of the elasticity of trade to trade costs, which we will call θ in Section 3, and the elasticity of trade costs to each of the trade cost proxies). Several papers have estimated these elasticities for primary commodities vs. other sectors (Tombe (2015), Caliendo and Parro (2015), Sotelo (2017), Farrokhi (2016), and Arkolakis et al. (2013)) and generally found that trade elasticities for commodities are not larger. For instance, Tombe (2015) estimates that θ equals 4.63 for manufacturing and 4.06 for agriculture. Caliendo and Parro (2015), however, find higher elasticities for mining and petroleum than most other industries, focusing on trade in North America. In our baseline calibration, we assume that the trade elasticity is the same across all sectors and examine the robustness of our results to this assumption by doubling the trade elasticity for primary commodities only.

Fact 5: The use of each commodity tends to be concentrated in a few specific downstream sectors. In the 2007 US input-output tables, defined across 6-digit NAICS commodity and industry categories (about 430 sectors), we find that the top purchasing industry accounts for 35% of total purchases of a primary commodity (on average) and the top-three purchasing industries amount to 60% of total purchases by commodity (on average across com-

Table 4: Gravity equation and trade cost coefficients across commodities

Dependent var.:	Trade flows				
	(1)	(2)	(3)	(4)	(5)
Industry	Aggregate trade	All commodities	Agriculture only	Fuel only	Minerals only
Distance (log)	-0.818	-1.652	-1.485	-2.003	-1.142
	[0.072]	(0.818)	(0.799)	(0.7)	(0.631)
Border effect	2.740	-3.914	-3.605	-2.192	-3.046
	[0.218]	(2.11)	(2.186)	(0.827)	(2.252)
Contiguity	0.404	0.378	0.352	0.643	0.285
	[0.120]	(1.337)	(1.188)	(0.435)	(0.869)
Common Language	0.502	0.7	0.524	0.63	0.188
	[0.146]	(0.881)	(0.865)	(0.252)	(0.749)
Colonial Link	0.036	0.102	0.102	-0.263	0.116
	[0.146]	(0.84)	(0.86)	(0.488)	(0.917)
In brackets:	Std Errors	Std. Dev.	Std. Dev.	Std. Dev.	Std. Dev.
Countries	94	143	143	143	143
Commodities	/	157	102	3	52

Notes: PPML with fixed effects by importer and exporter; robust standard errors in brackets. First column is from Fally (2015). Columns (2)-(5) report averages of coefficient estimates across gravity equations for separate commodities (166 separate commodities in column (2), less for columns (3)-(5)). The numbers in parentheses reported below the coefficient estimates for columns (2)-(5) are the standard deviations of the coefficient estimates, not standard errors.

modities). In the Global Trade Analysis Program (GTAP) data, which are more aggregated (57 sectors), an average of 50% of each commodity output is used by a single downstream sector. These high shares of top purchasers indicate fairly high specificity of each commodity. Moreover, these input-output tables are much more aggregated than our commodity data[12]. Furthermore, aggregation hides even more specialized uses across commodities. For instance, almost all iron ores are used in the production of steel, tungsten is used mainly in light bulbs and as tungsten carbide to strengthen cutting and drilling tools, nickel in stainless steel and magnets, phosphate in fertilizers, rare earth elements for electronics, crude petroleum in refineries, cocoa beans for chocolate, coffee beans for ground coffee, etc. Such specificities rarely appear in more aggregated industry-level input-output tables.

One should note also that commodity production tends to be upstream relative to most other industries. This can be shown by examining the "upstreamness" index documented in Fally (2012), Antràs et al. (2012) and Fally and Hillberry (2017). In US input-output tables (Fally, 2012), primary commodities other than fuels are associated with an usptreamness index

[12]For instance, "Iron, gold, silver, and other metal ore mining" and "other minerals" (omn) constitute only one category in the US input-output tables and GTAP tables respectively.

of 3.01 (and 3.48 for fuels), while the same index is equal to 2.11 or less for manufacturing and services, indicating that commodities are separated on average by one more production stage from final demand.

Fact 6: Commodities are intensive in natural resources. Intuitively, sales of commodities are the main source of income associated with natural resources. Conversely, the production of primary commodities is intensive in natural resources. According to GTAP version 8 data, the returns to natural resources account for 31% of the costs of production across primary commodities. As depicted in Table 5, natural resource intensities vary largely across types of commodities and less across countries.[13]

Table 5: Natural resource intensity in the GTAP 8 data

GTAP code	Commodity	Avg. resource intensity	Std. dev.
coa	Mining and agglomeration of coal	0.502	(0.160)
frs	Forestry	0.153	(0.137)
fsh	Fishing	0.448	(0.108)
gas	Extraction of natural gas	0.205	(0.175)
oil	Oil extraction	0.432	(0.133)
omn	Metal ores, mining n.e.c.	0.179	(0.143)
(aggregate)	Agriculture	0.242	(0.125)

Notes: share of land (agriculture) and natural resources (other than agriculture) in production costs by commodity on average; in parentheses: standard deviation across countries.

Fact 7: For many countries, commodities and natural resources account for a large share of their income. Table 6 shows the countries in our sample[14] for which natural resources constitute more than 25% of GDP, where natural resources are defined as rents from agriculture, forestry, minerals, and fuels. Most countries where natural resources compose a high share of GDP are developing countries, indicating that production and trade of products that use natural resources may be more important to developing countries than developed countries, which tend to have a comparative advantage in secondary and tertiary sectors.

Fact 8: For many countries, a few commodities account for a large share of their total exports and GDP. Defined at a similar level of aggregation as production data (a bit

[13] In a simple regression with country and industry fixed effects, industry variation accounts for half of the variance while country variation accounts for 11% of the variance.

[14] We have excluded trade and production data from countries with missing population or a population less than 1 million from our analysis.

Table 6: Countries with the largest share of income from natural resources

Country	Natural Resources Income Share	Country	Natural Resources Income Share
Turkmenistan	0.607	Uzbekistan	0.320
Libya	0.598	Liberia	0.316
Angola	0.552	Iran	0.306
Papua New Guinea	0.526	Chad	0.294
Congo	0.522	Sierra Leone	0.291
Iraq	0.517	Central African Rep.	0.290
Kuwait	0.512	Laos	0.281
Equatorial Guinea	0.502	Brunei	0.280
Saudi Arabia	0.493	Ethiopia	0.274
Azerbaijan	0.408	Algeria	0.269
Gabon	0.404	Guinea-Bissau	0.268
Oman	0.403	Comoros	0.267
Mongolia	0.394	Qatar	0.255
Yemen	0.351	Kazakhstan	0.253
Dem. Rep. of the Congo	0.349	Burundi	0.252
Myanmar	0.322	Syria	0.252
Nigeria	0.320	Sudan	0.252

Notes: Share of income from natural resource, countries for whom natural resources account for more than 25% of their total revenues. Source: World Bank. This includes agriculture, forestry, minerals and fuel commodities

fewer than 170 primary commodities among thousands of traded products), one or very few commodities account for majority of total exports for many countries. In table 7 we list the countries in our sample for which one product constitutes more than 40% of that country's exports. Although this is intuitive for smaller countries, this phenomenon is also true for many large countries, especially low-income countries. Our sample encompasses only countries with a population of more than 1 million[15], but despite their size (e.g. Venezuela) exports in a single commodity make up more than 50% of exports for several of them. Several other countries have the majority of their exports consisting in only three primary commodities, such as Angola. Petroleum is a commodity in which many countries specialize, but other commodities may also account for very large export shares, such as cashew nuts for Guiniea-Bissau and uranium for Eritrea.

This fact relates to Easterly and Reshef (2010) and Hanson et al. (2015) for overall exports. This leaves exporters especially vulnerable to price fluctuations in commodity prices, which are common (see Table 3). For many countries, especially developing countries, a large

[15] Or countries with available population data.

portion of fluctuations in growth can be accounted for by fluctuations in the prices of commodities (Drechsel and Tenreyro, 2017 estimate 38% for Argentina post-1950). But this extreme specialization pattern also sheds light on the very large gains from trade that we find in our calibration. International trade creates a much larger relative demand in commodities than would be sustainable domestically in these highly-specialized countries.

Table 7: Countries with the largest share of top commodity in total exports

Country	Top Commodity	Export Share Top Commodity	Export Share of Top 3 Comm.
Iraq	Petroleum	0.995	0.998
Chad	Petroleum	0.956	0.984
Angola	Petroleum	0.950	0.969
Kuwait	Petroleum	0.923	0.926
Nigeria	Petroleum	0.889	0.958
Azerbaijan	Petroleum	0.878	0.892
Iran	Petroleum	0.860	0.891
Saudi Arabia	Petroleum	0.857	0.871
Guinea-Bissau	Cashews	0.857	0.886
Yemen	Petroleum	0.852	0.857
Venezuela	Petroleum	0.847	0.896
Congo	Petroleum	0.803	0.841
Zambia	Copper (Smelted)	0.738	0.845
Turkmenistan	Natural Gas	0.737	0.963
Burkina Faso	Cotton	0.731	0.800
Algeria	Petroleum	0.711	0.974
Tajikistan	Aluminium	0.688	0.859
Gabon	Petroleum	0.678	0.755
Oman	Petroleum	0.671	0.856
Qatar	Petroleum	0.662	0.913
U.A.E.	Petroleum	0.586	0.639
Malawi	Tobacco	0.558	0.681
Mozambique	Aluminium	0.555	0.727
Cameroon	Petroleum	0.547	0.650
Kazakhstan	Petroleum	0.539	0.672
Ecuador	Petroleum	0.537	0.692
Russia	Petroleum	0.521	0.635
Laos	Copper (Smelted)	0.520	0.564
Jamaica	Alumina	0.501	0.624
Norway	Petroleum	0.458	0.643

Notes: Share of top and top-three commodities in total exports by country in 2007, showing the countries with the highest concentration of exports. Data shown for countries with a population larger than 1 million. Source: BACI data.

Fact 9: For many commodities, a few countries account for most of the world's supply... and demand. The converse of Fact 8 is that there are numerous commodities for which a limited number of producers make most of the world's supply. A common example is copper, for which Chile accounts for 37% of the world's primary ore production, making it the world's largest producer. However, many commodities are more geographically concentrated in terms of production than copper. This includes, for instance, many agricultural products (canary seeds, cassava, garlic, etc.) and mineral products (uranium, iodine, germanium, magnesium, etc). As seen in Appendix Table 6, for many commodities, one producer accounts for

Table 8: Products with the highest concentration of exports and imports from one country

Product	Largest Exporter	Export Share	Top 3 Share	Product	Largest Importer	Import Share	Top 3 Share
Canary seed	Canada	0.837	0.909	Cobalt (Mine)	China	0.628	0.879
Jute	Bangladesh	0.776	0.876	Forage products	Japan	0.603	0.833
Sorghum	USA	0.731	0.869	Cassava	China	0.597	0.799
Almonds	USA	0.706	0.825	Oats	USA	0.565	0.687
Linseed	Canada	0.671	0.794	Chromium	China	0.563	0.705
Uranium	S. African C.U.	0.667	0.994	Almonds	India	0.545	0.656
Oats	Canada	0.631	0.774	Germanium	Belarus	0.515	0.871
Cassava	Thailand	0.629	0.868	Fava beans	Egypt	0.487	0.612
Garlic	China	0.619	0.833	Linseed	Belgium	0.483	0.746
Antimony	China	0.611	0.773	Iridium	USA	0.468	0.803
Iodine	Chile	0.607	0.858	Legumes nec	India	0.463	0.625
Ginger	China	0.591	0.734	Avocados	USA	0.455	0.655
Mustard seeds	Canada	0.585	0.723	Mate	Uruguay	0.448	0.760
Forage products	USA	0.582	0.846	Flax	China	0.435	0.639
Bromine	Israel	0.581	0.815	Soy beans	China	0.434	0.562
Rare Earths	China	0.558	0.851	Rare Earths	Japan	0.425	0.680
Figs	Turkey	0.556	0.670	Buckwheat	Japan	0.422	0.573
Mandarins	Spain	0.555	0.697	Uranium	USA	0.422	0.811
Buckwheat	China	0.534	0.742	Papayas	USA	0.376	0.529
Germanium	Belgium	0.530	0.936	Asparagus	USA	0.371	0.558
Barytes	China	0.518	0.684	Vanilla	USA	0.360	0.657
Pineapples	Costa Rica	0.514	0.669	Berries	USA	0.359	0.665
Hops	Germany	0.514	0.719	Barytes	USA	0.340	0.459
Sillimanite	S. African C.U.	0.509	0.859	Cadmium	Belgium	0.331	0.684
Lentils	Canada	0.507	0.742	Roots	USA	0.330	0.632
Mate	Brazil	0.506	0.934	Ramie	China	0.328	0.506
Hazelnuts	USA	0.503	0.797	Silver	Mexico	0.327	0.594

Notes: Share of exports from largest exporter and share of imports from the largest importer for each HS6 product (or aggregated product), and showing the products with the highest concentration of exports or imports from the top three exporters and importers, respectively. Source: BACI data.

more than 50% of production. Overall, in 2012, 39.5% of the production of primary commodities in our sample came from countries responsible for the production of 50 percent or more of the world market. Similarly, the same table documents the Herfindal-Hirschman Index (HHI) for production of commodities across countries. We find that 81 commodities in our sample have HHI's above 0.25 in 2007, which indicates a high concentration of production from one country.

Notably, we also find a high degree of concentration in imports of many products, as shown in Table 8. The results here are intuitive, as the main importers of some of these commodities tend to be the largest manufacturers (China, US, Japan). However, the share of some of these countries in world imports tends to be larger than what can be purely explained by market size and final demand. An explanation is that many of these commodities represent inputs into the production process of downstream industries (supply chains), and that the largest importers are the countries with a comparative advantage in these downstream industries.

In some cases, these concentration patterns can be partially explained by spatial allocation of natural resources necessary to produce these commodities. Although known deposits of minerals and fuels can expand with additional effort, exploration costs, and new technology, fundamentally these resources are highly dispersed across countries. While this dispersion may seem limited to minerals and fuels, the land suitable for various agricultural commodities has a similar degree of dispersion across the world (see Appendix Figure 20 for plots of crop suitability for agricultural commodities with the highest worldwide total production value from 1970-2014). Even with high agricultural input levels, Global Agro-Ecological Zone (GAEZ) data from the FAO/IIASA (2010) suggest that many countries are naturally unsuitable for staple agricultural commodities that represent a large share of agricultural production. Although use of technology and labor, such as irrigation, allows production to occur outside of areas highly suitable for agricultural production of a given product, it can only be done at a low rate of substitution. Indeed, we find that production of agricultural commodities occurs largely within countries with land classified as suitable for agricultural production by the GAEZ data (see Appendix Figure 22 for plots of production of commodities by country for comparison). Similarly, Ramirez-Cabral et al. (2017) finds that a related measure of ecoclimatic conditions correlate highly with production regions of maize.

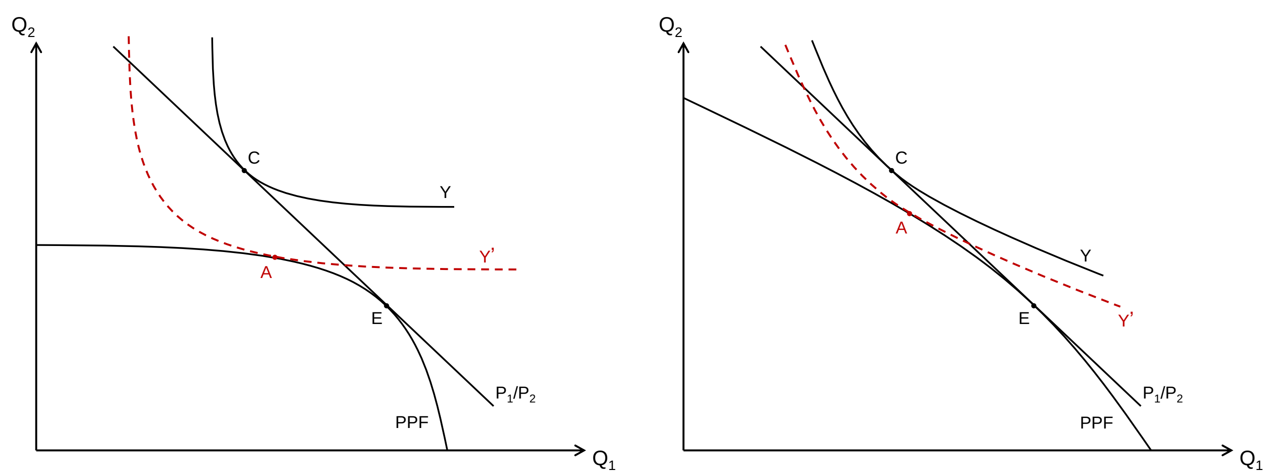
3 Theoretical framework

The model closely follows standard multi-sector models of trade (Costinot and Rodríguez-Clare, 2015, Caliendo and Parro, 2015) featuring gravity-type equations within each sector and inter-industry linkages. The main difference is that we emphasize the role of primary commodities and adapt the model to account for key features of primary commodity trade described in the previous section.

First, instead of assuming Cobb Douglas production functions, we allow for lower elasticities of substitution in production functions across different production stages in order to generate low demand and supply elasticities for commodities. Second, we introduce specific factors used to produce each commodities. This generates sources of income other than labor, contributes to lower supply elasticities, and rationalize high concentration of commodity supply among a few exporters.

We first present the general framework (Section 2.1). Then we introduce the "exact hat algebra" used to describe counterfactual equilibria and simulate the effect of a change in trade costs (Section 2.2). Next, we move on to describe the gains from trade relative to Autarky and examine special cases where we can provide closed-form solutions for the gains from trade (Section 2.3).

Figure 2: Elasticity of substitution, convexity and gains from trade



(a) Low elasticity of substitution (b) Low elasticity of substitution

3.1 Setting and equilibrium conditions

There are potentially many countries, indexed by n or i. There are two types of goods: final goods k (downstream industries) and commodities g (upstream industries). The production of final goods k relies on labor and primary commodities g. In turn, the production function of commodities is a CES combination between natural resources and labor. Production features constant returns to scale under perfect competition in all sectors of the economy. Both commodities g and final goods k can be traded.

Demand for final goods We assume that utility has constant elasticity of substitution across final goods k, with elasticity σ. Expenditure in final good k in destination n, denoted by D_{nk}, is:

$$D_{nk} = (P^F_{nk}/P^F_n)^{1-\sigma}\ a_{nk} E_n \tag{1}$$

where E_n refers to total expenditures in country n and where a_{nk} is a good-by-country-specific utility shifter. With CES, the overall consumer price index is defined as:

$$P^F_n = \left[\sum_k a_{nk}(P^F_{nk})^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \tag{2}$$

Note that, in turn, we could model each final good sector k as the aggregation of a continuum of product varieties with a CES sub-utility function involving an elasticity of substitution that may differ from σ. Following Eaton and Kortum (2002), Costinot et al. (2011), Caliendo and Parro (2015) among others, one could assume that the consumption bundle in industry k is a CES aggregate of a continuum of varieties $\omega_k \in (0,1)$ such that: $Q_{nk} = \left(\int_{\omega_k=0}^1 q(\omega_{nk})^{\frac{\xi_{nk}-1}{\xi_{nk}}} d\omega_k\right)^{\frac{\xi_{nk}}{\xi_{nk}-1}}$ with elasticities ξ_k. Such elasticities ξ_{nk} may be allowed to differ across countries n and sectors k, but they would play no role here and would not alter the counterfactuals equilibrium conditions described in the next sections. On the contrary, the elasticity of substitution σ across broad types of goods can potentially play an important role.

Trade in final goods k As common in the trade literature, we assume iceberg transport costs $d_{nik} \geq 1$ from country i to country n in sector k. We denote by C^F_{ik} the cost of producing goods k in country i, such that the cost of supplying these goods in destination n is given by $d_{nik}C^F_{ik}$ once we adjust for trade costs.

We then assume that trade follows the typical "gravity" equation within each sector. In brief, we assume that trade in final goods k, from i to n is given by:

$$X^F_{nik} = \frac{(C^F_{ik} d_{nik})^{-\theta_k}}{\sum_j (C^F_{jk} d_{njk})^{-\theta_k}}\ D_{nk} \tag{3}$$

where θ_k denotes the elasticity of trade to trade costs. In this framework, the price index of goods k in destination country n is then a CES function of the cost of producing these goods across source countries i:

$$P^F_{nk} = \left[\sum_i (C^F_{ik} d_{nik})^{-\theta_k}\right]^{-\frac{1}{\theta_k}} \tag{4}$$

Such outcomes for trade flows and price indexes ("gravity equations") can be micro-founded and obtained under various alternative sets of assumptions: i) under perfect competition and perfect substitution with a continuum of varieties (Eaton and Kortum (2002) and related literature), ii) under perfect competition and imperfect substitution across source countries (Anderson, 1979) as in the CGE literature; iii) under imperfect competition with homogeneous productivity (Krugman, 1980) or heterogeneous productivity (Chaney, 2008)).

For instance, following Eaton and Kortum (2002), Costinot et al. (2011), Caliendo and Parro (2015), one could assume that there is a continuum of varieties ω_k with random productivity draw $Z_{ik}(\omega_k)$ and perfect competition such that the price would equal:

$$p_{nk}(\omega_k) = \min_i \left\{ \frac{d_{nik} C^F_{ik}}{Z_{ik}(j_k)} \right\}$$

in each destination country n, after taking the minimum across the costs of production and shipment across source countries i. If we further assume that productivity $Z_{ik}(\omega_k)$ is drawn independently across countries i and sectors k from a Frechet distribution: $F_{ik}(z) = \exp\left[-(z/z_{ik})^{-\theta_k}\right]$, we obtain exactly the same equilibrium conditions as those described above and the same counterfactual conditions as in the following sections.

Multi-sector extensions of Anderson (1979), Krugman (1980) and Chaney (2008) would also provide frameworks that would yield the same equilibrium conditions as those described above, i.e. lead to gravity equations within sectors, with price indexes satisfying (4). See Arkolakis et al. (2012), Costinot and Rodríguez-Clare (2015) and Anderson (2011) for discussion of the equivalence between these models.

Production of final goods k For each good k, we assume constant elasticity production functions with constant returns to scale and elasticity of substitution η_k between inputs. As discussed previously, we assume that sector k relies on labor and a set of commodities $g \in G(k)$. Thus, denoting labor wages by w_i and the price of commodity g by P^C_{ig}, the cost of producing final good k in producing country i can be written as:

$$C^F_{ik} = A^F_{ik} \left[\beta^F_{ik,L} w_i^{1-\eta_k} + \sum_g \beta^F_{ik,g} (P^C_{ig})^{1-\eta_k} \right]^{\frac{1}{1-\eta_k}} \quad (5)$$

This cost function allows for productivity terms A^F_{ik} as well as factor requirements $\beta^F_{ik,L}$ (for labor) and $\beta^F_{ik,g}$ (for commodity g) that may vary across sectors k and countries i to reflect differences in technology.

Under these assumptions, Shephard's Lemma yields the following expenditures (demand) in commodity g in destination i by industry k:

$$D_{igk} = \beta^F_{ik,g}(P^C_{ig}/C^F_{ik})^{1-\eta_k}\; Y^F_{ik} \tag{6}$$

where $Y^F_{ik} = \sum_n X^F_{nik}$ denotes production value of good k in i. We obtain total demand D_{ig} for commodity g by summing across downstream industries: $D_{ig} = \sum_k D_{igk}$.

Assuming that a given commodity g corresponds to a small share of total costs of downstream industries k, and holding Y_{ik} and wages w_i constant, the price elasticity of demand in commodity g is approximately given by η_k:

$$\frac{\partial \log(D_{igk}/P^C_{ig})}{\partial \log P^C_{ig}} \approx -\eta_k$$

We will subsequently use this property to calibrate η_k and account for the low demand elasticities facing most primary commodities (see Section 3).

Trade in commodities g For primary commodities, we adopt the same assumptions for trade as for final goods k, although we allow trade costs d_{nig} and trade elasticities θ_g to differ from those associated with final goods k. We assume that trade for commodity g from i to n is given by:

$$X^C_{nig} = \frac{(C^C_{ig} d_{nig})^{-\theta_g}}{\sum_j (C^C_{jg} d_{njg})^{-\theta_g}}\; D_{ng} \tag{7}$$

while the price index of commodity g in destination n:

$$P^C_{ng} = \left[\sum_i (C^C_{ig} d_{nig})^{-\theta_g}\right]^{-\frac{1}{\theta_g}} \tag{8}$$

where C^C_{ig} denotes the cost of producing commodity g in source country i.

Production of commodities g In turn, the cost of producing commodities is again a CES function of factor prices. We assume that the production of a commodity g in country i uses two inputs: labor and natural resources that are specific to commodity g, such as minerals or oil reserves, with an elasticity of substitution ρ_g between them.[16] If we denote by r_{ig} the price

[16]Although mineral resources are certainly in finite supply, extracting costs increase with the required supply of the commodity. Here the convexity in costs is generated by the use of another input that is mobile (here labor), which has to increase in order to produce larger amounts of a commodity. Here we refer to that common input as labor, but one could think of that common input as additional machines and technologies required to extract larger amounts from natural resources.

of natural resources for commodity g, the cost of producing commodity g is:

$$C_{ig}^C = A_{ig}^C \left[\beta_{ig}^C r_{ig}^{1-\rho_g} + (1-\beta_{ig}^C) w_i^{1-\rho_g} \right]^{\frac{1}{1-\rho_g}} \tag{9}$$

Two features of this cost equation can influence the supply elasticity of commodity g: i) assuming that the supply of natural resources is fixed, a higher share of natural resources in total costs leads to a lower elasticity of supply; ii) a lower elasticity of substitution ρ_g between labor and natural resources also lead to a lower elasticity of supply. Holding wages and natural resources fixed, the price elasticity of supply is:

$$\frac{\partial \log(Y_{ig}^C / C_{ig}^C)}{\partial \log C_{ig}^C} = \frac{\rho_g \, \varphi_{ig,L}}{\varphi_{ig,R}} \tag{10}$$

where $\varphi_{ig,R}$ and $\varphi_{ig,L} = 1 - \varphi_{ig,R}$ denote the share of natural resources and labor in the total production cost of commodity g.

Sources of income Since there are two types of factors of production, labor (mobile across industries) and natural resources (specific to each commodity), there are also two types of income sources.

Income from natural resources associated with commodity g is $R_{ig} r_{ig}$, where R_{ig} is the (fixed) endowment in natural resources. In equilibrium, it equals the value of production of commodity g in country i multiplied by the share of natural resources in the production costs of this commodity:

$$R_{ig} r_{ig} = \beta_{ig}^C (r_{ig}/C_{ig}^C)^{1-\rho_g} \; Y_{ig}^C \tag{11}$$

where $Y_{ig}^C = \sum_n X_{nig}^C$ denotes the production of commodity g in country i.

In turn, income from labor in country i stems from all sectors of the economy: final goods sectors k and commodity sectors g. We denote by L_i the mass of workers in country i, assumed to be fixed. In equilibrium, income from labor is determined by:

$$L_i w_i = \sum_g (1-\beta_{ig}^C)(w_i/C_{ig}^C)^{1-\rho_g} \; Y_{ig}^C \quad + \quad \sum_k \beta_{ik,L}^F (w_i/C_{ik}^F)^{1-\eta_k} \; Y_{ik}^F \tag{12}$$

where $Y_{ik}^F \equiv \sum_n X_{nik}^F$ and $Y_{ig}^C \equiv \sum_n X_{nig}^C$ denote the production of final good k and commodity g respectively.

Finally, we obtain total income (also total GDP) by summing income across all sources:

$$E_n = w_n L_n + \sum_g r_{ng} V_{ng} \tag{13}$$

For now, we assume away any trade deficit on aggregate, hence income equals total expenditures.

Equilibrium An equilibrium is defined as the solution in (D_{nk}, P_n^F, X_{nik}^F, P_{nk}^F, C_{nk}^F, D_{ng}, X_{nig}^C, P_{ng}^C, C_{ng}^C, r_{ng}, w_n, E_n) satisfying equations (1) to (13).

3.2 Counterfactual equilibria

3.2.1 Exact hat algebra

Assuming that the world economy is in equilibrium, we are primarily interested in how a change in trade costs and other key parameters will affect the the equilibrium and how it will affect welfare across countries, i.e. the ratio of income to final goods prices $\frac{E_n}{P_n^F}$.

Following Dekle et al. (2008) and Caliendo and Parro (2015) among others, the model lends itself naturally to counterfactual simulations in general equilibrium. By rewriting the above equilibrium conditions in terms of changes relative to the baseline observed equilibrium, the problem can be formulated as a function of a set of observed variables and only a few parameters to estimate. We do so with the help of "exact hat" notation, where $\widehat{Z} = Z'/Z$ denotes the relative change for variable Z (Z' referring to the value in the new equilibrium).[17]

Counterfactual equilibrium The change in equilibrium outcomes ($\widehat{D}_{nk}$, $\widehat{P^F}_n$, $\widehat{X^F}_{nik}$, $\widehat{P^F}_{nk}$, $\widehat{C^F}_{nk}$, $\widehat{D}_{ng}$, $\widehat{X^C}_{nig}$, $\widehat{P^C}_{ng}$, $\widehat{C^C}_{ng}$, $\widehat{r}_{ng}$, $\widehat{w}_n$, $\widehat{E}_n$) is the solution to the following set of equations:

$$\widehat{E}_i = e_{iL}\hat{w}_i + \sum_g e_{ig,R}\hat{r}_{ig} \tag{14}$$

$$\widehat{P_n^F} = \left[\sum_k \alpha_{nk}\widehat{P_{nk}^F}^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \tag{15}$$

$$\widehat{P_{nk}^F} = \left[\sum_i \lambda_{nik}^F(\widehat{C^F}_{ik}\widehat{d_{nik}})^{-\theta_k}\right]^{-\frac{1}{\theta_k}} \tag{16}$$

$$\widehat{P_{ng}^C} = \left[\sum_i \lambda_{nig}^C(\widehat{C^C}_{ig}\widehat{d_{nig}})^{-\theta_g}\right]^{-\frac{1}{\theta_g}} \tag{17}$$

$$\widehat{D_{nk}} = \left(\frac{\widehat{P_{nk}^F}}{\widehat{P_k^F}}\right)^{1-\sigma}\widehat{E_n} \tag{18}$$

[17] Note also that these equations are "exact" in the sense that the changes are not approximated, as opposed to the hat notation used in the business cycle literature to describe first-order approximations of log changes.

$$\widehat{D_{ng}} = \sum_k d_{nkg} \left(\frac{\widehat{P^C_{ng}}}{\widehat{C^F_{nk}}} \right)^{1-\eta_k} \widehat{Y^F_{nk}} \tag{19}$$

$$\widehat{Y^F}_{ik} = \sum_n \pi^F_{nik} (\widehat{C^F}_{ik} \widehat{d_{nik}})^{-\theta_k} (\widehat{P^F}_{nk})^{\theta_k} \widehat{D_{nk}} \tag{20}$$

$$\widehat{Y^C}_{ig} = \sum_n \pi^C_{nig} (\widehat{C^C}_{ig} \widehat{d_{nig}})^{-\theta_g} (\widehat{P^C}_{ng})^{\theta_g} \widehat{D_{ng}} \tag{21}$$

$$\widehat{C^F_{ik}} = \left[\varphi_{ik,L} \hat{w}_i^{1-\eta_k} + \sum_g \varphi_{ik,g} (\widehat{P^C_{ig}})^{1-\eta_k} \right]^{\frac{1}{1-\eta_k}} \tag{22}$$

$$\widehat{C^C_{ig}} = \left[\varphi_{ig,R} \hat{r}_{ig}^{1-\rho_g} + \varphi_{ig,L} \hat{w}_i^{1-\rho_g} \right]^{\frac{1}{1-\rho_g}} \tag{23}$$

$$\hat{r}_{ig} = (\hat{r}_{ig} / \widehat{C^C_{ig}})^{1-\rho_g} \widehat{Y^C_{ig}} \tag{24}$$

$$\hat{w}_i = \sum_g s^L_{ig} (\hat{w}_i / \widehat{C^C_{ig}})^{1-\rho_g} \widehat{Y^C_{ig}} + \sum_k s^L_{ik} (\hat{w}_i / \widehat{C^F_{ik}})^{1-\eta_g} \widehat{Y^F_{ik}} \tag{25}$$

These equations are formulated in terms of the key elasticities of the model: σ, η_k, ρ_g, θ_k and θ_g, as well as observable outcomes (shares) that describe the initial equilibrium.

- The share of labor and resources in g in total income in the baseline equilibrium:

$$e_{nL} = \frac{w_n L_n}{E_n} \qquad \text{and} \qquad e_{ng} = \frac{r_{ng} V_{ng}}{E_n}.$$

- The expenditure share of good k in the baseline equilibrium:

$$\alpha_{nk} = a_{nk} \left(\frac{P^F_{nk}}{P^F_n} \right)^{1-\sigma}.$$

- The share of industry k in total demand for commodity g in each country i:

$$d_{ikg} = \frac{D_{nkg}}{D_{ng}} = \frac{D_{nkg}}{\sum_{k'} D_{nk'g}}$$

- Import shares, i.e. the share of goods from source country i in the consumption of good g in country n (with $n = i$ for domestic flows):

$$\lambda^F_{nik} = \frac{X^F_{nik}}{D_{nk}} = \frac{(C^F_{ik} d_{nik})^{-\theta_k}}{{P^F_{nk}}^{-\theta_k}} \qquad \text{and} \qquad \lambda^C_{nig} = \frac{X^C_{nig}}{D_{ng}} = \frac{(C^C_{ig} d_{nig})^{-\theta_g}}{{P^C_{ng}}^{-\theta_g}}.$$

- Export shares, i.e. the share of goods g produced in country i that are exported to country

n (with $n = i$ for domestic flows):

$$\pi^F_{nik} = \frac{X^F_{nik}}{Y^F_{ik}} \qquad \text{and} \qquad \pi^C_{nig} = \frac{X^C_{nig}}{Y^C_{ig}}.$$

- The share of labor and commodity g in manufacturing costs:

$$\varphi^F_{ik,L} = \frac{{A^F_{ik}}^{1-\eta_k} \beta^F_{ik,L} w_i^{1-\eta_k}}{{C^F_{ik}}^{1-\eta_k}} \qquad \text{and} \qquad \varphi^F_{ik,g} = \frac{{A^F_{ik}}^{1-\eta_k} \beta^F_{ik,g} (P^C_{ig})^{1-\eta_k}}{{C^F_{ik}}^{1-\eta_k}}.$$

- The share of labor and resources in the production costs of commodity g: $\varphi_{ig,R}$ and $\varphi_{ig,L}$.

- The share of labor in the production of final goods k and commodity g: s^L_{ik} and s^L_{ig}.

These shares can be directly observed in the data and they are easier to calibrate than the model primitives that enter equilibrium equations (1) to (13). Note that we can ignore one of the equilibrium conditions above for a reference country (Walras Law) and make one normalization if the above shares are consistent with equilibrium (see Appendix).

3.2.2 Gains from trade

One can further link the gains from trade to changes in key equilibrium outcomes. With constant elasticities of substitution, one can relate the change in prices to the cost of a specific input or good, adjusting for the change in the share of that input or good. This can be applied to price indexes (Feenstra, 1994), gains from trade (Arkolakis et al., 2012), production costs (Blaum et al., 2015), or other features. In our framework, this insight can be applied to several equilibrium outcomes. For the gains from trade in a particular industry k or commodity g (as in Arkolakis et al. (2012)), we have:

$$\widehat{P^F_{ik}} = \widehat{\lambda^F_{iik}}^{-\frac{1}{\theta_k}} \widehat{C^F_{ik}} \qquad ; \qquad \widehat{P^C_{ig}} = \widehat{\lambda^C_{iig}}^{-\frac{1}{\theta_g}} \widehat{C^C_{ig}} \tag{26}$$

where λ^F_{iik} and λ^C_{iik} denotes the share of domestic production in demand in country i for good k and commodity g respecitvely. Applying the same tools to the share of inputs in production functions, we link the change in total costs to the share of labor, commodities or natural resources and their unit costs:

$$\widehat{C^F_{ik}} = \widehat{\varphi_{ik,L}}^{-\frac{1}{1-\eta_k}} \hat{w}_i \qquad \widehat{C^F_{ik}} = \widehat{\varphi_{ik,g}}^{-\frac{1}{1-\eta_k}} \widehat{P^C_{ig}} \qquad ; \qquad \widehat{C^C_{ig}} = \widehat{\varphi_{ig,R}}^{-\frac{1}{1-\eta_k}} \widehat{r_{ig}} \tag{27}$$

Finally, applying the same trick to final goods shares, we have:

$$\widehat{P^F_i} = \widehat{\alpha_{ik}}^{-\frac{1}{1-\sigma}} \widehat{P^F_{ik}} \tag{28}$$

Hence, combining the first two equations, the gains from trade for workers are given by:

$$GT_i^L = \widehat{P_i^F} = \left[\sum_k \alpha_{ik} \widehat{P_{ik}^F}^{1-\sigma}\right]^{\frac{1}{1-\sigma}} = \left[\sum_k \alpha_{ik} \widehat{\lambda_{iik}^F}^{-\frac{1-\sigma}{\theta_k}} \widehat{\varphi_{ik,L}}^{-\frac{1-\sigma}{1-\eta_k}}\right]^{\frac{1}{1-\sigma}} \tag{29}$$

As a first-order approximation, the upper-level elasticity σ does not play an important role. However, this expression suggests that elasticities of substitution η_k can greatly influence the gains from trade in commodities, with larger gains from trade when η_k is smaller, conditional on the change in a commodity cost share.

For factors g, we can link welfare gains from trade to the change in the consumption share $\widehat{\alpha_{ik}}$ of downstream good k (assuming that downstream industry k has a positive demand for commodity g) and the change in input shares of commodity g and resources g. Using the tools described above, we obtain the gains from trade for owners of natural resources associated with commodity g:

$$GT_{ig}^R = \frac{\widehat{P_i^F}}{\widehat{r_{ig}}} = \widehat{\alpha_{ik}}^{-\frac{1}{1-\sigma}} \widehat{\lambda_{iik}^F}^{-\frac{1}{\theta_k}} \widehat{\varphi_{ik,g}}^{-\frac{1}{1-\eta_k}} \widehat{\lambda_{iig}^C}^{-\frac{1}{\theta_g}} \widehat{\varphi_{ig,R}}^{-\frac{1}{1-\rho_g}} \tag{30}$$

We can also note that, relative to labor, the change in revenues for natural resources g is:

$$\widehat{r_{ig}} = (\widehat{\varphi_{ik,g}}/\widehat{\varphi_{ik,L}})^{\frac{1}{1-\eta_k}} \widehat{\lambda_{iig}^C}^{\frac{1}{\theta_g}} \widehat{\varphi_{ig,R}}^{\frac{1}{1-\rho_g}} \tag{31}$$

Both these expressions highlight the role of η_k and ρ_g, which can both magnify the gains from trade. In addition, as we will describe in our calibration, lower η_k and ρ_g also lead to larger changes in input shares $\widehat{\varphi_{ik,L}}$, $\widehat{\varphi_{ik,g}}$ and $\widehat{\varphi_{ig,R}}$.

Finally, since $\widehat{E_i} = e_{iL} + \sum_g e_{ig}\widehat{r_{ig}}$, aggregate gains can be computed by taking the harmonic average of the previous two expressions:

$$1/GT_i = e_{iL}/GT_i^L + \sum_g e_{ig}/GT_{ig}^R$$

3.3 Comparison to Autarky

Of particular interest are the gains from trade relative to complete Autarky. Since Autarky involves large changes, we focus on the "exact hat algebra" without approximations. Moreover, we can obtain analytical expressions for the gains from trade in some special cases that we discuss below.

Some of the above equations describing the changes from baseline equilibrium to Autarky can be simplified in this case. Trade costs are now such that $\widehat{d_{nik}} = +\infty$ and $\widehat{d_{nig}} = +\infty$ whenever $n \neq i$. Moreover, production has to equal demand in Autarky for each good k and commodity g. Hence, we have equalities $D_{nk}\widehat{D_{nk}} = Y_{nk}\widehat{Y_{nk}}$ and $D_{ng}\widehat{D_{ng}} = Y_{ng}\widehat{Y_{ng}}$ which we can use to combine equations in demand and production. Equations (16) to (21) can then be replaced by the following set of equations:

$$\widehat{P^F_{nk}} = (\lambda^F_{nnk})^{-\frac{1}{\theta_k}}\widehat{C^F_{nk}} \tag{32}$$

$$\widehat{P^C_{ng}} = (\lambda^C_{nng})^{-\frac{1}{\theta_g}}\widehat{C^C_{ng}} \tag{33}$$

$$\widehat{Y_{nk}} = \left(\frac{\widehat{P^F_{nk}}}{\widehat{P^F_k}}\right)^{1-\sigma}\widehat{E_n}\,\frac{D_{nk}}{Y_{nk}} \tag{34}$$

$$\widehat{Y_{ng}} = \frac{D_{ng}}{Y_{ng}}\sum_k d_{nkg}\widehat{Y^F_{nk}}\left(\frac{\widehat{P^C_{ng}}}{\widehat{C^F_{nk}}}\right)^{1-\eta_k} \tag{35}$$

while other equations (14), (15) and (22) to (25) remain the same.

Closed-form solutions when demand and supply elasticities are equal

First, when supply and demand elasticities are equal, $\rho_g = \eta_k \equiv \eta$, one can express the change in revenues from natural resources as a function of the change in production and costs in downstream industries:

$$\hat{r}_{ig} = \left(\lambda_{ig}^{-\frac{1-\eta}{\theta_g}}\,\frac{D^C_{ig}}{Y^C_{ig}}\,\sum_k d_{nkg}\frac{\widehat{Y^F_{ik}}}{\widehat{C^F_{ik}}^{1-\eta}}\right)^{\frac{1}{\eta}} \tag{36}$$

and thus the change in income, using equation (14). In this expression, one can see that Autarky leads to larger income r_{ig} if initial demand exceeds production and if the product is purchased by downstream industries with the highest cost increases C^F_{ik} by switching to Autarky. The change in revenues is also magnified when the elasticity η is smaller (as it is the case with most commodities, see Fact 2).

Using equation (23), $\widehat{C^C_{ig}}^{1-\eta} = \varphi_{ig,L} + \varphi_{ig,R}\hat{r}_{ig}^{1-\eta}$, we can then also obtain production costs for commodity g and downstream industry k:

$$\widehat{C^F_{ik}}^{1-\eta} = \varphi_{ik,L} + \sum_g \varphi_{ik,g}\varphi_{ig,L}\lambda_{ig}^{-\frac{1-\eta}{\theta_g}} + \frac{E_i\widehat{C^F_{ik}}^{1-\eta}}{Y^F_{ik}\widehat{Y^F_{ik}}}\sum_g e_{ig}\left(\lambda_{ig}^{-\frac{1-\eta}{\theta_g}}\,\frac{D^C_{ig}}{Y^C_{ig}}\,\sum_k d_{nkg}\frac{\widehat{Y^F_{ik}}}{\widehat{C^F_{ik}}^{1-\eta}}\right)^{\frac{1}{\eta}} \tag{37}$$

This greatly reduces the dimensionality of the problem (to countries and industries k) and reduces the number of equations and unknowns. Together with the equation above, equations

(32), (34), (14) and (15) are sufficient to characterize the counterfactual equilibrium.

Closed-form solutions for the gains from trade We obtain a model with analytical solutions for the gains from trade if, in addition to the equality between supply and demand elasticities in commodity markets, we also assume that these elasticities are equal to the consumption elasticity of substitution between broad groups of final goods k, i.e. assuming $\rho_g = \eta_k = \sigma$ across all industries k and commodities g. The main source of tractability in this special case is that the changes in price indexes due to the changes in natural resources revenues $\hat{r}_{ig}$ are proportional to e_{iL}, the share of revenues in total income.[18]

Using this property, we obtain that the change in income for resources g is given by:

$$\hat{r}_{ig} = \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \Lambda_i^{\sigma-1} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k \frac{d_{nkg} D_{ik}^F}{Y_{ik}^F} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}} \right)^{\frac{1}{\sigma}} \tag{38}$$

where Λ_i is defined as:

$$\Lambda_i^{1-\sigma} \equiv \frac{1}{e_{iL}} \sum_k \alpha_k \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}} \left[\varphi_{ik,L} + \sum_g \varphi_{ik,g} \varphi_{ig,L} \lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \right] \tag{39}$$

This expression highlights the role of relative supply and demand for commodity g in the initial equilibrium, as well as commodity-industry linkages and the relative supply and demand in downstream industries k. Again, these changes are magnified when elasticity σ is small.

We can also obtain analytical expressions for the changes in price indexes and overall GDP, as well as the aggregate gains from trade.

Proposition 1 *Relative to Autarky, the aggregate gains from trade are:*

$$GT_i = \left[e_{iL} \Lambda_i^{\frac{1-\sigma}{\sigma}} + \sum_g e_{ig,R} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k \frac{d_{nkg} D_{ik}^F}{Y_{ik}^F} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}} \right)^{\frac{1}{\sigma}} \right]^{\frac{\sigma}{1-\sigma}} \tag{40}$$

if we assume that $\rho_g = \eta_k = \sigma$, where Λ_i is defined as above (equation 39).

In this expression, Λ_i corresponds to the gains from trade if labor is the only input in the production of primary commodities (no natural resources). The absence of a role for natural resources greatly reduces the gains from trade since the production of a required commodity is no longer tied to a country's endowment in natural resources. In general, we obtain that the

[18] Thanks to this property, we also obtain: $\frac{\widehat{E_i}}{\widehat{P_i^F}^{1-\sigma}} = \frac{1}{\Lambda_i^{1-\sigma}}$. See Appendix for details.

gains from trade are larger than without natural resources, as we will illustrate quantitatively in our counterfactual simulations.

We can further compute the gains from trade for workers and for natural resource owners separately. For workers, whose wages are normalized ($\widehat{w}_i = 1$), the gains from trade are given by how much the price index would increase in Autarky relative to the baseline equilibrium:

$$\widehat{P^F}_i \;=\; \Lambda_i \left[e_{iL} + \sum_g e_{ig,R} \hat{r}_{ig} \right]^{\frac{1}{1-\sigma}} \tag{41}$$

while the gains from trade for natural resource owners are given by $\left(\frac{\hat{r}_{ig}}{\widehat{P^F}_i}\right)^{-1}$, using the solutions above for $\widehat{P^F}_i$ and $\hat{r}_{ig}$ (equation 38) for commodity g.

An interesting and practical special case is to assume that is there only one downstream industry, $k = M$ (manufacturing industry). In that case, the formula describing the gains from trade simplifies to:

$$GT_i \;=\; \lambda_{iM}^{-\frac{1}{\theta_M}} \left[e_{iL} \left(\frac{\varphi_{iM,L} + \sum_g \varphi_{iM,g} \varphi_{ig,L} \lambda_{ig}^{-\frac{1-\sigma}{\theta_g}}}{e_{iL}} \right)^{\frac{1}{\sigma}} + \sum_g e_{ig,R} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{E_i}{Y_i^F} \frac{D_{ig}^C}{Y_{ig}^C} \right)^{\frac{1}{\sigma}} \right]^{\frac{\sigma}{1-\sigma}} \tag{42}$$

This case is easier to calibrate as it requires less information on input-output links between upstream and downstream industries. But this case also understate the gains from trade. Suppose that a specific commodity g (e.g. copper) is used primarily in a downstream industry k (e.g. copper wires and circuitry) and that goods from downstream industries k are mainly imported by country i. Switching to Autarky will increase the demand for copper which may be difficult to meet if the country does not have copper mines. Proposition 1 accounts for such linkages. However, if we assume that there is only one manufacturing industry downstream, we would miss the demand for copper embodied in electronic goods and would mistakenly infer that this country would also have a low demand for copper in Autarky.

3.4 Two alternative specifications

3.4.1 Choke prices

A critical aspect of production functions with a constant elasticity of substitution that remains below unity is that the cost goes to infinity as the price of a single commodity goes to infinity. Hence, the losses of going to Autarky are infinite for any country that cannot produce a specific commodity but has a positive demand for it, in which case the price of that commodity goes to infinity.

One may argue, however, that technology or sufficient effort might provide a substitute for a commodity at a finite cost. To allow for such a possibility, and to allow for a higher elasticity of substitution when a specific commodity becomes too expensive, we consider an alternative production function for downstream industries that leads to a choke price in each commodity, i.e. a finite price level above which demand for that commodity is null. Specifically, we consider a the following production function:

$$C_{ik} = \left[\beta^F_{ik,L} w_i^{1-\eta_k} + \sum_g \beta^F_{ik,g} \left(P_{ig}^{1-\eta_k} - (1-\eta_k) P_{ig} (a_{ig} w_i)^{-\eta_k}\right)\right]^{\frac{1}{1-\eta_k}} \tag{43}$$

for as long as $\frac{\partial C_{ik}}{\partial P_{ig}} \geq 0$, i.e. as long as $P_{ig} \leq a_{ig} w_i$, where a_{ig} is a constant term. This leads to a demand curve for each commodity that is a leftward translation of the standard CES demand curve

$$\frac{D_{igk}}{P_{ig}} = \max\left\{0, \beta^F_{ik,g}\left(P_{ig}^{-\eta_k} - (a_{ig} w_i)^{-\eta_k}\right) \cdot \frac{Y^F_{ik}}{C_{ik}^{1-\eta_k}}\right\} \tag{44}$$

with a choke price $P^*_{ig} = a_{ig} w_i$. The elasticity of the share of commodity g in manufacturing costs with respect to the price of commodity g here is given by

$$\frac{\partial \log \varphi_{ik,g}}{\partial \log P_{ig}} - 1 \;=\; -\frac{\eta_k}{1 - \Delta_{ig}}$$

where we define Δ_{ig} as the relative gap to the choke price: $\Delta_{ig} = (a_{ig} w_i / P_{ig})^{-\eta_k} \leq 1$.

We then express the counterfactual changes in costs and demand for commodities as a function the relative gap Δ_{ig}:

$$\widehat{D_{ngk}} \;=\; \left(\frac{1 - \Delta_{ig} (\widehat{P_{ng}} / \widehat{w}_i)^{\eta_k}}{1 - \Delta_{ig}}\right) \frac{\widehat{P_{ng}}^{1-\eta_k} \; \widehat{Y_{nk}}}{\widehat{C_{nk}}^{1-\eta_k}} \tag{45}$$

$$\widehat{C^F_{ik}}^{1-\eta_k} = \varphi_{ik,L} \hat{w}_i^{1-\eta_k} + \sum_g \varphi_{ik,g} \widehat{P_{ig}}^{1-\eta_k} + \sum_g \frac{\varphi_{ik,g} \Delta_{ig}}{1 - \Delta_{ig}} \left[\widehat{P_{ig}}^{1-\eta_k} - \eta_k \hat{w}_i^{1-\eta_k} - (1-\eta_k) \widehat{P_{ig}} \hat{w}_i^{-\eta_k}\right] \tag{46}$$

where the CES case can be seen as the limit case where $\Delta_{ig} = 0$. The higher is Δ_{ig}, the lower the potential loss from trade as prices are close to their upper limit.

3.4.2 Land allocation

In our baseline model, each commodity relies on a specific natural resource. Instead, one could argue that natural resources, such as land, can be used to produce any commodity, with varying productivities.

To do so, we assume a production function in one input (land) with a constant elasticity of transformation between outputs. This generates a productivity possibility frontier (PPF) that is sufficiently concave, which reflects the low elasticity of supply for commodities. This specification is equivalent to other studies in the trade literature modeling land allocation (Costinot et al., 2016) and labor allocation (Galle et al., 2017) across crops, tasks, or industries. A constant elasticity of transformation PPF as here is isomorphic to production with heterogeneous inputs (heterogeneous land parcels or heterogeneous workers) whose productivity for each type of output (crop or industry) is drawn independently from a Frechet distribution for which the distribution parameter is identical across crops or industries.

Specifically, we assume that land can be used to produce any commodity g with productivity A_{ig} such that the following constraint holds:

$$\sum_g (Q_{ig}/A_{ig})^{\frac{1+\rho}{\rho}} = T_i^{\frac{1+\rho}{\rho}}. \tag{47}$$

For a given set of prices, maximizing the overall value of production leads to the following production value for commodity g:

$$Y_{ig} \ = \ A_{ig}^{1+\rho} C_{ig}^{1+\rho} T_i \Phi_i^{-\rho} \ = \ \pi_{ig}^T T_i \Phi_i$$

where $\Phi_i = \left(\sum_g A_{ig}^{1+\rho} C_{ig}^{1+\rho}\right)^{\frac{1}{1+\rho}}$ corresponds to the value of a parcel of land (i.e. corresponds to a commodity producer price index) and where

$$\pi_{ig}^T = \frac{A_{ig}^{1+\rho} C_{ig}^{1+\rho}}{\sum_{g'} A_{ig'}^{1+\rho} C_{ig'}^{1+\rho}}$$

is both the share of land T_i devoted to the production of commodity g and the share of land income associated with commodity g. Total income from land is then given by $\sum_g Y_{ig} = T_i \Phi_i$.

With this specification, if we assume that each commodity accounts for a relatively small share of total land use, the supply elasticity of supply is simply equal to the elasticity of transformation ρ.

Comparing the baseline to a new counterfactual equilibrium, we find that the changes in production, costs and income are given by:

$$\widehat{Y_{ig}} \ = \ \widehat{C_{ig}}^{1+\rho} \widehat{\Phi}_i^{-\rho} \tag{48}$$

$$\widehat{\Phi}_i^{1+\rho} \ = \ \sum_g \pi_{ig}^T \widehat{C_{ig}}^{1+\rho} \tag{49}$$

$$\widehat{\Phi}_i = \sum_g \pi_{ig}^T \widehat{Y_{ig}} \tag{50}$$

As with the baseline case, it is possible to obtain a closed-form solution for the gains from trade when the elasticity of substitution between commodities (in the CES production function of final goods) is equal to the elasticity of substitution between final goods in preferences:

$$GT_i = \left\{ e_{i,L}\Lambda_i^{\frac{1-\sigma}{\sigma}} + e_{i,R} \left[\sum_g \pi_{ig}^T \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k d_{nkg} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}} \frac{D_{ik}^F}{Y_{ik}^F} \right)^{\frac{1+\rho}{\rho+\sigma}} \right]^{\frac{\rho+\sigma}{\sigma(1+\rho)}} \right\}^{\frac{\sigma}{1-\sigma}}$$

where Λ_i is defined by (39) as in the baseline specification. This expression is very close to equation (40) for the baseline model when the exponent $\frac{\rho+\sigma}{\sigma(1+\rho)}$ is close to unity (see Appendix for details).

4 Calibration of the model

In this section, we describe how our data can be used to calibrate the model in order to compute the gains from trade.

Commodity production and trade. We use our production and trade data at the commodity level[19] to directly calibrate production Y_{ig}, demand D_{ig}, import shares λ_{nig}, and export shares π_{nig}. One potential concern, though, is that trade and production data at this level of granularity may be somewhat noisy and subject to measurement error. In a robustness check, we use fitted trade shares instead of observed shares; estimating this with PPML. Note that with PPML, output and expenditure values do not change, since fitted output and expenditures are both equal to observed outcomes when information on output or expenditures is available (Fally, 2015).

Downstream industries. We then combine with data on secondary industries across broad sectors: production Y_{ik}, demand D_{ik}, trade shares λ_{nik} and π_{nik}, expenditure shares α_{nk} as well as end use shares, i.e. the share of commodity g output used in manufacturing industry k. Here, we compare two strategies to construct commodity-industry linkages:

Focusing on year 2007, we use GTAP data to obtain harmonized cross-country production and consumption data across 29 downstream manufacturing sectors. We also use GTAP data to

[19] Each commodity g generally corresponds to a 4-digit or 6-digit HS (harmonized system) category, with a few exceptions; see appendix for more details on the level of product aggregation.

provide commodity uses by downstream industries for all agricultural industries in our sample (when GTAP commodity sectors are more aggregated we associate downstream industries on a proportional basis). For minerals, we use data from USGS to obtain end use by finely-defined commodity and NAICS 3-digit purchasing industry matched with the GTAP classification.[20] The combination of GTAP and USGS data provide d_{igk} which we then use to construct the direct use coefficients $\varphi_{ik,g} = d_{igk} D_{ig}/Y_{ik}$, i.e. the value of commodities g used to produce one dollar of output in industry k in the baseline equilibrium. Finally, the share of labor simply equals $\varphi_{ik,L} = 1 - \sum_g \varphi_{ik,g}$.

A more simple alternative, which we use as a robustness check and which can be generalized to other years, is to assume that there are two downstream industries: services and manufacturing. Since many countries now import a large share of manufactured goods from China, such a calibration would already account for the large volumes of commodities absorbed by Chinese manufacturers before being consumed in other countries, for example. Here, we calibrate production in each sector in order to match overall GDP (adjusted for value-added in primary sectors) and the share of services provided by the World Bank online data.

Natural resources. We need to calibrate the share of natural resources in the production costs of each commodity, as well as the share of natural resources in total income.

We pursue two strategies. A first option, that we choose for the baseline calibration, is to assume that the share $\varphi_{ig,R}$ of natural resources in production costs is constant and equals φ_{iR} across commodities within a country i. If this is the case, the share of resources in total income is given by:

$$\sum_g e_{ig} = \frac{\sum_g \varphi_{ig,R} Y_{ig}^C}{E_i} = \varphi_{i,R} \frac{\sum_g Y_{ig}^C}{E_i}$$

Using our data on commodity production, GDP and the aggregate share of commodities in GDP (World Bank), we calibrate $\varphi_{i,R}$ to satisfy the above equality.

An alternative option is to assume that these shares $\varphi_{ig,R}$ are constant across countries for a given type of commodity. We would then use GTAP data to obtain information on the share of Land and Natural resources in the production costs of commodities (available across broadly defined industries). These shares are between 30 and 45% for most commodities, and close to the ones obtained with our baseline strategy.

[20] USGS provide end uses for each mineral across US manufacturing industries. For other countries, we reallocate the use of commodities g across industries k proportionally to output Y_{ik} of each industry k in that country.

Extreme dependence All countries have at least one commodity with positive demand but no production. This implies that $\lambda_{ig}^{-\frac{1}{\theta_g}}$ is infinite for some commodities, hence domestic prices for such commodities and losses from trade are also infinite. To alleviate such extreme dependence in such commodities, we set demand (imports) for commodity g to zero whenever domestic production is too small. In the baseline calibration, we set demand to zero when λ_{ig} is smaller than 0.001. Results are robust to setting higher thresholds (e.g. 0.01). Dependence in such commodities is however not a concern for specifications with choke prices (as described in Section 3.4.1) which provide alternative means to alleviate the dependence in a few commodities.

Elasticities. Finally, we need to calibrate the model parameters θ_k (trade elasticity for downstream sectors), θ_g (trade elasticity for commodities), η_k (elasticity of substitution between labor and commodities in the downstream sectors), ρ_g (elasticity of substitution between and σ.

We follow Simonovska and Waugh (2014) and other papers estimating trade elasticities and assign $\theta_k = 5$ for downstream industries. As documented in figure 4, commodities do not seem to have significantly higher trade elasticities. Hence we set $\theta_g = 5$ for commodities in our baseline calibration. We also explore alternative value choices as robustness checks; we double the trade elasticity $\theta_g = 10$ for all primary commodities, keeping $\theta_k = 5$ for downstream industries.

More important are the demand and supply elasticities, which are determined by η_k and ρ_g in our model. We use a value of 0.4 for both η_k and ρ_g, which generate price elasticities of demand close to 0.4 and price elasticities of supply close to 0.6 (see equation 10 with $\frac{\varphi_{ig,L}}{\varphi_{ig,R}} \approx 1.5$). This is a conservative choice. As documented in Figure 2 and Appendix Figures 6, 18 and 19, this is above a majority of elasticity estimates in the literature. We will also examine alternative value choices to illustrate the role of these elasticities.

The elasticity of substitution between industries k in final demand plays a less central role. In the baseline model, we assume $\sigma = 1$ (Cobb-Douglas) as standard in recent trade models (Caliendo and Parro, 2015). In alternative calibrations, we specify $\sigma = 0.4$ as for other elasticities of substitution (this value is close to the panel estimates of Comin et al. (2015) which allows us to obtain closed form solutions for the gains from trade relative to Autarky (Proposition 1).

5 Counterfactual simulations

We can now solve for equations (14)-(25) to simulate partial trade costs changes and equations (14), (15), (22)-(25) and (32)-(35) to simulate full Autarky.

5.1 Gains from trade relative to Autarky

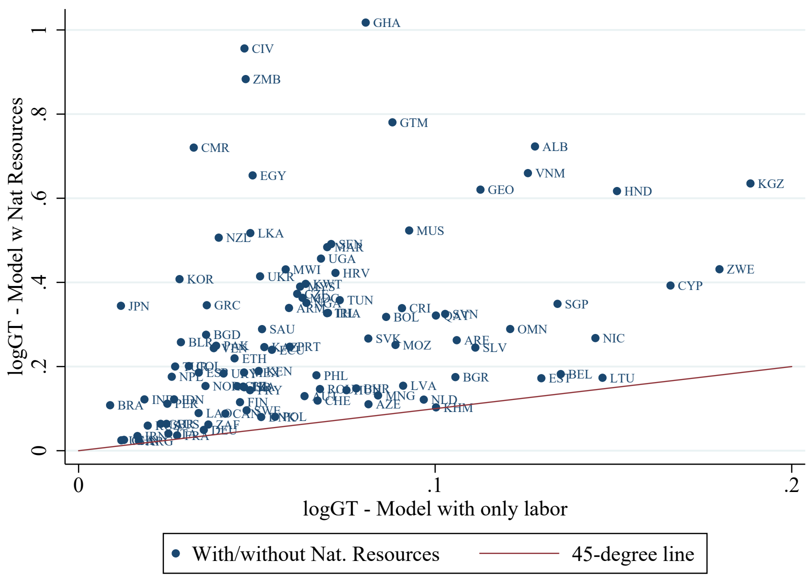


Figure 3: Gains from trade relative to model with only labor

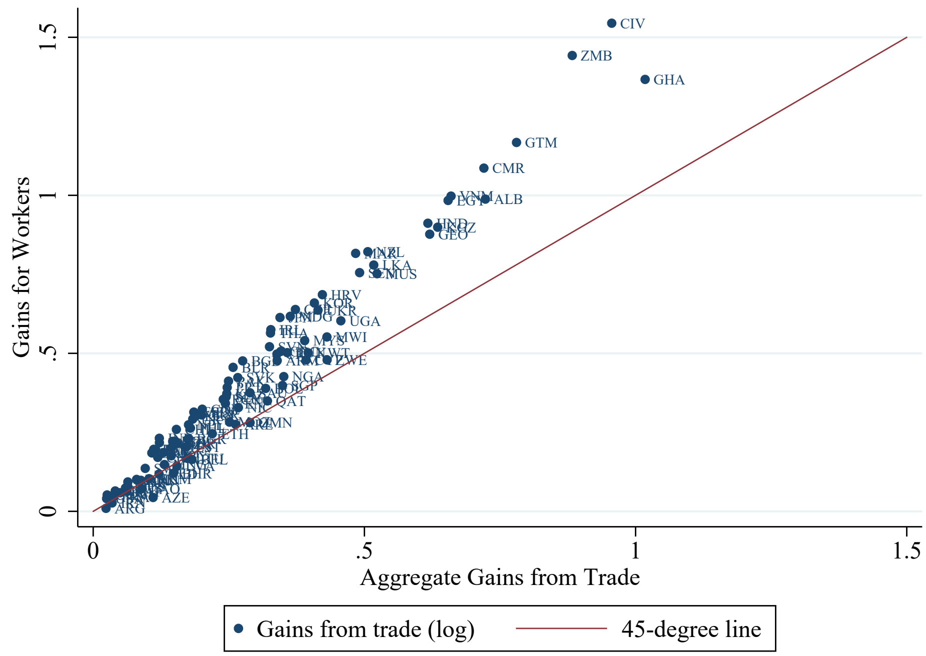
Aggregate gains from trade We show in Figure 3 the gains from trade in our baseline calibration (with commodities and natural resources), with log gains from trade on the vertical axis, compared to a model that uses labor as the only input to the commodity production process, with its predicted log gains from trade on the horizontal axis. In comparison, the use of natural resources in the production process yields much larger gains from trade (all outcomes are above the 45-degree line).

We also compute the gains from trade in our model relative to a model that only has final goods as possible products. In Appendix Figure 26, we show that we obtain similar results to those in Figure 3: the difference between the two models is now even slightly larger, since trade in final goods alone yields lower gains.

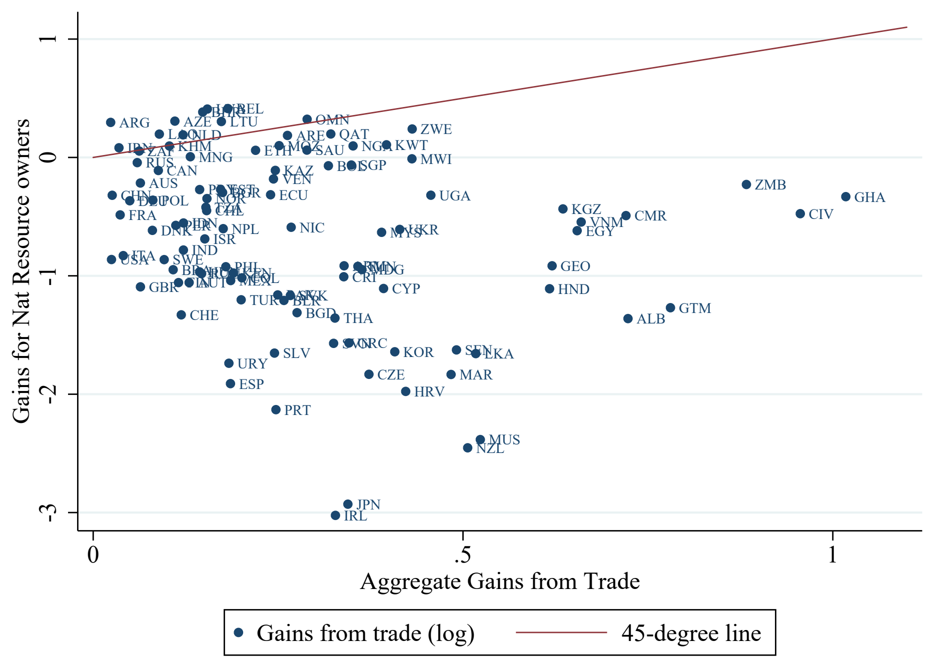
Heterogeneous gains from trade Panel (a) of Figure 4 compares the gains from trade for workers and Natural resources relative to the aggregate gains from trade. First, we can see that workers fare better in our model as a country opens to trade, reflecting a decrease in the cost of commodity sourcing relative to wages, and that their welfare improves more than the average for the aggregate economy (all points are above the 45 degree line, with workers welfare gains on the vertical axis and aggregate welfare gains on the horizontal axis).

Figure 4: Heterogeneous gains from trade

(a) Workers vs aggregate gains from Trade



(a) Natural Resources owners vs. aggregate gains from Trade



In Panel (b) of Figure 4, we examine the gains from trade for owners of natural resources, on average across resources (average weighted by initial income). Results differ starkly from Panel (a). We find that the gains from trade for natural resource owners are smaller than for the aggregate economy. In particular, natural resources often lose from trade in our model (negative log GT). Switching back to Autarky, since natural resources are scarce, a country would need to increase the share of laborers working in the production of commodities. Increasing the share of laborers in commodity production increases the marginal product of a unit of natural resources, and hence the returns to natural resource owners. As we will discuss later (see Appendix Figure 27), the gains from trade for natural resources owners are higher the larger is the share of natural resources in total income.

Role of supply and demand elasticities. As noted in the theory section, gains from trade in primary commodities depend on supply and demand elasticities. To illustrate the role of these elasticities, we solve for a counterfactual Autarky equilibrium with alternative values of demand and supply elasticities. In our baseline calibration, we assume that the elasticities of substitution η_k and ρ_g are equal to 0.5. In Figure 5, we examine the gains from trade for our model if we assume $\eta_k = \rho_g = 0.95$, i.e. almost Cobb-Douglas. For each alternative calibration, we compare our results to a model with only factor (labor), i.e. without any role for natural resources to produce a specific commodity. We plot gains from trade (in log, relative to Autarky) for each specific on the vertical axis while we plot gains from trade from the single-factor model on the horizontal axis. As one can see, the gains from trade decrease very quickly when we assume higher elasticities of substitution. For elasticities close to unity, the gains from trade are fairly similar to the single-factor model (45-degree line). For elasticities larger than unity, gains from trade are essentially identical to the single-factor model and considerably smaller than in our baseline model.

Resource owners often experience negative gains from trade (panel (b) of Figure 4) but interestingly this result does not hold for larger elasticities of substitution. In Figure 6, we show that the gains from trade for natural resource owners are mostly positive and close to the aggregate gains for the country when there is a higher degree of substitutability between labor and natural resources in the production process. When elasticities are high, a country in Autarky can more easily employ labor to substitute for limited natural resources, thereby decreasing the marginal product and returns to natural resources.

While the results above highlight the role of the supply and demand elasticities for commodities, one can notice that the gains from trade are large in spite of relatively higher elasticities of substitution between final goods in consumer preferences ($\sigma = 1$ in the baseline specification). This implies that this elasticity of substitution is not as crucial but its role is not negligible. If

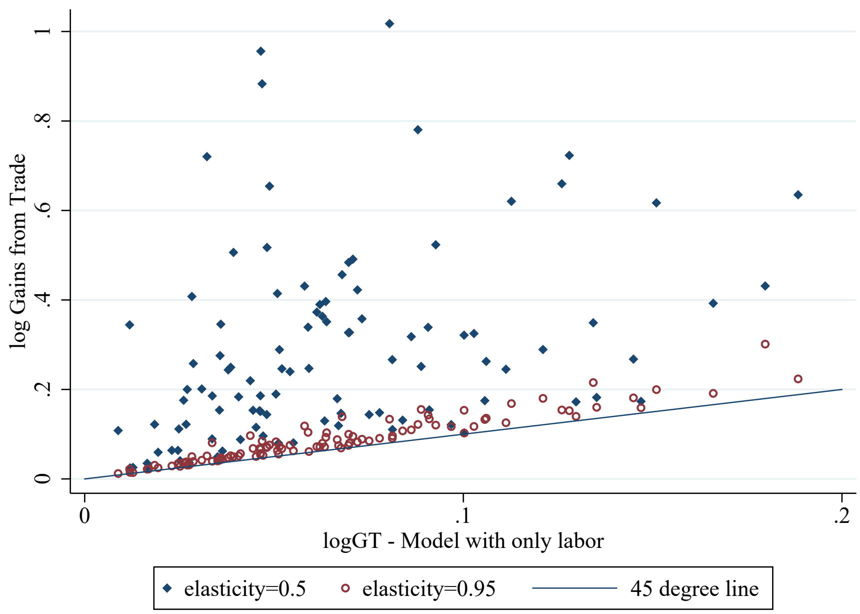


Figure 5: Gains from Trade (Aggregate) for Different Elasticities of Substitution

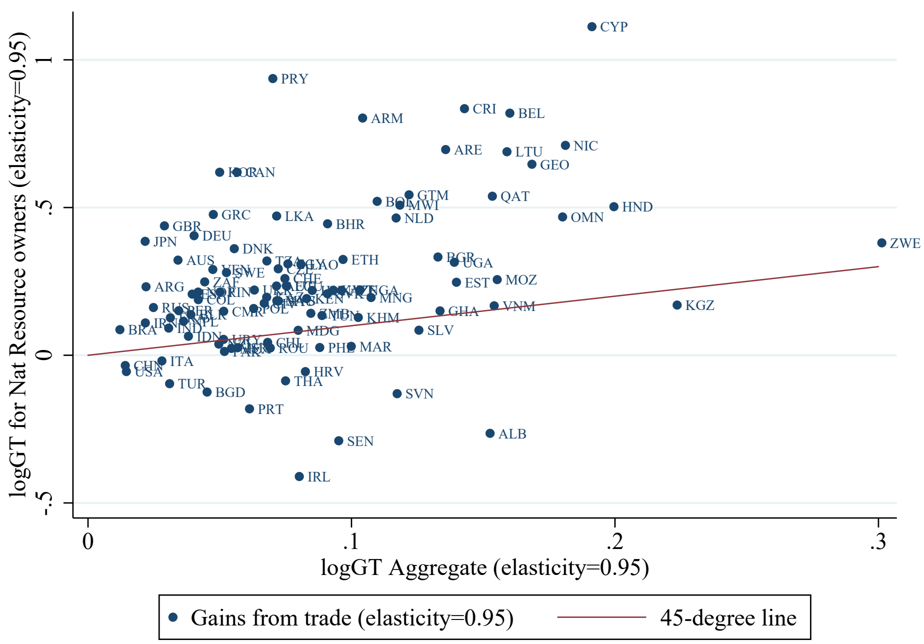


Figure 6: Gains from Trade for Resource Owners for Different Elasticities of Substitution

a commodity becomes prohibitively expensive, substitution with final goods that do not rely on this commodity alleviates the loss from Autarky. In fact, we obtain even larger gains from trade, especially for small countries, when we specify a lower elasticity of substitution between final goods – see Figure 28 in Appendix with $\sigma = 0.4$.

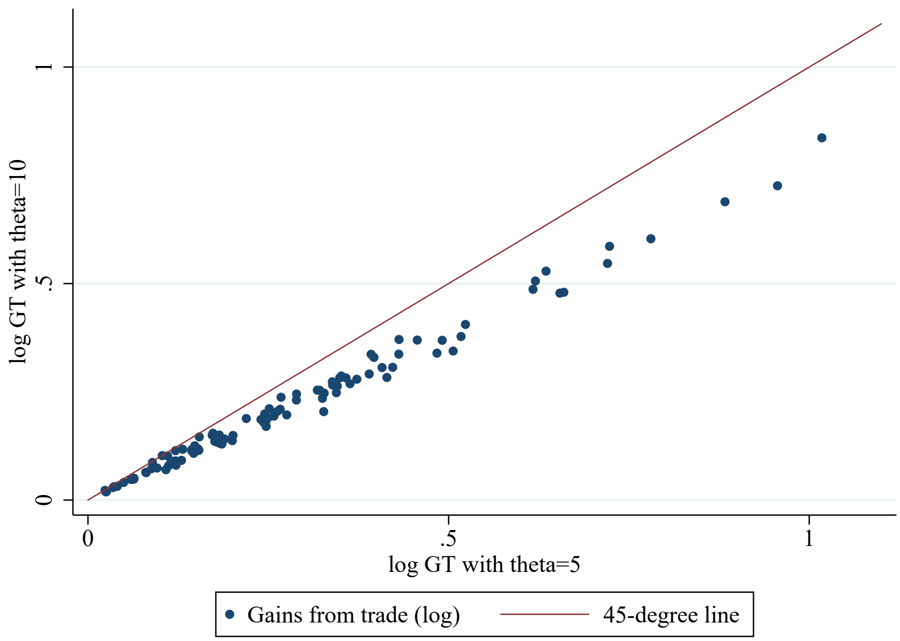


Figure 7: Gains from Trade with Higher Trade Elasticity for Commodities: $\theta_g = 10$

The trade elasticity for commodities plays a more muted role in explaining the gains from trade in commodities, unlike in standard models where the gains from trade (in log) are proportional to the trade elasticity. Figure 7 indicates that the gains from trade are higher with a trade elasticity $\theta_g = 10$ (vertical axis) than with a trade elasticity $\theta_g = 5$ (horizontal axis), but the difference however is not very large. Contrary to the standard formula for the gains from trade (Arkolakis et al., 2012), doubling the trade elasticity for commodities does not halve the gains: the gains from trade in our model still largely exceed the gains from trade without natural resources.

Covariates Next we examine how some key country characteristics correlate with the gains from trade in our model in Figure 8.

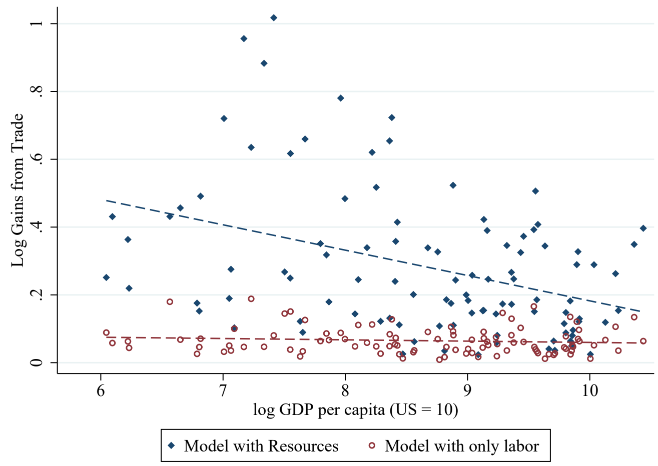
Firstly, as documented in panel (a) of Figure 8, we find a negative and significant relationship between the gains from trade and per capita income across countries. In comparison, this correlation is weak and insignificant in a standard model with only labor, where natural resources do not play a role. The negative correlation with per capita income is partly driven

Figure 8: Determinants of the gains from trade, compared with labor-only model

(a) Gains from Trade and Per Capita Income

Baseline model:
$corr(\log GT_i, \log w_i) = -0.377^{***}$

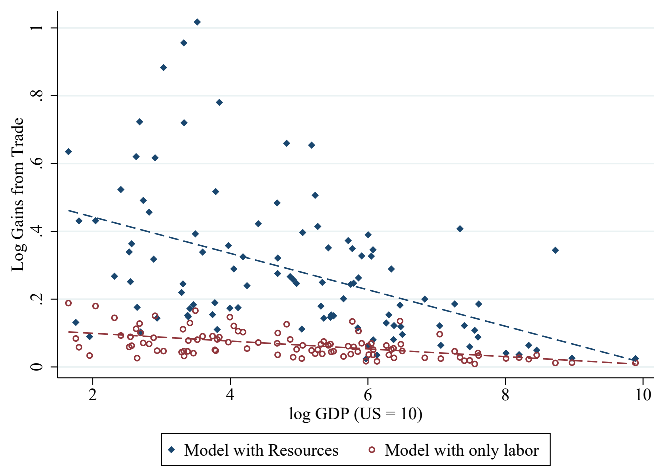
Single-factor model:
$corr(\log GT_i, \log w_i) = -0.086$



(b) Gains from Trade and Market Size

Baseline model:
$corr(\log GT_i, \log E_i) = -0.547^{***}$

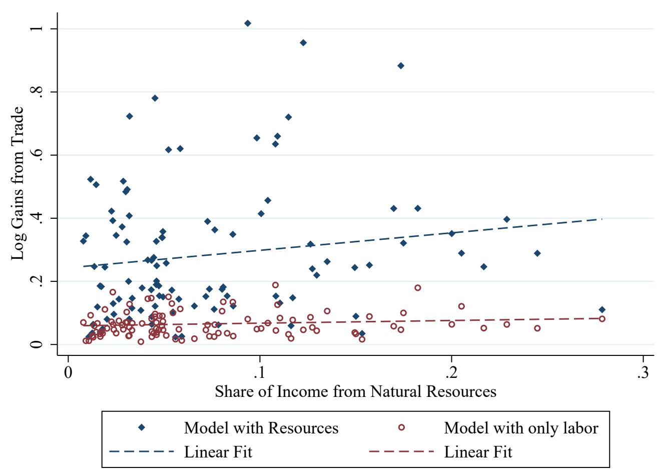
Single-factor model:
$corr(\log GT_i, \log E_i) = -0.475^{***}$



(c) Gains from Trade and Share of Income from Resources

Baseline model:
$corr(\log GT_i, \log e_{iR}) = 0.154$

Single-factor model:
$corr(\log GT_i, \log e_{iR}) = 0.127$



by the higher reliance on natural resources in poorer countries, and partly by the fact that poorer countries also tend to be associated with smaller market size (GDP).

Indeed, as we show in panel (b), we find that the negative correlation between gains from trade and market size is even starker (more negative) than in standard models. The intuition is simple. Smaller countries tend to have less diverse natural resources and, when they open to trade, specialize in the production of only a few commodities and gain access to various other commodities that cannot be produced domestically.[21]

Thirdly, in panel (c) of Figure 8, we plot the gains from trade against a country's share of natural resources. Interestingly, the gains from trade from moving from Autarky tend to be significantly larger for countries with a larger share of income from natural resources, as countries shift production into commodities and goods in which they have a comparative advantage (also see Appendix Figure 27 focusing on the gains from trade for natural resource owners). We see of course no such effect in the model where labor is the only input in the production process and where natural resources no longer matter.

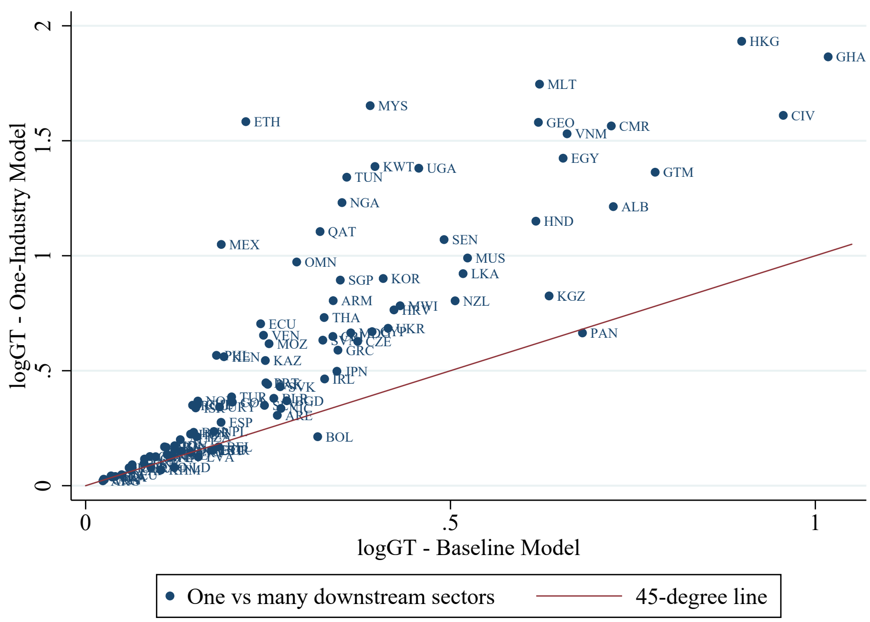


Figure 9: Gains from Trade in a Model with only one Downstream Sectors

[21]We also find a stronger (negative) correlation with country size in terms of land area.

5.2 Sensitivity to alternative specifications

Choke prices Very large gains from trade arise when prices are very high for at least some commodities. One may be worried however that, in those cases, an economy would be able to find substitutes to that commodity. Such substitution would lead to a choke price, i.e. a price upper bound above which demand for that commodity would drop to zero.

We describe in Section 3.4.1 one way to account for such choke price. To calibrate such model, one needs to know the value of Δ_{ig} capturing the ratio of the current price relative to the choke price. To illustrate the sensitivity of our results to the presence of choke prices, we provide alternative counterfactual simulations with values $\Delta_{ig} = 0.05$, 0.1 and 0.2 respectively.

Results are depicted in Figure 10. In spite of the presence of a choke price, we find that the gains from trade are still much larger than in the case without natural resources (and without choke prices). Of course, higher values of Δ_{ig} – corresponding to lower choke prices – lead to smaller gains from trade.

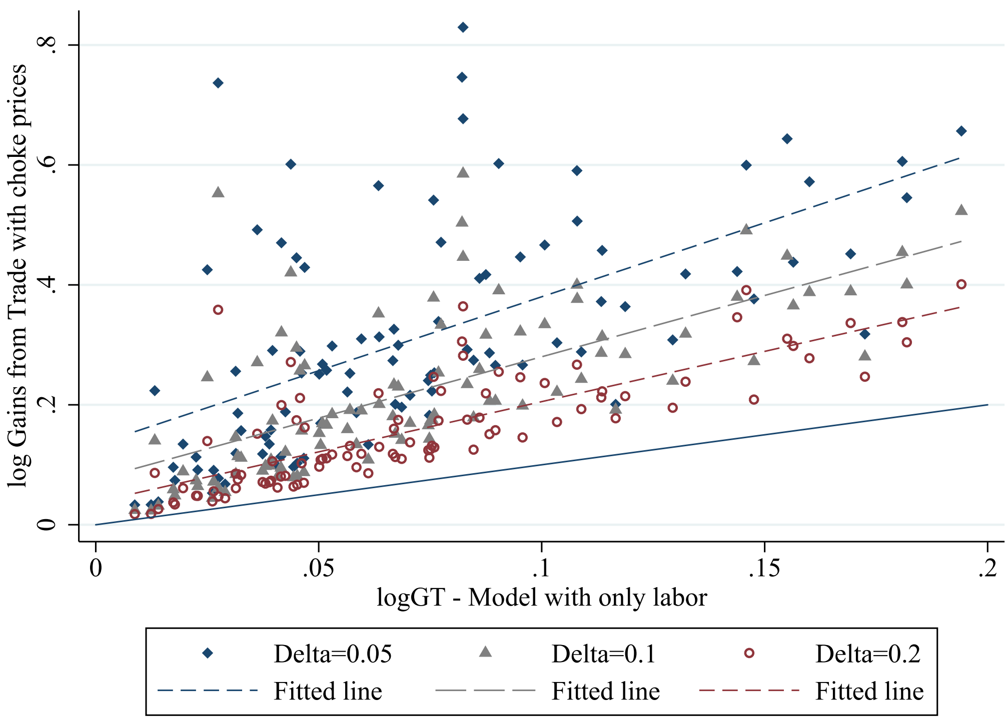


Figure 10: Gains from trade with choke prices

Model of land allocation In Section 3.4.2, we consider an alternative model of commodity production with a single factor of production (land) that can be allocated to producing different commodities with a constant elasticity of transformation (CET). This version is also isomorphic to a Roy model of land allocation with a continuum of parcels with i.i.d. productivity draws (from a Frechet distribution) associated with each commodity (as in Galle et al 2017). We now calibrate this model using the same production and trade data and the same parameter values for $\rho = 0.4$ and $\eta = 0.4$ as in the baseline model.[22]

As shown in Figure 11, in this model of land allocation we find that the gains from trade are still quite large; gains from trade tend to be larger with the CET model of land allocation than in the baseline model, with a few exceptions such as New Zealand and Japan.

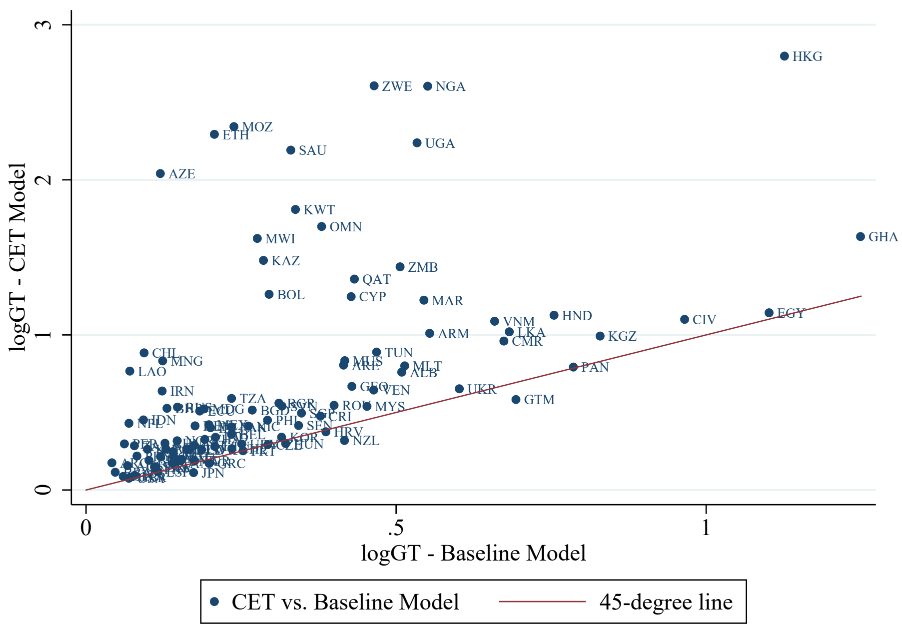


Figure 11: Gains from trade – Land allocation with CET production function

Aggregation of downstream sectors In Figure 9, we compare the gains from trade from our baseline model with services and multiple downstream sectors to a model with services but only one downstream sector, manufacturing. We find that the gains from trade are larger with only one manufacturing sector. The main reason is that in our baseline model consumers can better substitute between cars and chemicals and plastic products when either one lacks a key commodity and becomes very expensive. The upper elasticity is one with Cobb-Douglas, while the elasticity of substitution is $\eta_k = 0.4$ in the production function. In a one-sector model, the final good requires all commodities and is more difficult to replace.

[22]Here we compare the two models with a low elasticity of substitution $\sigma = 0.4$ between final goods, in line with the closed-form solution provided in Section 3.4.2.

A third point of comparison would be to have preferences with a lower elasticity of substitution σ between multiple final goods. If we set $\sigma = 0.4$ instead of unity (Cobb-Douglas), we actually find larger gains from trade than both the Cobb-Douglas and the single-industry specifications.

Other years If downstream sectors are aggregated and detailed downstream sector data from GTAP are not used, we can calibrate the model for other years than 2007. In Figure 29 in Appendix we calibrate the gains from trade in a model with 1995-2013 commodity production data in the single-downstream-sector model. We find a similar distribution of the gains from trade across all years, indicating that our results are specific to 2007.

Aggregation of commodities One of the key issues that we highlight in this paper is that it is important to examine detailed data by commodity. If we were to only use aggregate data for primary production (e.g. aggregating all minerals), we would miss a big part of the gains from trade and specialization. We illustrate this point in Figure 12 where we compare the gains from trade in our baseline model to one where all primary commodities are pooled into one single commodity sector. As shown in Figure 12, imputed gains from trade are much smaller when commodities are aggregated into a single sector.

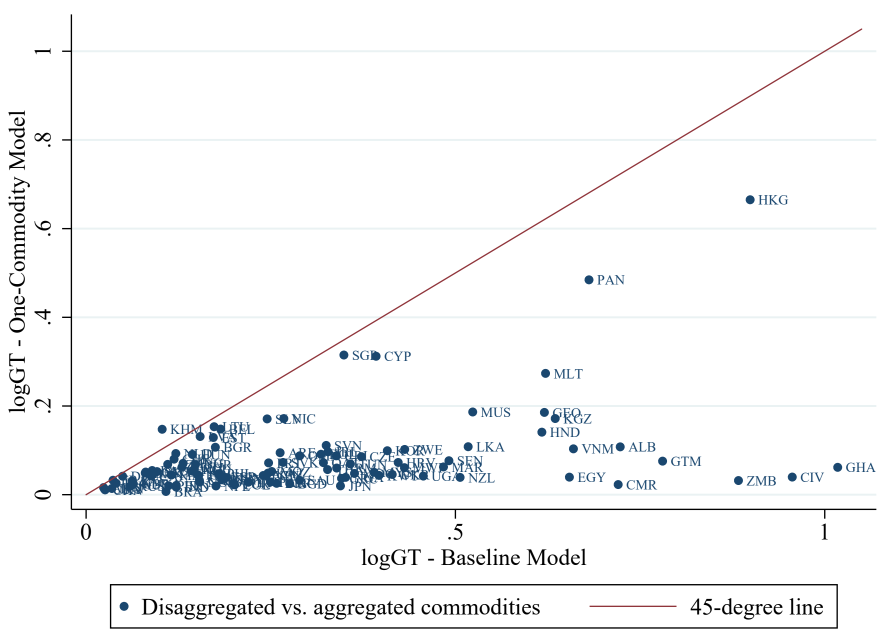


Figure 12: Gains from trade estimated after aggregating commodity production and trade

Types of commodities Are the large gains from trade with commodities driven by specific groups of commodities? We examine the robustness of our results by replacing natural resources (fixed factors) by labor for certain groups of commodities: either fuels, minerals or agricultural products. Results are shown in Figure 13 and indicate that broadly our findings are not driven by a few specific commodities (e.g. petroleum). On average, we obtain large gains from trade even when we "remove" a broad type of commodity, i.e. shutting down the role of natural resources for either type of commodity: fuels, minerals or agriculture.

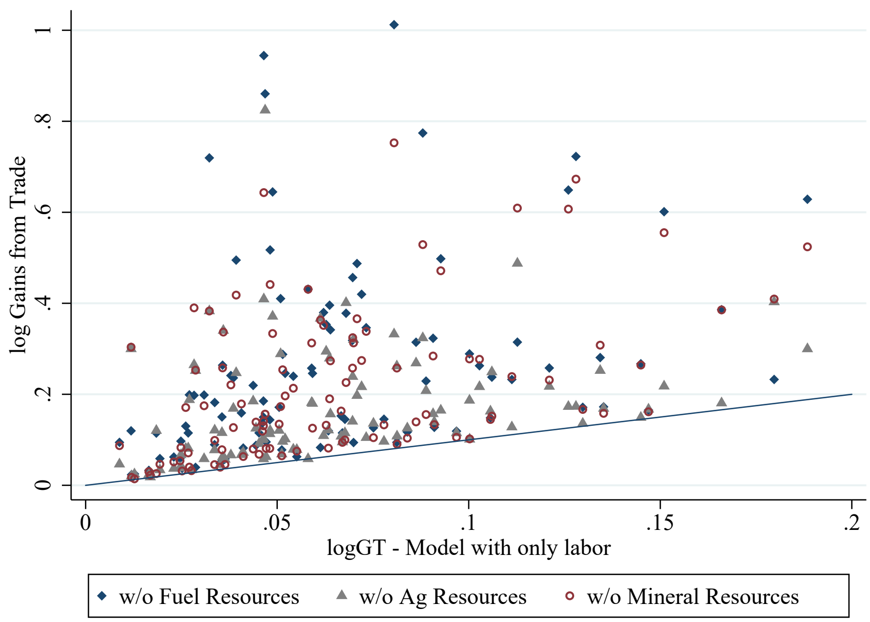


Figure 13: Gains from Trade – sensitivity to removing certain types of commodities

5.3 Partial trade cost changes and tariffs

Instead of comparing with Autarky, the next counterfactuals examine how partial changes in trade costs and tariffs generate gains from trade.

Non-linearity Since commodities face a low elasticity of demand (difficult to substitute) but account for only a modest share of world trade, the effects of trade costs are very non-linear. The elasticity of substitution does not matter as a first order approximation when changes in trade costs are small (i.e. the ACR formula provides a good approximation), but a sizable difference appears when trade costs changes are fairly large as seen in Figure 14. In this figure, we increase trade costs increase by 7% in each iteration. After ten iterations (roughly doubling trade costs), welfare losses are about 30% larger with low elasticities of substitution.

If we focus on labor, the standard model no longer provides a good approximation of the gains from trade. Even for small changes in trade costs (dash lines in Figure 14), the gains from trade for labor in a model with primary commodities are about 50% larger (on average across countries) than in standard models with higher substitution or no natural resources. We document the heterogeneity across countries in Figure 15.

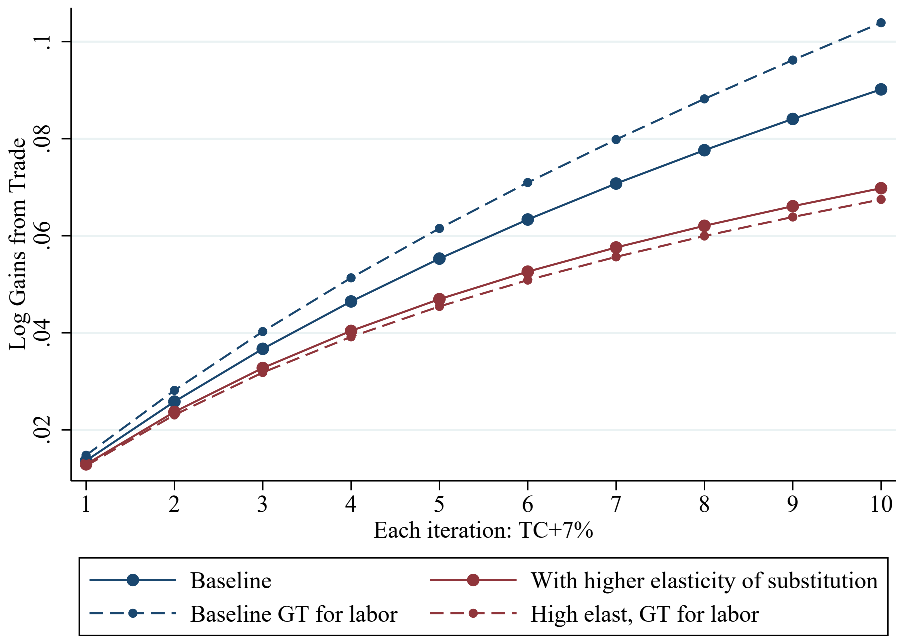


Figure 14: Gains from trade – increasing trade costs by 7% at each iteration

Tariffs Rather than changes in trade costs, one may be interested in changes in tariffs and tariffs revenues generated by trade in commodities. With particularly low demand and supply elasticities, one can expect smaller dead-weight losses and thus much smaller welfare losses compared with changes in trade costs.

With import tariffs t_{ng} and t_{nk} on commodities g and industries k, the change in trade costs is now:

$$\widehat{d_{nik}} = 1 + t_{nik} \qquad \widehat{d_{nig}} = 1 + t_{nig}$$

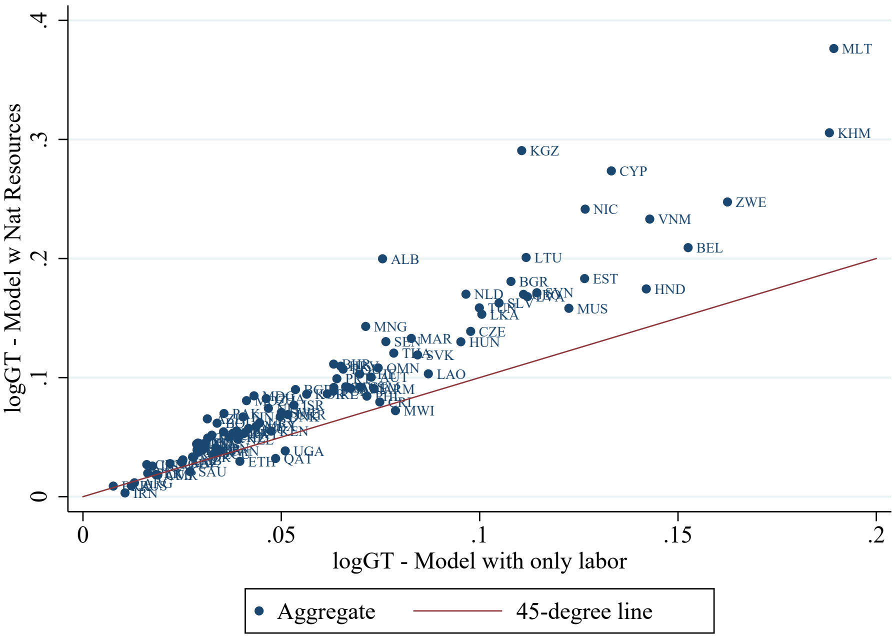


Figure 15: Gains from trade across countries – intermediate changes in trade costs

Income now includes tariff revenues, given by:

$$T_n \;=\; \sum_{i,k} \frac{t_{nik}}{1+t_{nik}} X_{nik} \;+\; \sum_{i,g} \frac{t_{nig}}{1+t_{nig}} X_{nig}$$

and sales are:

$$Y^C_{ig} = \sum_n (C_{ig} d_{nig})^{-\theta_g} (1+t_{ng})^{-1-\theta_g} P_{ng}^{\theta_g} D_{ng}$$

with a similar expression for sales in industry k. Notice the -1 added to the trade elasticity, since only a share $1/(1+t_{ng})$ of the value of trade flows is earned by country i.

The equation describing counterfactual changes in income is now:

$$\widehat{E}_i \;=\; e_{iL}\hat{w}_i \;+\; \sum_g e_{ig,R}\hat{r}_{ig} \;+\; \sum_g \frac{t_{ng}M_{ng}}{D_{ng}E_n} \sum_i \lambda^C_{nig} \widehat{X^C}_{nig} \;+\; \sum_k \frac{t_{nk}M_{nk}}{D_{nk}E_n} \sum_i \lambda^C_{nik} \widehat{X^F}_{nik}$$

where the last two terms capture additional revenues from import tariffs. Changes in output are then given by:

$$\widehat{Y^C}_{ig} = \sum_n (1+t_{ng})^{-1-\theta_g} \pi^C_{nig} (\widehat{C^C}_{ig})^{-\theta_g} (\widehat{P^C}_{ng})^{\theta_g} \; \widehat{D_{ng}}$$

with a similar expression for industry k.

We simulate a 100% worldwide increase in tariffs with 10% increments across iterations, and illustrate the results in Figure 16. Once tariff revenues are accounted for, one can see in Figure 16 that there is virtually no difference in aggregate welfare losses between the baseline model and a standard model without natural resources. Implications for labor income are however non-negligible, as shown with difference between the two dash lines, indicating larger effects on redistribution of welfare across factors of production within countries.

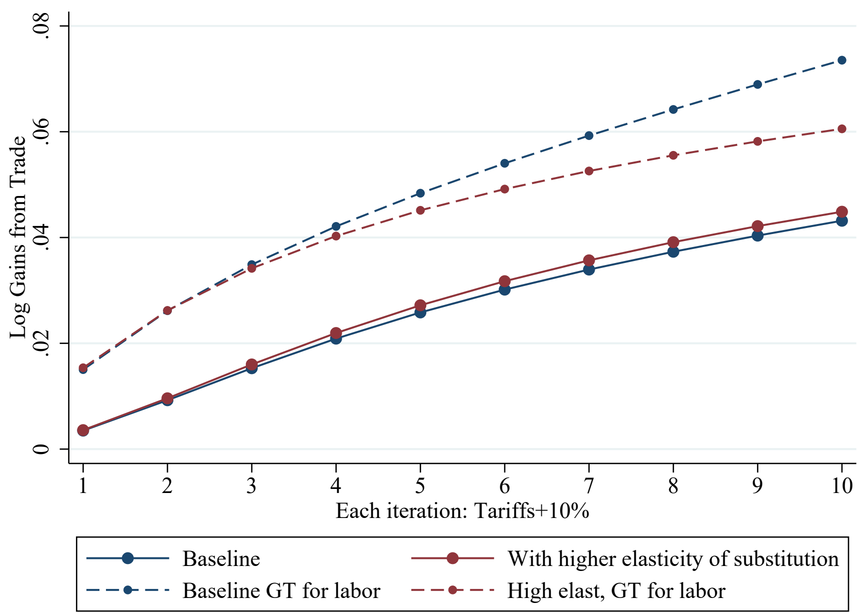
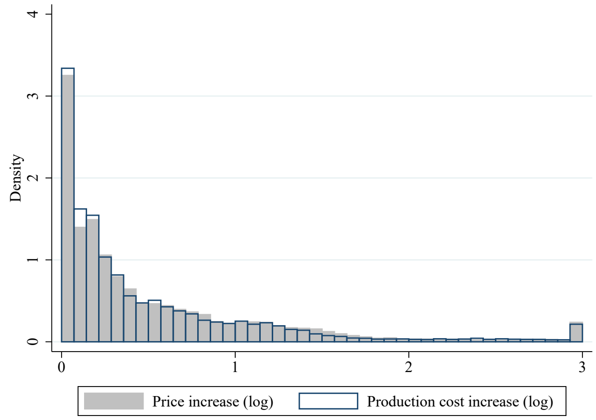


Figure 16: Gains from trade – increasing tariffs by 10% at each iteration

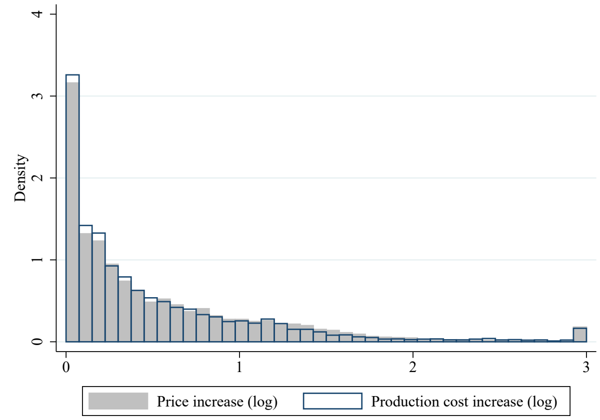
Critical suppliers To conclude, we conduct a set of counterfactuals to illustrate the interdependence of nations and the critical role of the top exporter of any given commodity. As we have shown earlier in Fact 9, the production of commodities is highly specialized across a few key exporters. This reliance on a few suppliers would lead to high costs associated with barriers to trade with such suppliers.

To illustrate and quantify the role of critical suppliers, we simulate a counterfactual equilibrium for each commodity where we shut down trade with the top exporter of that commodity, looking at how that affect prices for that commodity across other countries. There are two main channels through which these barriers to trade with a specific country affects prices. First, holding factor prices and production costs $\widehat{C}_{ig}$ constant, cutting trade from a source country leads to a higher price index $\widehat{P}_{ig}$ – this effect is highest for the largest exporter. Second, shutting down

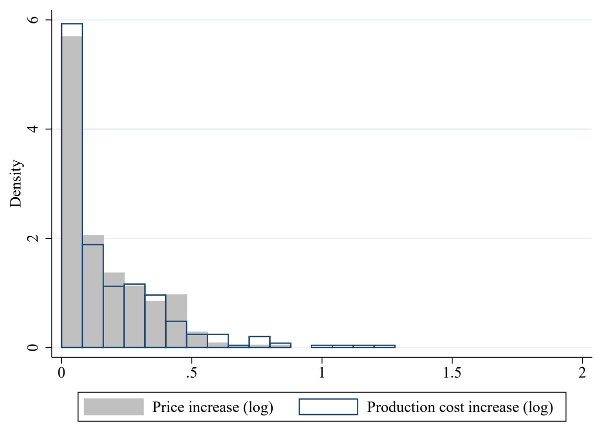
Figure 17: Shutting down trade with the top exporter – Effect on prices and production costs (one commodity at a time)



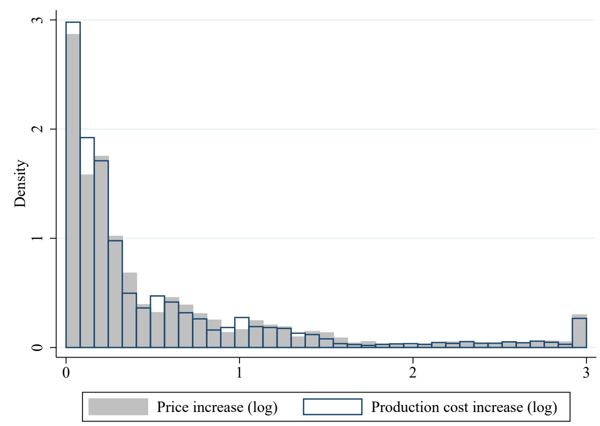
(a) Across all commodities



(b) Agricultural commodities



(c) Fuel commodities



(d) Minerals

trade with any given exporter forces to increase production of that commodity in other source countries. Given the low price elasticity of supply facing commodities, this can potentially lead to large increases in producer prices and costs $\widehat{C}_{ig}$ – in the model, this is due to hiring additional workers at a low marginal product of labor.

We provide the results of these counterfactuals in Figure 17 where we plot the distribution of $\log(\widehat{P}_{ig})$ and $\log(\widehat{C}_{ig})$ across countries i and commodities g after excluding from world trade the main exporter of that commodity (e.g. Chile for copper, Indonesia for tin). These figures indicate very large increases in prices, pooling all commodities (panel a), or looking at agricultural products (b), fuels (c) or minerals (d) separately. The relatively smaller effects on fuel prices indicate the smaller share of the top exporter in world supply of fuel commodities (petroleum, coal and gas).

A large part of the price increase corresponds to the cost of having to produce more, as shown in Figure 17 where the distribution of $\log(\widehat{C}_{ig})$ (with blue contours) is close to the one for $\log(\widehat{P}_{ig})$.

6 Concluding remarks

In this paper, we highlight the importance of commodities in international trade and demonstrate that upon consideration of the specific characteristics of primary commodity markets, such as low elasticities of demand and supply and high concentration ratios, the gains from trade exceed standard models. To do so, we compile a new dataset containing information on trade, production, prices and demand for commodities at a disaggregated level. We use these data to document a series of stylized facts and calibrate a general-equilibrium model of trade and production that accounts for key features of commodity trade. Relative to Autarky, we find that the gains from trade are at least twice as large as in standard models, with especially large gains for small economies with less diverse natural resources.

Our results suggest that although primary commodities have a modest share in world trade, commodities are crucial inputs to many production processes, and thus have critical importance to international trade policy and welfare. The decline of the share of primary commodities in world trade must be considered against the large decreases in tariffs and transportation costs over the past seventy years, and the resulting large increase in trade volume relative to GDP. Increasing barriers to trade would lead to a resurgence of the share of primary commodities in total costs and larger welfare losses.

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Appendix (Not for publication)

A- Exact hat algebra: counterfactual equilibrium conditions

$\widehat{X}$ denotes the ratio of the new equilibrium value for variable X over the baseline value, i.e. $\widehat{X} = X'/X$. Hence $X\widehat{X}$ denotes the new equilibrium value for variable X.

- For income, we have:

$$\widehat{E_n}E_n = \widehat{w_n}w_nL_n + \sum_g \widehat{r_{ng}}r_{ng}V_{ng}$$

  Hence:

$$\widehat{E_n} = \frac{w_nL_n}{E_n}\widehat{w_n} + \sum_g \frac{r_{ng}V_{ng}}{E_n}\widehat{r_{ng}}$$

  we obtain the equation in the text by denoting: $e_{nL} = \frac{w_nL_n}{E_n}$ and $e_{ng} = \frac{r_{ng}V_{ng}}{E_n}$.

- CES Utility:

$$\widehat{P_n^F}P_n^F = \left[\sum_k a_{nk}(\widehat{P_{nk}^F}P_{nk}^F)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$$

  hence:

$$\widehat{P_n^F} = \left[\sum_k a_{nk}\left(\frac{\widehat{P_{nk}^F}P_{nk}^F}{P_n^F}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$$

  we obtain the equation in the text after noticing that $\alpha_{nk} = a_{nk}\left(\frac{P_{nk}^F}{P_n^F}\right)^{1-\sigma}$ is the expenditure share of good k in the baseline equilibrium.

- The same logic applies to the price index and trade shares:

$$\widehat{P_{nk}^F} = \left[\sum_i \lambda_{nik}^F(\widehat{C^F}_{ik}\widehat{d_{nik}})^{-\theta_k}\right]^{-\frac{1}{\theta_k}}$$

$$\widehat{P_{ng}^C} = \left[\sum_i \lambda_{nig}^C(\widehat{C^C}_{ig}\widehat{d_{nig}})^{-\theta_g}\right]^{-\frac{1}{\theta_g}}$$

  using trade shares $\lambda_{nik}^F = \frac{(C_{ik}^F d_{nik})^{-\theta_k}}{P_{nk}^{F\ -\theta_k}}$ and $\lambda_{nig}^C = \frac{(C_{ig}^C d_{nig})^{-\theta_g}}{P_{ng}^{C\ -\theta_g}}$.

- Expenditure in final good k is such that:

$$D_{nk}\widehat{D_{nk}} = a_{nk}\left(\frac{\widehat{P_{nk}^F}P_{nk}^F}{\widehat{P_k^F}P_n^F}\right)^{1-\sigma}E_n\widehat{E_n}$$

  hence:

$$\widehat{D_{nk}} = \left(\frac{\widehat{P_{nk}^F}}{\widehat{P_k^F}}\right)^{1-\sigma}\widehat{E_n}$$

- For the cost of producing final good k in producing country i, we have:

$$C_{ik}^F\widehat{C^F}_{ik} = A_{ik}^F\left[\beta_{ik,L}^F w_i^{1-\eta_k}\widehat{w_i}^{1-\eta_k} + \sum_{g\in G(k)}\beta_{ik,g}^F(P_{ig}^C\widehat{P_{ig}^C})^{1-\eta_k}\right]^{\frac{1}{1-\eta_k}}$$

which gives:

$$\widehat{C^F}_{ik} = \left[\frac{A_{ik}^{F\,1-\eta_k} \beta_{ik,L}^F w_i^{1-\eta_k}}{C_{ik}^{F\,1-\eta_k}} \widehat{w_i}^{1-\eta_k} + \sum_{g \in G(k)} \frac{A_{ik}^{F\,1-\eta_k} \beta_{ik,g}^F (P_{ig}^C)^{1-\eta_k}}{C_{ik}^{F\,1-\eta_k}} \widehat{P_{ig}^C}^{1-\eta_k} \right]^{\frac{1}{1-\eta_k}}$$

We obtain the equation in the text after noticing that $\varphi_{ik,L}^F = \frac{A_{ik}^{F\,1-\eta_k} \beta_{ik,L}^F w_i^{1-\eta_k}}{C_{ik}^{F\,1-\eta_k}}$ and $\varphi_{ik,g}^F = \frac{A_{ik}^{F\,1-\eta_k} \beta_{ik,g}^F (P_{ig}^C)^{1-\eta_k}}{C_{ik}^{F\,1-\eta_k}}$ are the cost shares of labor and commodity g respectively.

- We get a similar expression for the change in the cost for commodity g.
- Trade in final goods k, from i to n is then:

$$X_{nik}^F = \frac{(C_{ik}^F d_{nik})^{-\theta_k}}{\sum_j (C_{jk}^F d_{njk})^{-\theta_k}} D_{nk}$$

- Demand for commodity g in destination i, is:

$$D_{ig} = \beta_{ik,g}^F (P_{ig}^C / C_{ik}^F)^{1-\eta_k} Y_{ik}^F$$

where $k = k(g)$ is the industry downstream of commodity g and where $Y_{ik}^F = \sum_n X_{nik}^F$ denotes production of good k in i.

- Trade in good k, from i to n: in each equilibrium we have:

$$X_{nik}^F = (C_{ik}^F d_{nik})^{-\theta_k} (P_{nk}^F)^{\theta_k} D_{nk}$$

Hence:

$$\widehat{X^F}_{nik} = (\widehat{C^F}_{ik} \widehat{d_{nik}})^{-\theta_k} (\widehat{P^F}_{nk})^{\theta_k} \widehat{D_{nk}}$$

We obtain the change in production after noticing that:

$$\widehat{Y^F}_{ik} = \sum_n \pi_{nik}^F \widehat{X^F}_{nik}$$

where π_{nig}^C are exports to n as a share of total production in country i.

- Trade for commodity g, from i to n: in each equilibrium we have:

$$X_{nig}^C = (C_{ig}^C d_{nig})^{-\theta_g} (P_{ng}^C)^{\theta_g} D_{ng}$$

Hence:

$$\widehat{X^C}_{nig} = (\widehat{C^C}_{ig} \widehat{d_{nig}})^{-\theta_g} (\widehat{P^C}_{ng})^{\theta_g} \widehat{D_{ng}}$$

We obtain the change in production after noticing that:

$$\widehat{Y^C}_{ig} = \sum_n \pi_{nig}^C \widehat{X^C}_{nig}$$

where π_{nig}^C are exports to n as a share of total production in country i.

- Income from specific factor g:

$$R_{ig} r_{ig} = \beta_{ig}^C (r_{ig} / C_{ig}^C)^{1-\rho_g} Y_{ig}^C$$

where $Y_{ig}^C = \sum_n X_{nig}^C$ denotes the production of commodity g in country i.

- Income from labor:

$$L_i w_i = \sum_g (1 - \beta_{ig}^C)(w_i / C_{ig}^C)^{1-\rho_g} Y_{ig}^C + \sum_k \beta_{ik,L}^F (w_i / C_{ik}^F)^{1-\eta_k} Y_i^F$$

where $Y_{ik}^F \equiv \sum_n X_{ni}^F$ and $Y_{ig}^C \equiv \sum_n X_{nig}^C$ denote the production of final good k and commodity g respectively.

B- Closed-form solutions

Here we normalize $\hat{w}_i = 1$. We focus on the case where downstream and upstream substitution elasticities are equal, denoted by σ.

As described above, the change in production of commodity g is given by:

$$\widehat{Y_{ig}^C} = \widehat{P_{ig}^C}^{1-\sigma} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k d_{nkg} \frac{\widehat{Y_{ik}^F}}{\widehat{C_{ik}^F}^{1-\sigma}}$$

In that case, it is then simple to express income from specific factor R_{ng} as a function of the change in manufacturing prices and production. Using $\widehat{C_{ig}^C} = \lambda_{ig}^{\frac{1}{\theta_g}} \widehat{P_{ig}^C}$, we get:

$$\begin{aligned} \hat{r}_{ig} &= \widehat{C_{ig}^C}^{-\frac{1-\sigma}{\sigma}} \widehat{Y_{ig}^C}^{\frac{1}{\sigma}} && (51) \\ &= \lambda_{ig}^{-\frac{1-\sigma}{\theta_g \sigma}} \widehat{P_{ig}^C}^{-\frac{1-\sigma}{\sigma}} \widehat{Y_{ig}^C}^{\frac{1}{\sigma}} && (52) \\ &= \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k d_{nkg} \frac{\widehat{Y_{ik}^F}}{\widehat{C_{ik}^F}^{1-\sigma}} \right)^{\frac{1}{\sigma}} && (53) \end{aligned}$$

The change in the cost of commodity g is then:

$$\begin{aligned} \widehat{C_{ig}^C}^{1-\sigma} &= \varphi_{ig,L} + \varphi_{ig,R} \hat{r}_{ig}^{1-\sigma} && (54) \\ &= \varphi_{ig,L} + \varphi_{ig,R} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k d_{nkg} \frac{\widehat{Y_{ik}^F}}{\widehat{C_{ik}^F}^{1-\sigma}} \right)^{\frac{1-\sigma}{\sigma}} && (55) \end{aligned}$$

Combining with $\widehat{P_{ig}^C} = \lambda_{ig}^{-\frac{1}{\theta_g}} \widehat{C_{ig}^C}$ and the equation above to describe the change in production, we obtain:

$$\begin{aligned} \widehat{P_{ig}^C}^{1-\sigma} &= \varphi_{ig,L} \lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} + \varphi_{ig,R} \lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \hat{r}_{ig}^{1-\sigma} && (56) \\ &= \varphi_{ig,L} \lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} + \varphi_{ig,R} \lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k d_{nkg} \frac{\widehat{Y_{ik}^F}}{\widehat{C_{ik}^F}^{1-\sigma}} \right)^{\frac{1-\sigma}{\sigma}} && (57) \end{aligned}$$

and:

$$\begin{aligned} \widehat{Y_{ig}^C} &= \widehat{C_{ig}^C}^{1-\sigma} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k d_{nkg} \frac{\widehat{Y_{ik}^F}}{\widehat{C_{ik}^F}^{1-\sigma}} \right) && (58) \\ &= \varphi_{ig,L} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{\widehat{Y_{ik}^F}}{\widehat{C_i^F}^{1-\sigma}} \frac{D_{ig}^C}{Y_{ig}^C} \right) + \varphi_{ig,R} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k d_{nkg} \frac{\widehat{Y_{ik}^F}}{\widehat{C_{ik}^F}^{1-\sigma}} \right)^{\frac{1}{\sigma}} && (59) \end{aligned}$$

For the cost of manufacturing $\widehat{C^F_{ik}}^{1-\sigma} = \varphi_{ik,L} + \sum_g \varphi_{ik,g}(\widehat{P^C_{ig}})^{1-\sigma}$, we get:

$$\begin{aligned}
\widehat{C^F_{ik}}^{1-\sigma} &= \varphi_{ik,L} + \sum_g \varphi_{ik,g}\varphi_{ig,L}\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} + \sum_g \varphi_{ik,g}\varphi_{ig,R}\,\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}}\ \frac{D^C_{ig}}{Y^C_{ig}}\ \sum_h d_{nhg}\frac{\widehat{Y^F_{ih}}}{\widehat{C^F_{ih}}^{1-\sigma}}\right)^{\frac{1-\sigma}{\sigma}} \\
&= \varphi_{ik,L} + \sum_g \varphi_{ik,g}\varphi_{ig,L}\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} + \sum_g \frac{\varphi_{ik,g}\varphi_{ig,R}Y^C_{ig}}{D^C_{ig}}\,\frac{\hat{r}_{ig}^{\frac{1}{\sigma}}}{\sum_h d_{nhg}\widehat{Y^F_{ih}}\widehat{C^F_{ih}}^{\sigma-1}}
\end{aligned}$$

Using $D_{ig}d_{ik,g} = \varphi_{ik,g}Y^F_{ik}$ and $e_{ig,R}E_i = \varphi_{ig,R}Y^C_{ig}$, we get:

$$\widehat{C^F_{ik}}^{1-\sigma} = \varphi_{ik,L} + \sum_g \varphi_{ik,g}\varphi_{ig,L}\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} + \sum_g \frac{E_i e_{ig,R}\hat{r}_{ig}^{\frac{1}{\sigma}}}{Y^F_{ik}}\,\frac{d_{ik,g}}{\sum_h d_{ih,g}\widehat{Y^F_{ih}}\widehat{C^F_{ih}}^{\sigma-1}}$$

Rearranging, and noticing that $\frac{\widehat{Y^F_{ik}}}{\widehat{C^F_{ik}}^{1-\sigma}} = \frac{D^F_{ik}}{Y^F_{ik}}\frac{\widehat{E_i}}{\widehat{P^F_i}^{1-\sigma}}\lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}$, we obtain:

$$\begin{aligned}
Y^F_{ik}\widehat{Y^F_{ik}} &= \frac{Y^F_{ik}\widehat{Y^F_{ik}}}{\widehat{C^F_{ik}}^{1-\sigma}}\left[\varphi_{ik,L} + \sum_g \varphi_{ik,g}\varphi_{ig,L}\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}}\right] + E_i\sum_g e_{ig,R}\hat{r}_{ig}^{\frac{1}{\sigma}}\,\frac{d_{nkg}\widehat{Y^F_{ik}}\widehat{C^F_{ik}}^{\sigma-1}}{\sum_h d_{nhg}\widehat{Y^F_{ih}}\widehat{C^F_{ih}}^{\sigma-1}} \\
&= \frac{\widehat{E_i}D^F_{ik}}{\widehat{P^F_i}^{1-\sigma}}\lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}\left[\varphi_{ik,L} + \sum_g \varphi_{ik,g}\varphi_{ig,L}\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}}\right] + E_i\sum_g e_{ig,R}\hat{r}_{ig}^{\frac{1}{\sigma}}\,\frac{d_{nkg}\widehat{Y^F_{ik}}\widehat{C^F_{ik}}^{\sigma-1}}{\sum_h d_{nhg}\widehat{Y^F_{ih}}\widehat{C^F_{ih}}^{\sigma-1}}
\end{aligned}$$

and summing across industries, we get:

$$E_i\widehat{E_i} = \sum_k Y^F_{ik}\widehat{Y^F_{ik}} = \sum_k \frac{\widehat{E_i}D^F_{ik}}{\widehat{P^F_i}^{1-\sigma}}\lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}\left[\varphi_{ik,L} + \sum_g \varphi_{ik,g}\varphi_{ig,L}\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}}\right] + E_i\sum_g e_{ig,R}\hat{r}_{ig}^{\frac{1}{\sigma}}$$

which can be rewritten:

$$\widehat{E_i} - \sum_g e_{ig,R}\hat{r}_{ig}^{\frac{1}{\sigma}} = \frac{\widehat{E_i}}{\widehat{P^F_i}^{1-\sigma}}\sum_k \alpha_{ik}\lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}\left[\varphi_{ik,L} + \sum_g \varphi_{ik,g}\varphi_{ig,L}\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}}\right]$$

The counterfactual equation describing the change in income provides: $\widehat{E}_i = e_{iL} + \sum_g e_{ig,R}\hat{r}_{ig}$. Combining with the equation above, we obtain:

$$\frac{\widehat{E_i}}{\widehat{P^F_i}^{1-\sigma}}\sum_k \alpha_{ik}\lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}\left[\varphi_{ik,L} + \sum_g \varphi_{ik,g}\varphi_{ig,L}\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}}\right] = e_{iL}$$

Hence:

$$\frac{\widehat{E_i}}{\widehat{P^F_i}^{1-\sigma}} = \Lambda_i^{\sigma-1}$$

where Λ_i is defined as:

$$\Lambda_i^{1-\sigma} \equiv \frac{1}{e_{iL}}\sum_k \alpha_k\lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}\left[\varphi_{ik,L} + \sum_g \varphi_{ik,g}\varphi_{ig,L}\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}}\right] \tag{60}$$

Plugging it back into 53, and using again $\frac{\widehat{Y^F_{ik}}}{\widehat{C^F_{ik}}^{1-\sigma}} = \frac{D^F_{ik}}{Y^F_{ik}}\frac{\widehat{E_i}}{\widehat{P^F_i}^{1-\sigma}}\lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}$, we obtain an analytical expression for the change in income for natural resources:

$$\begin{aligned}
\hat{r}_{ig} &= \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k d_{nkg} \frac{\widehat{Y_{ik}^F}}{\widehat{C_{ik}^F}^{1-\sigma}}\right)^{\frac{1}{\sigma}} \\
&= \left(\frac{\widehat{E_i}}{\widehat{P_i^F}^{1-\sigma}}\right)^{\frac{1}{\sigma}} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k \frac{d_{nkg} D_{ik}^F}{Y_{ik}^F} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}\right)^{\frac{1}{\sigma}} \\
&= \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{1}{\Lambda_i^{1-\sigma}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k \frac{d_{nkg} D_{ik}^F}{Y_{ik}^F} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}\right)^{\frac{1}{\sigma}}
\end{aligned}$$

Next, using again the counterfactual equation describing the change in income, we obtain the change in GDP:

$$\begin{aligned}
\widehat{E}_i &= e_{iL} + \sum_g e_{ig,R} \hat{r}_{ig} \\
&= e_{iL} + \sum_g e_{ig,R} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{e_{iL}}{\Lambda_i^{1-\sigma}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k \frac{d_{nkg} D_{ik}^F}{Y_{ik}^F} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}\right)^{\frac{1}{\sigma}}
\end{aligned}$$

For the price index of manufacturing goods, we get:

$$\begin{aligned}
\widehat{P_i^F}^{1-\sigma} &= \widehat{E_i}\, \Lambda_i^{1-\sigma} \\
&= \Lambda_i^{1-\sigma} \left[e_{iL} + \sum_g e_{ig,R} \hat{r}_{ig}\right] \\
\widehat{P_i^F} &= \Lambda_i \left[e_{iL} + \sum_g e_{ig,R} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{1}{\Lambda_i^{1-\sigma}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k \frac{d_{nkg} D_{ik}^F}{Y_{ik}^F} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}\right)^{\frac{1}{\sigma}}\right]^{\frac{1}{1-\sigma}}
\end{aligned}$$

Finally, we obtain that the gains from trade are:

$$\begin{aligned}
GT_i = \frac{\widehat{P_i^F}}{\widehat{E_i}} &= \Lambda_i \left[e_{iL} + \sum_g e_{ig,R} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{1}{\Lambda_i^{1-\sigma}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k \frac{d_{nkg} D_{ik}^F}{Y_{ik}^F} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}\right)^{\frac{1}{\sigma}}\right]^{\frac{\sigma}{1-\sigma}} \\
&= \left[\Lambda_i^{\frac{1-\sigma}{\sigma}} + \sum_g e_{ig,R} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k \frac{d_{nkg} D_{ik}^F}{Y_{ik}^F} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}\right)^{\frac{1}{\sigma}}\right]^{\frac{\sigma}{1-\sigma}}
\end{aligned}$$

C - Alternative model specifications

Choke prices. With the alternative production function of downstream industries specified in Section 3.4.1, the cost and demand for labor and commodities correspond to:

$$\begin{aligned}
C_{ik} &= \left[\beta_{ik,L}^F w_i^{1-\eta_k} + \sum_g \beta_{ik,g}^F \left(P_{ig}^{1-\eta_k} - (1-\eta_k) P_{ig} (a_{ig} w_i)^{-\eta_k}\right)\right]^{\frac{1}{1-\eta_k}} \\
D_{igk} &= \beta_{ik,g}^F \left(P_{ig}^{1-\eta_k} - (a_{ig} w_i)^{-\eta_k} P_{ig}\right) \cdot \frac{Y_{ik}^F}{C_{ik}^{1-\eta_k}}
\end{aligned}$$

$$w_i L_{igk} = \left[\beta^F_{ik,L} w_i^{1-\eta_k} + \eta_k \sum_g \beta^F_{ik,g} P_{ig} (a_{ig} w_i)^{-\eta_k}\right] \cdot \frac{Y^F_{ik}}{C_{ik}^{1-\eta_k}}$$

In this case, note that the share of commodity g in costs is now:

$$\varphi_{ik,g} = \frac{\partial \log C_{ik}}{\partial \log P_{ig}} = \frac{\beta^F_{ik,g} P_{ig} \left(P_{ig}^{-\eta_k} - (a_{ig} w_i)^{-\eta_k}\right)}{C_{ik}^{1-\eta_k}}$$

while the share of labor is:

$$\varphi_{ik,L} = \frac{\partial \log C_{ik}}{\partial \log w_i} = \frac{\beta^F_{ik,L} w_i^{1-\eta_k}}{C_{ik}^{1-\eta_k}} + \eta_k \sum_g \frac{\beta^F_{ik,g} P_{ig} (a_{ig} w_i)^{-\eta_k}}{C_{ik}^{1-\eta_k}}$$

Now the counterfactual change in downstream costs corresponds to:

$$\begin{aligned}
\widehat{C^F_{ik}}^{1-\eta_k} &= \frac{\beta^F_{ik,L} w_i^{1-\eta_k} \widehat{w_i}^{1-\eta_k}}{C_{ik}^{1-\eta_k}} + \sum_g \left[\frac{\beta^F_{ik,g} P_{ig}^{1-\eta_k} \widehat{P_{ig}}^{1-\eta_k}}{C_{ik}^{1-\eta_k}} - \frac{(1-\eta_k)\beta^F_{ik,g} P_{ig} (a_{ig} w_i)^{-\eta_k} \widehat{P_{ig}} \hat{w}_i^{-\eta_k}}{C_{ik}^{1-\eta_k}}\right] \\
&= \varphi_{ik,L} \hat{w}_i^{1-\eta_k} + \sum_g \varphi_{ik,g} \widehat{P_{ig}}^{1-\eta_k} + \sum_g \frac{\beta^F_{ik,g} P_{ig} (a_{ig} w_i)^{-\eta_k}}{C_{ik}^{1-\eta_k}} \left[\widehat{P_{ig}}^{1-\eta_k} - \eta_k \hat{w}_i^{1-\eta_k} - (1-\eta_k) \widehat{P_{ig}} \hat{w}_i^{-\eta_k}\right] \\
&= \varphi_{ik,L} \hat{w}_i^{1-\eta_k} + \sum_g \varphi_{ik,g} \widehat{P_{ig}}^{1-\eta_k} + \sum_g \frac{\varphi_{ik,g} \Delta_{ig}}{1 - \Delta_{ig}} \left[\widehat{P_{ig}}^{1-\eta_k} - \eta_k \hat{w}_i^{1-\eta_k} - (1-\eta_k) \widehat{P_{ig}} \hat{w}_i^{-\eta_k}\right]
\end{aligned}$$

Note that $\frac{\beta^F_{ik,g} P_{ig} (a_{ig} w_i)^{-\eta_k}}{C_{ik}^{1-\eta_k}} = \varphi_{ik,g} \frac{(a_{ig} w_i)^{-\eta_k}}{P_{ig}^{-\eta_k} - (a_{ig} w_i)^{-\eta_k}} = \varphi_{ik,g} \frac{\Delta_{ig}}{1 - \Delta_{ig}}$

For the counterfactual change in the demand in commodity g, we get:

$$\begin{aligned}
\widehat{D_{ngk}} &= \left(\frac{P_{ig}^{-\eta_k} \widehat{P_{ng}}^{-\eta_k} - (a_{ig} w_i)^{-\eta_k} \widehat{w_i}^{-\eta_k}}{P_{ig}^{-\eta_k} - (a_{ig} w_i)^{-\eta_k}}\right) \frac{\widehat{P^C_{ng}}\ \widehat{Y_{nk}}}{\widehat{C_{nk}}^{1-\eta_k}} && (61) \\
&= \left(\frac{1 - \Delta_{ig} (\widehat{P_{ng}} / \widehat{w_i})^{\eta_k}}{1 - \Delta_{ig}}\right) \frac{\widehat{P_{ng}}^{1-\eta_k}\ \widehat{Y_{nk}}}{\widehat{C_{nk}}^{1-\eta_k}} && (62)
\end{aligned}$$

Note that $\Delta_{ig} (\widehat{P_{ng}} / \widehat{w_i})^{\eta_k}$ must remain smaller than unity, i.e. the counterfactual price must remain below the choke price.

From labor demand, we now get:

$$\begin{aligned}
\hat{w}_i &= s^L_{i,Serv} \hat{w}_i + \sum_g \frac{s^L_{ig}\ \widehat{Y^C_{ig}}\ \hat{w}_i^{1-\rho_g}}{\widehat{C}_{ig}^{1-\rho_g}} \\
&+ \sum_k s^L_{i,k} \left(\frac{\beta^F_{ik,L} w_i^{1-\eta_k} + \eta_k \sum_g \beta^F_{ik,g} P_{ig} (a_{ig} w_i)^{-\eta_k} \widehat{P_{ng}} / \hat{w}_i}{\beta^F_{ik,L} w_i^{1-\eta_k} + \eta_k \sum_g \beta^F_{ik,g} P_{ig} (a_{ig} w_i)^{-\eta_k}}\right) \frac{\hat{w}_i^{1-\eta_k} \widehat{Y^F_{ik}}}{\widehat{C_{ik}}^{1-\eta_k}} \\
&= s^L_{i,Serv} \hat{w}_i + \sum_g \frac{s^L_{ig}\ \widehat{Y^C_{ig}}\ \hat{w}_i^{1-\rho_g}}{\widehat{C}_{ig}^{1-\rho_g}} \\
&+ \sum_k s^L_{i,k} \left(1 + \eta_k \sum_g \frac{\varphi_{ik,g} (a_{ig} w_i)^{-\eta_k}}{\varphi_{ik,L} \left(P_{ig}^{-\eta_k} - (a_{ig} w_i)^{-\eta_k}\right)} \frac{\widehat{P_{ng}}}{\hat{w}_i}\right) \frac{\hat{w}_i^{1-\eta_k} \widehat{Y^F_{ik}}}{\widehat{C_{ik}}^{1-\eta_k}}
\end{aligned}$$

$$= \quad s^L_{i,Serv}\hat{w}_i \; + \; \sum_g \frac{s^L_{ig}\; \widehat{Y^C_{ig}}\; \hat{w}_i^{1-\rho_g}}{\widehat{C}_{ig}^{1-\rho_g}} + \sum_k s^L_{i,k}\; \frac{\hat{w}_i^{1-\eta_k}\widehat{Y^F_{ik}}}{\widehat{C_{ik}}^{1-\eta_k}} \; + \; \sum_{k,g} \frac{\eta_k s^L_{i,k}\varphi_{ik,g}\Delta_{ig}}{\varphi_{ik,L}(1-\Delta_{ig})} \frac{\widehat{P_{ng}}\hat{w}_i^{-\eta_k}\widehat{Y^F_{ik}}}{\widehat{C_{ik}}^{1-\eta_k}}$$

Land allocation with constant elasticity of transformation. Suppose that country i is endowed with land T_i, which can be used to produce commodity g with productivity A_{ig}.

$$\sum_g (Q_{ig}/A_{ig})^{\frac{1+\rho}{\rho}} = T_i^{\frac{1+\rho}{\rho}}$$

Maximizing income from land (C_{ig} is the producer price for commodity g):

$$\sum_g C_{ig}Q_{ig}$$

leads to:

$$Y_{ig} = C_{ig}Q_{ig} = \lambda_i (Q_{ig}/A_{ig})^{\frac{1+\rho}{\rho}}$$

Rewriting, we get:

$$Q_{ig} = \lambda_i^{-\rho} A_{ig}^{1+\rho} C_{ig}^{\rho}$$

and:

$$(Q_{ig}/A_{ig})^{\frac{1+\rho}{\rho}} = \lambda_i^{-(1+\rho)} A_{ig}^{-\frac{1+\rho}{\rho}+\frac{(1+\rho)^2}{\rho}} C_{ig}^{1+\rho} = \lambda_i^{-(1+\rho)} A_{ig}^{1+\rho} P_{ig}^{1+\rho}$$

Taking the sum, we obtain:

$$T_i^{\frac{1+\rho}{\rho}} = \sum_g (Q_{ig}/A_{ig})^{\frac{1+\rho}{\rho}} = \sum_g \lambda_i^{-(1+\rho)} A_{ig}^{1+\rho} C_{ig}^{1+\rho} \qquad \Longrightarrow \quad \lambda_i^{1+\rho} = \sum_g A_{ig}^{1+\rho} C_{ig}^{1+\rho} T_i^{-\frac{1+\rho}{\rho}}$$

which leads to the expression in the main text after substituting λ_i.

Closed-form solution with CET for the gains from trade relative to Autarky.

$$\widehat{C_{ig}} = \widehat{\Phi_i}^{\frac{\rho}{1+\rho}} \widehat{Y_{ig}}^{\frac{1}{1+\rho}}$$

combined with:

$$\widehat{Y_{ig}} = \widehat{C_{ig}}^{1-\sigma} \; \lambda_{ig}^{-\frac{1-\sigma}{\theta_g \sigma}} \; \frac{D^C_{ig}}{Y^C_{ig}} \; \sum_k d_{nkg} \frac{\widehat{Y^F_{ik}}}{\widehat{C^F_{ik}}^{1-\sigma}}$$

leads to:

$$\widehat{C_{ig}} = \widehat{\Phi_i}^{\frac{\rho}{\rho+\sigma}} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \; \frac{D^C_{ig}}{Y^C_{ig}} \; \sum_k d_{nkg} \frac{\widehat{Y^F_{ik}}}{\widehat{C^F_{ik}}^{1-\sigma}} \right)^{\frac{1}{\rho+\sigma}}$$

Plugging it back into the expression for Φ_i, we obtain:

$$\widehat{\Phi_i}^{\frac{\sigma(1+\rho)}{\rho+\sigma}} \quad = \quad \sum_g \pi^T_{ig} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \; \frac{D^C_{ig}}{Y^C_{ig}} \; \sum_k d_{nkg} \frac{\widehat{Y^F_{ik}}}{\widehat{C^F_{ik}}^{1-\sigma}} \right)^{\frac{1+\rho}{\rho+\sigma}}$$

In turn, for the cost of downstream industries, we obtain

$$\widehat{C^F_{ik}}^{1-\sigma} \quad = \quad \varphi_{ik,L} + \sum_g \varphi_{ik,g} (\widehat{P^C_{ig}})^{1-\sigma} \; = \; \varphi_{ik,L} + \sum_g \varphi_{ik,g} \lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \widehat{C_{ig}}^{1-\sigma}$$

$$= \quad \varphi_{ik,L} + \widehat{\Phi}_i^{\frac{\rho(1-\sigma)}{\rho+\sigma}} \sum_g \varphi_{ik,g} \lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k d_{nkg} \frac{\widehat{Y_{ik}^F}}{\widehat{C_{ik}^F}^{1-\sigma}} \right)^{\frac{1-\sigma}{\rho+\sigma}}$$

With $\widehat{P_i^F}^{1-\sigma} = \sum_k \alpha_{ik} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}} \widehat{C_{ik}^F}^{1-\sigma}$, we get:

$$\begin{aligned} \widehat{P_i^F}^{1-\sigma} &= \sum_k \alpha_{ik} \varphi_{ik,L} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}} + \widehat{\Phi}_i^{\frac{\rho(1-\sigma)}{\rho+\sigma}} \sum_{k,g} \alpha_{ik} \varphi_{ik,g} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}} \lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k d_{nkg} \frac{\widehat{Y_{ik}^F}}{\widehat{C_{ik}^F}^{1-\sigma}} \right)^{\frac{1-\sigma}{\rho+\sigma}} \\ &= \sum_k \alpha_{ik} \varphi_{ik,L} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}} + \widehat{\Phi}_i^{\frac{\rho(1-\sigma)}{\rho+\sigma}} \sum_{k,g} \frac{\alpha_{ik} \varphi_{ik,g} Y_{ig} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}}{D_{ig} \sum_k d_{nkg} \widehat{Y_{ik}^F} \widehat{C_{ik}^F}^{\sigma-1}} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k d_{nkg} \frac{\widehat{Y_{ik}^F}}{\widehat{C_{ik}^F}^{1-\sigma}} \right)^{\frac{1+\rho}{\rho+\sigma}} \end{aligned}$$

Using $D_{ig} d_{igk} = \varphi_{ik,g} Y_{ik}^F$ and $e_{ig,R} E_i = Y_{ig}^C$ and $\alpha_{ik} E_i$, we get:

$$\widehat{P_i^F}^{1-\sigma} = \sum_k \alpha_{ik} \varphi_{ik,L} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}} + \widehat{\Phi}_i^{\frac{\rho(1-\sigma)}{\rho+\sigma}} \sum_{k,g} \frac{D_{ik}\ d_{ik,g} e_{ig,R} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}}{Y_{ik} \sum_k d_{nkg} \widehat{Y_{ik}^F} \widehat{C_{ik}^F}^{\sigma-1}} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k d_{nkg} \frac{\widehat{Y_{ik}^F}}{\widehat{C_{ik}^F}^{1-\sigma}} \right)^{\frac{1+\rho}{\rho+\sigma}}$$

Rearranging, and noticing that $\widehat{Y_{ik}^F} \widehat{C_{ik}^F}^{\sigma-1} = \frac{D_{ik}^F}{Y_{ik}^F} \widehat{E_i} \widehat{P_i^F}^{\sigma-1} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}$, we obtain:

$$\begin{aligned} \widehat{E_i} &= \widehat{E_i} \widehat{P_i^F}^{\sigma-1} \sum_k \alpha_{ik} \varphi_{ik,L} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}} + \widehat{\Phi}_i^{\frac{\rho(1-\sigma)}{\rho+\sigma}} \sum_g e_{ig,R} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k d_{nkg} \frac{\widehat{Y_{ik}^F}}{\widehat{C_{ik}^F}^{1-\sigma}} \right)^{\frac{1+\rho}{\rho+\sigma}} \\ &= \widehat{E_i} \widehat{P_i^F}^{\sigma-1} \sum_k \alpha_{ik} \varphi_{ik,L} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}} + e_{iR} \widehat{\Phi_i} \end{aligned}$$

Using $\widehat{E}_i = e_{iL} + e_{i,R} \widehat{\Phi_i}$, we obtain:

$$\widehat{E_i} \widehat{P_i^F}^{\sigma-1} = \Lambda_i^{\sigma-1}$$

where Λ_i is defined as:

$$\Lambda_i^{1-\sigma} \equiv \frac{1}{e_{iL}} \sum_k \alpha_{ik} \varphi_{ik,L} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}$$

Plugging it back into the expression for $\widehat{\Phi}_i$, and using again $\frac{\widehat{Y_{ik}^F}}{\widehat{C_{ik}^F}^{1-\sigma}} = \frac{D_{ik}^F}{Y_{ik}^F} \frac{\widehat{E_i}}{\widehat{P_i^F}^{1-\sigma}} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}} = \Lambda_i^{\sigma-1} \frac{D_{ik}^F}{Y_{ik}^F} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}$, we obtain an analytical expression for the change in income for natural resources:

$$\widehat{\Phi_i} = \left[\sum_g \pi_{ig}^T \left(\frac{\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}}}{\Lambda_i^{1-\sigma}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k d_{nkg} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}} \frac{D_{ik}^F}{Y_{ik}^F} \right)^{\frac{1+\rho}{\rho+\sigma}} \right]^{\frac{\rho+\sigma}{\sigma(1+\rho)}}$$

Change in income is then:

$$\widehat{E_i} = e_{iL} + e_{i,R} \widehat{\Phi_i} = e_{iL} + e_{i,R} \left[\sum_g \pi_{ig}^T \left(\frac{\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}}}{\Lambda_i^{1-\sigma}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k d_{nkg} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}} \frac{D_{ik}^F}{Y_{ik}^F} \right)^{\frac{1+\rho}{\rho+\sigma}} \right]^{\frac{\rho+\sigma}{\sigma(1+\rho)}}$$

For the final goods price index, we get:

$$\widehat{P_i^F}^{1-\sigma} = \widehat{E_i}\,\Lambda_i^{1-\sigma} = \Lambda_i^{1-\sigma}\left[e_{iL} + e_{i,R}\widehat{\Phi_i}\right]$$

Finally, we obtain that the gains from trade are:

$$\begin{aligned}
GT_i &= \frac{\widehat{P_i^F}}{\widehat{E_i}} = \frac{\widehat{P_i^F}}{\widehat{E_i}^{\frac{1}{1-\sigma}}}\widehat{E_i}^{\frac{\sigma}{1-\sigma}} = \Lambda_i \widehat{E_i}^{\frac{\sigma}{1-\sigma}} \\
&= \Lambda_i \left\{ e_{iL} + e_{i,R}\left[\sum_g \pi_{ig}^T \left(\frac{\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}}}{\Lambda_i^{1-\sigma}}\ \frac{D_{ig}^C}{Y_{ig}^C}\ \sum_k d_{nkg}\lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}\frac{D_{ik}^F}{Y_{ik}^F}\right)^{\frac{1+\rho}{\rho+\sigma}}\right]^{\frac{\rho+\sigma}{\sigma(1+\rho)}}\right\}^{\frac{\sigma}{1-\sigma}} \\
&= \left\{ e_{iL}\Lambda_i^{\frac{1-\sigma}{\sigma}} + e_{i,R}\left[\sum_g \pi_{ig}^T \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}}\ \frac{D_{ig}^C}{Y_{ig}^C}\ \sum_k d_{nkg}\lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}\frac{D_{ik}^F}{Y_{ik}^F}\right)^{\frac{1+\rho}{\rho+\sigma}}\right]^{\frac{\rho+\sigma}{\sigma(1+\rho)}}\right\}^{\frac{\sigma}{1-\sigma}}
\end{aligned}$$

D - Survey of Elasticity Estimates

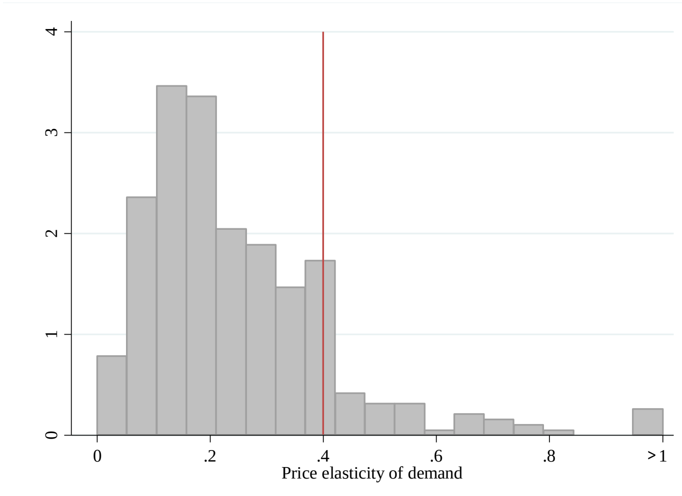


Figure 18: Meta-distribution of price elasticity of demand

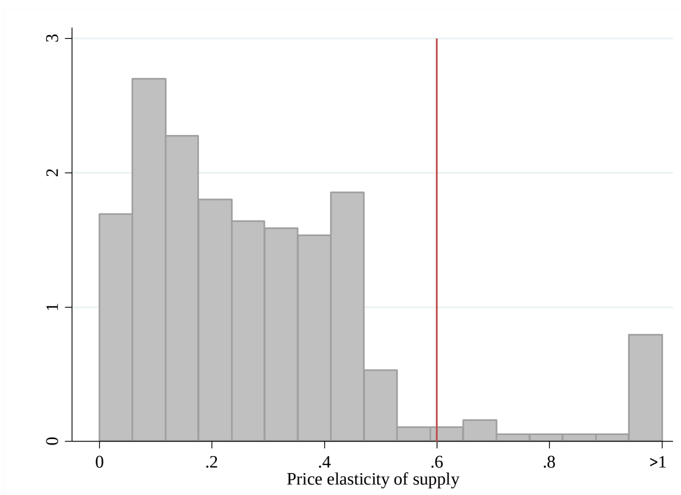


Figure 19: Meta-distribution of price elasticity of supply

Commodity	PED	PES	Location	Citation
Poultry		(0.3 to 0.6)	World	Jenkins (2011).
Canned Tuna	-0.3	0.2	US	Babula and Corey Jr (2004)
Snow Crab	(-1.72 to -1.43)	(2.83 to 4.43)	US, Japan	Greenberg et al. (1995)
Tomatoes	-0.32	0.27 (SR), 0.403 (LR)	US, California	Russo et al. (2008)
Almonds	-0.48 to -0.35	0.19	US, California	Russo et al. (2008)
Peanuts	(-0.3 to -0.1)	(0.04 to 0.4)	Various	FAPRI
Pulse grains		0.1695	India	Kumar et al. (2010)
Walnuts	(-0.267 to -0.251)	0.02 (SR), 0.08 (LR)	US, California	Russo et al. (2008)
Bananas		(0.2 to 0.4)	World	Jenkins (2011).
Coffee	-.2 (SR), -.339 (LR)		US	Okunade (1992).
Coffee		(0.14 to 0.24) (SR) (0.37 to 0.6) (LR)	Africa	Askari and Cummings (1977).
Coffee		0.28 (SR), 0.52 (LR)	Latin America	Askari and Cummings (1977).
Coffee		0.1 (SR), 0.11 (LR)	Brazil	Askari and Cummings (1977).
Coffee		(0.1 to 0.4)	World	Jenkins (2011).
Wheat	(-0.33 to -0.26)	0.12	EU	FAPRI
Wheat		0.2164	India	Kumar et al. (2010)
Wheat		(0.02 to 0.36)	US, Ukraine	Haile et al. (2016)
Barley	(-0.41 to -0.14)	0.12	EU	FAPRI
Corn	(-0.44 to -0.24)	0.08	EU	FAPRI
Corn		(0.02 to 0.49)	China, US	Haile et al. (2016)
Rice		0.2357	India	Kumar et al. (2010)
Rice		(-0.02 to 0.3)	China	Haile et al. (2016)
Rice	-0.14	(0.18 to 0.23)	US, California	Russo et al. (2008)
Sorghum	(-0.49 to -0.3)	0.53	Argentina	FAPRI
Soybeans		(0.04 to 0.61)	India, Ukraine	Haile et al. (2016)
Soybeans		(0.4 to 0.6)	World	Jenkins (2011).
Oilseeds		0.5079	India	Kumar et al. (2010)
Rapeseed	(-0.3 to -0.08)	(0.26 to 0.36)	Various	FAPRI
Sugar	-0.13	0.14	Australia	FAPRI
Sugar		(0.1 to 0.5)	World	Jenkins (2011).
Sugar(cane)		0.1216	India	Kumar et al. (2010)
Alfalfa	-0.107	0.44	US, California	Russo et al. (2008)
Soybean Oil		(0.4 to 0.6)	World	Jenkins (2011).
Iron ore	-0.0865		World	Evans and Lewis (2002)
Iron ore		0.589	World	Damuth (2011)
Iron ore		(0.25 to 0.4)	World	Jenkins (2011).
Manganese	-0.1		World	Radetzki (1984)
Manganese		> 1 (SR)		Brookes (2015)
Copper	-0.42			MacKinnon and Olewiler (1980)
Copper	-0.4		12 Countries	Stuermer (2017)
Copper		1.2 (SR), 6 (LR)		Foley and Clark (1981)
Copper		0.453 (SR), 1.67 (LR)		Fisher et al. (1972)
Copper	-0.2 (SR), -1.35 (LR)			Varon and Takeuchi (1974)
Copper		(0.1 to 0.25)	World	Jenkins (2011)
Copper		0.77		Connelly and Perlman (1975)
Nickel	-0.0376		World	Evans and Lewis (2002)
Nickel		0.23	Canada	Donges (2012)
Nickel		0.9 (SR), 1.2 (LR)	North America	Donges (2012)
Nickel		1.04 (SR), 5.5 (LR)	Oceania	Donges (2012)
Nickel		2.03		Connelly and Perlman (1975)
Cobalt	-0.5		World	Radetzki (1984)
Cobalt		< 1	World	Sibley (1980)
Aluminium	-0.07	0.17	Europe	Blomberg and Hellmer (2000)
Aluminium	-0.7		12 Countries	Stuermer (2017)
Aluminium	-0.2 (SR), -2.5 (LR)			Varon and Takeuchi (1974)
Aluminium	-0.6524		World	Evans and Lewis (2002)
Aluminium		(0.25 to 0.4)	World	Jenkins (2011)
Aluminium		1.15		Connelly and Perlman (1975)

Notes: Many elasticity estimates of agricultural products from the Food and Agricultural Policy Research Institute (FAPRI) have been omitted from this table, although we use these to generate a range of elasticity estimates in Table 2 in the main section.

Commodity	PED	PES	Location	Citation
Lead	-0.22		12 Countries	Stuermer (2017)
Lead	-0.1108		World	Evans and Lewis (2002)
Lead		0.1 (LR)	US	Sigman (2004)
Lead		0.81 (LR)	US	Sigman (1995)
Lead		1.84		Connelly and Perlman (1975)
Zinc	-0.064		12 Countries	Stuermer (2017)
Zinc	-0.0635		World	Evans and Lewis (2002)
Zinc		(0.1 to 0.25)	World	Jenkins (2011)
Zinc		1.75		Connelly and Perlman (1975)
Tin	-0.169		12 Countries	Stuermer (2017)
Tin	-0.55 (SR) -1.262 (LR)			Banks (1972)
Tin	-0.0968		World	Evans and Lewis (2002)
Tin		0.31 (SR), 0.7 (LR)	Malaysia	Chhabra et al. (1979)
Tin	(-0.11 to -0.49) (SR) -1.6 (LR)	0.3 (SR), 0.7 (LR)	OECD	Chhabra et al. (1979)
Tin	-0.11 (SR), -0.15 (LR)	1.11 (SR), 2.09 (LR)	Rest of World	Chhabra et al. (1979)
Chromium	-0.2771		World	Evans and Lewis (2002)
Chromium	-0.1		World	Radetzki (1984)
Tungsten	-.15 (SR), -.3 (LR)	0.15 (SR), 0.95 (LR)	US	Phillips (1974)
Tungsten	-.15 (SR), -.37 (LR)	0.11 (SR), 0.5 (LR)	Rest of World	Phillips (1974)
Tungsten	-0.5		World	Radetzki (1984)
Tungsten		0.3932 (LR)	Rest of World	Tan (1977)
Tungsten		0.7007 (LR)	China	Tan (1977)
Uranium		2.35		Schneider and Sailor (2008)
Uranium		11.4		Connelly and Perlman (1975)
Titanium	-0.1602		World	Evans and Lewis (2002)
Niobium	-0.2946		World	Evans and Lewis (2002)
Niobium	-0.3		World	Radetzki (1984)
Vanadium	-0.2537		World	Evans and Lewis (2002)
Vanadium	-0.3		World	Radetzki (1984)
Crude Oil		(0.1 to 0.25)	World	Jenkins (2011)
Sawn wood		(0.2 to 0.6)	World	Jenkins (2011)
Cotton	-0.684	0.497 (SR), .0503 (LR)	US, California	Russo et al. (2008)
Silver	-0.0423		World	Evans and Lewis (2002)
Gold	-0.4115		World	Evans and Lewis (2002)
Gold		1.426	World	Blose and Shieh (1995)
Palladium	-.2 (SR) (-1 to -.4) (LR)			Phillips (1974)
Platinum	-0.7 (SR) (-2.8 to -1.3) (LR)			Phillips (1974)
Platinum	-0.28		World	Evans and Lewis (2002)
Cocoa	(-.14 to -.01)		UK, US, France	Behrman (1965)
Cocoa		0.03 (SR), 0.15 (LR)	Dom. Rep.	Askari and Cummings (1977).
Cocoa		0.12 (SR), 0.38 (LR)	Venezuela	Askari and Cummings (1977).
Beef		(0.3 to 0.6)	World	Jenkins (2011)
Oil	-0.13	0.13		Caldara et al. (2016)
Chemical Pulp		(0.2 to 0.6)	World	Jenkins (2011)
Ethanol	(-3.606 to -2.08)	0.121	US	Luchansky and Monks (2009)
Fishmeal		(0.4 to 0.6)	World	Jenkins (2011)
Petroleum	(-0.31 to -0.22) (SR) (-1.01 to -0.8) (LR)		Lit. Review	Dahl and Sterner (1991)
Petroleum	-0.23 (SR), -0.43 (LR)		Median of Lit. Review	Espey (1998)
Petroleum	-0.24		World	Kilian and Murphy (2014)
Petroleum	(-0.077 to -0.034) (SR)		US, 2001-2006	Hughes et al. (2008)
Petroleum	(-0.34 to -0.21) (SR)		US, 1975-1980	Hughes et al. (2008)
Petroleum		0.85	World, 1973-1999	Krichene (2002)
Petroleum	-0.07	0.29	US, 1990-2009	Coyle et al. (2012)
Petroleum		0.09 (SR), 0.58 (LR)		Hogan (1989)
Natural Gas		0.37	World, 1973-1999	Krichene (2002)
Natural Gas		(0.014 to 0.15)		Barret (1992)
Natural Gas	(-0.95 to -0.053) (SR) (-4.6 to -0.39) (LR)		Lit. Review	Al-Sahlawi (1989)
Natural Gas	(-0.23 to -0.17) (MR)		California	Auffhammer and Rubin (2017)
Coal		0.05 (SR), 0.11 (LR)		Labys et al. (1979)
Coal	(-0.7 to -0.3)		China, 2012	Burke and Liao (2015)

Notes: SR indicates a short run elasticity estimate, and LR indicates a long run elasticity estimate.

E - List of primary commodities under consideration

Table 9: List of primary commodities under consideration

Almonds	Figs	Peaches
Alumina	Flax	Peanuts
Aluminium	Fluorspar	Pears
Antimony	Forage products	Peas
Apples	Gallium,indium,rhenium, thallium	Pepper
Apricots	Garlic	Peppers
Arsenic	Germanium	Perfume plants
Asbestos	Ginger	Petroleum
Asparagus	Gold	Phosphate
Avocados	Grapefruit	Pineapples
Bananas	Grapes	Pistachios
Barley	Graphite	Platinum
Barytes	Gypsum	Plums
Bauxite	Hazelnuts	Poppy seeds
Beans	Hops	Potash
Berries	Iodine	Potatoes
Beryl	Iridium, Osmium, Ruthenium	Ramie
Bismuth	Iron & Steel	Rapeseed
Borates	Jute	Rare Earths
Brazil nuts	Lead	Rhodium
Bromine	Leeks	Rice
Brussel sprouts	Legumes	Roots
Buckwheat	Legumes nec	Rye
Cadmium	Lemons	Salt
Canary seed	Lentils	Sand and gravel
Carrots	Lettuce	Seeds
Cashews	Linseed	Seeds nec
Cassava	Lithium	Selenium
Cauliflowers	Magnesium	Sesame seeds
Celery, radishes	Maize	Sillimanite
Cement	Mandarins	Silver
Cherries	Manganese	Sorghum
Chestnuts	Mangoes	Soy beans
Chickpeas	Mate	Spices
Chromium	Melons	Spinach
Cinnamon	Mercury	Strawberries
Citruses	Mica	Strontium
Cloves	Millet	Sugar
Coal	Molybdenum	Sunflower seeds
Cobalt (Metal)	Mushrooms	Sweet potatoes
Cobalt (Mine)	Mustard seeds	Talc
Cocoa	Natural Gas	Tea
Coconuts	Natural gums	Tellurium
Coffee	Natural rubber	Tin
Copper (Mine)	Nickel	Titanium
Copper (Refined)	Niobium, tantalum, vanadium	Tobacco
Copper (Smelted)	Nutmeg	Tomatoes
Cotton	Nuts nec	Tungsten
Cotton seeds	Oats	Uranium
Cucumbers	Oil seeds nec	Vanilla
Dates	Onions	Vermiculite
Diamond	Oranges	Walnuts
Diatomite	Other cereals	Wheat
Dried peppers	Palladium	Wollastonite
Eggplants	Palm oil	Zinc
Fava beans	Papayas	Zirconium
Feldspar		

F - Additional Figures

Figure 20: Crop suitability for cotton (green = high potential yield)

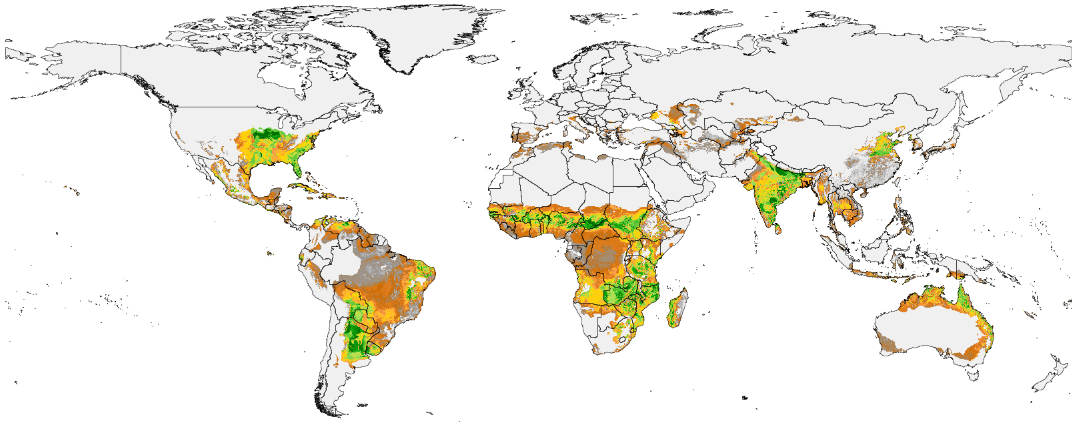
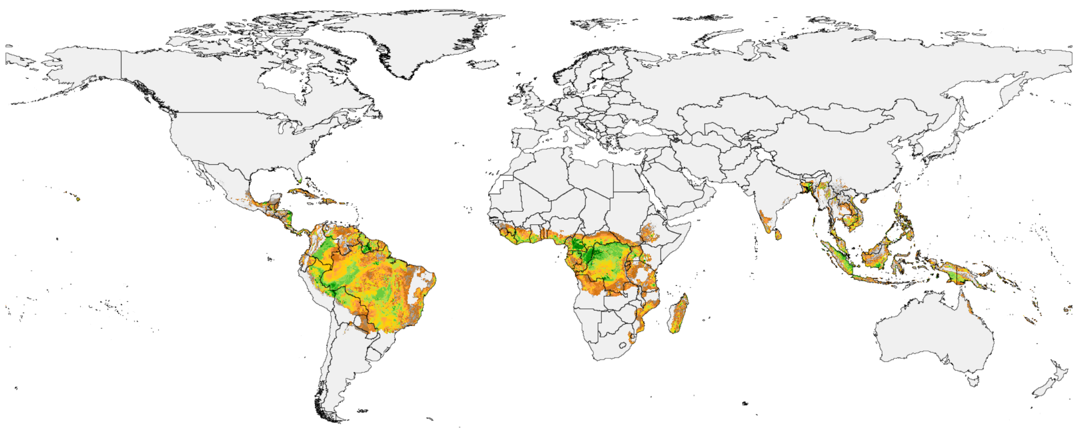


Figure 21: Crop suitability for coffee



Source: Global Agro-Ecological Zones (GAEZ) data, FAO. Model output is from GAEZ data at baseline years, an average of crop suitability from 1961-1990. Water supply is from rainfall, scarce data exists for irrigated crop suitability in GAEZ database. Model output is based on high inputs and advanced crop management, but the total amount of land which is suitable is not particularly sensitive to this asssumption.

Figure 22: Harvested area of cotton (green = higher concentration)

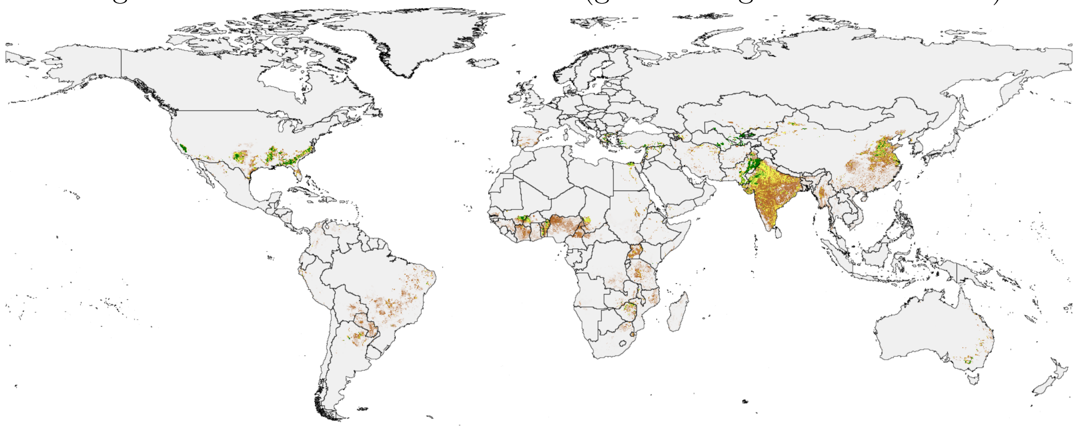
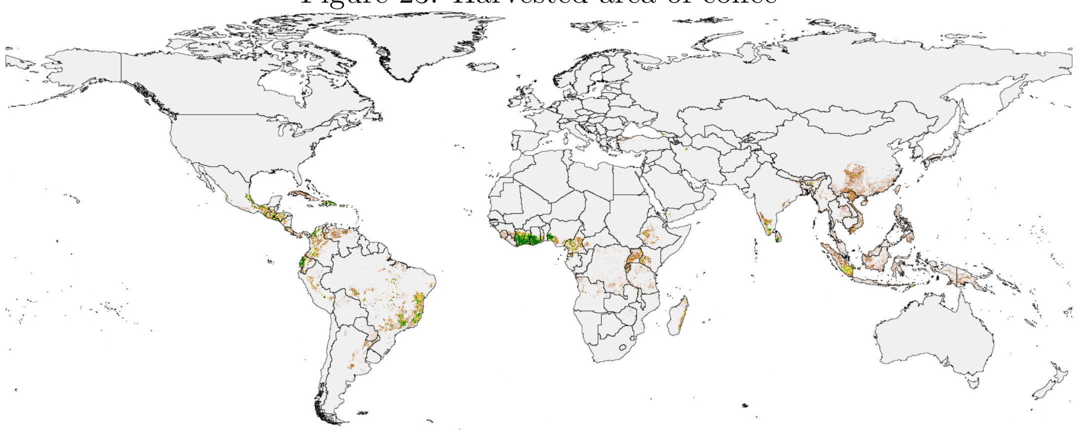


Figure 23: Harvested area of coffee



Source: Global Agro-Ecological Zones (GAEZ) data, FAO. Model output is crop harvested area for both irrigated and rain-fed land.

Figure 24: Crop suitability for maize; source: GAEZ

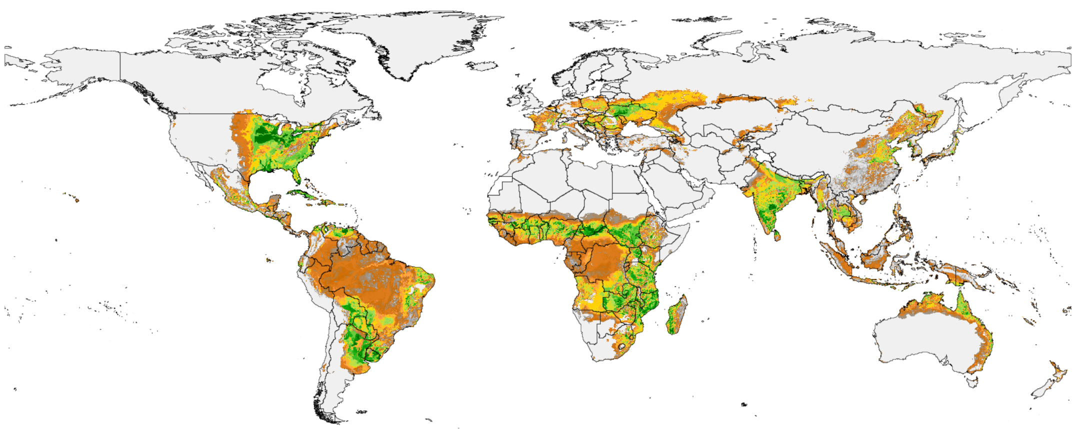
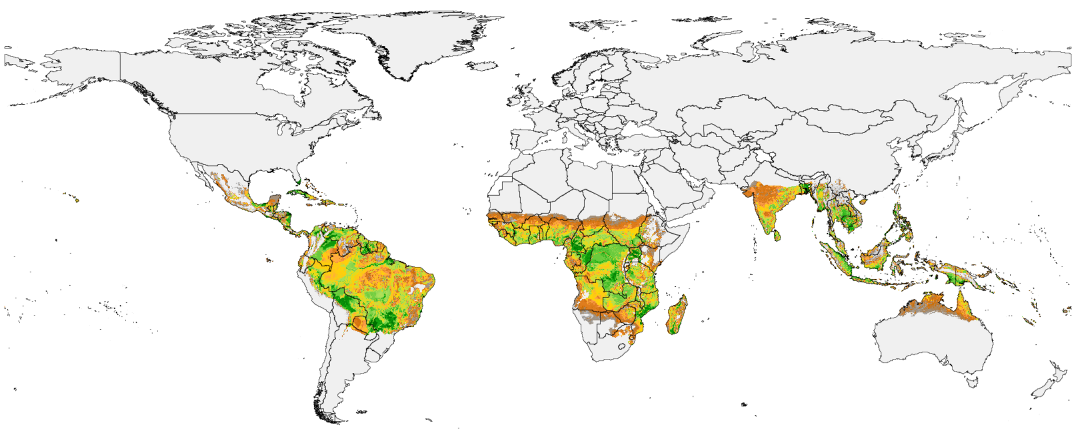


Figure 25: Crop suitability for dryland rice; source: GAEZ



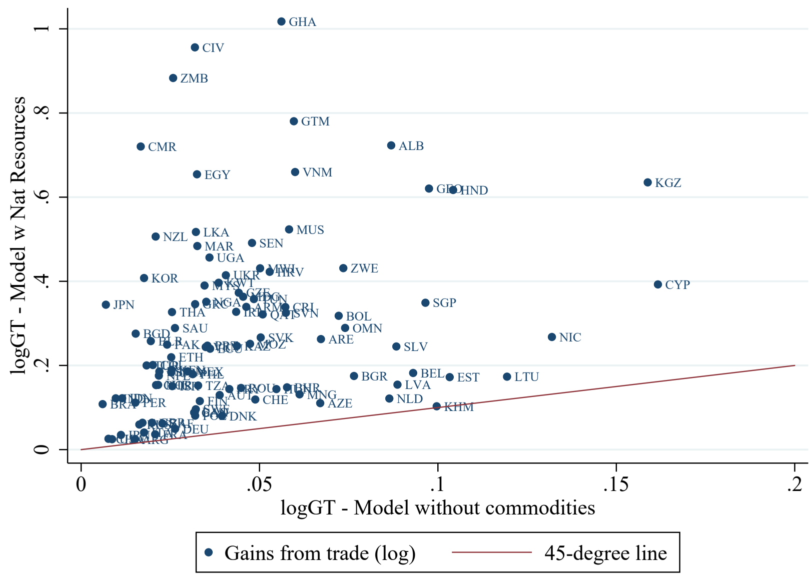


Figure 26: Gains from trade relative to gains from trade in manufacturing only

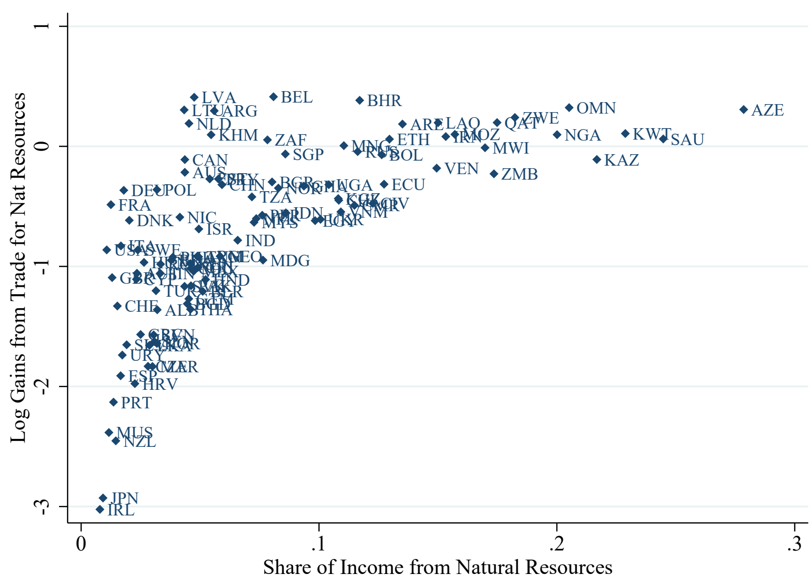


Figure 27: Natural resources owners' gains from trade and share of income from natural resources

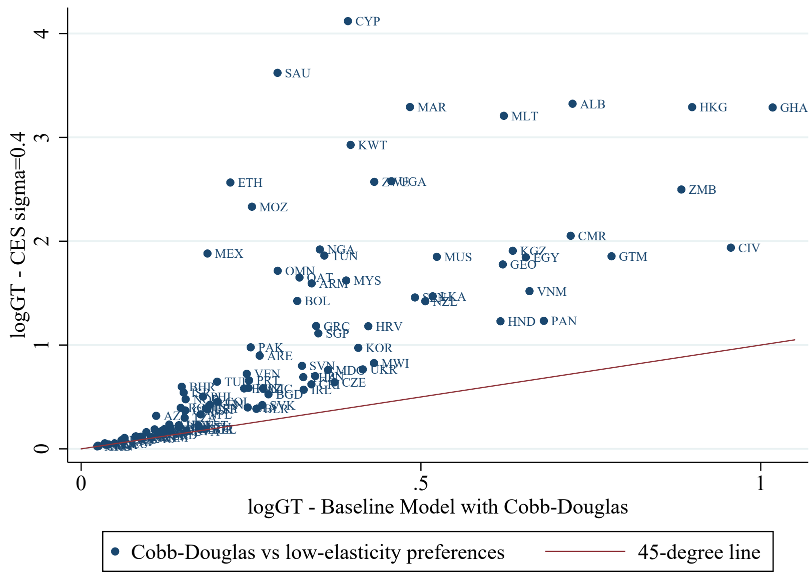


Figure 28: Role of the elasticity of substitution in preferences across final goods

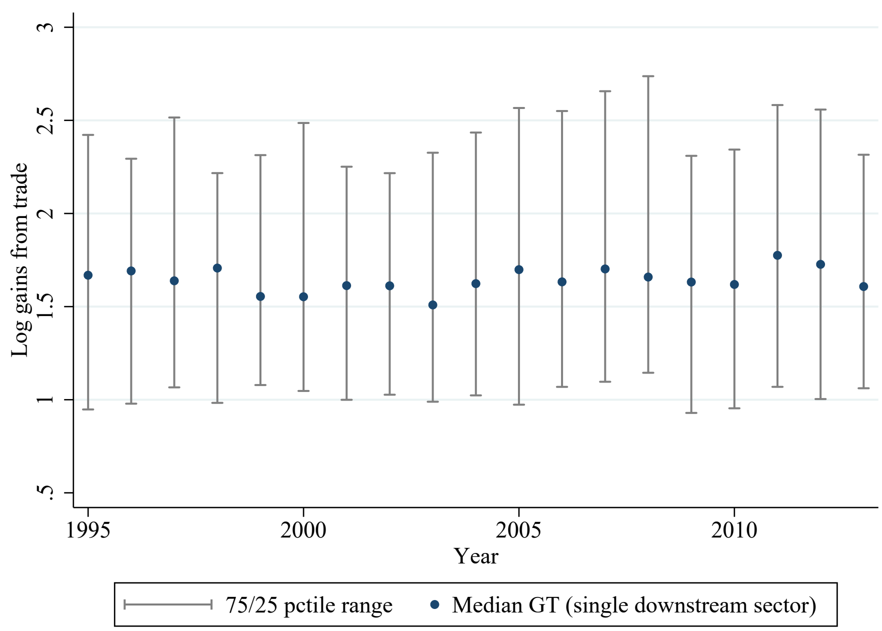


Figure 29: Gains from trade – aggregating downstream industries

Table 10: Products with the highest concentration of production from one country

Product	Largest Producer	Prod. Share	HHI	Product	Largest Producer	Prod. Share	HHI
Natural gums	Mexico	0.998	0.996	Jute	India	0.632	0.474
Rare Earths	China	0.984	0.969	Brazil nuts	Brazil	0.620	0.466
Germanium	China	0.943	0.892	Magnesium	China	0.616	0.402
Asparagus	China	0.939	0.883	Apples	China	0.607	0.376
Spinach	China	0.935	0.874	Fava beans	China	0.605	0.386
Antimony	China	0.896	0.804	Cauliflowers	China	0.602	0.409
Garlic	China	0.893	0.798	Carrots	China	0.601	0.367
Chestnuts	China	0.886	0.787	Roots	Nigeria	0.595	0.378
Eggplants	China	0.883	0.781	Peas	China	0.592	0.372
Canary seed	Canada	0.879	0.776	Mercury	China	0.588	0.410
Sweet potatoes	China	0.878	0.771	Wollastonite	China	0.583	0.395
Beryl	USA	0.874	0.777	Iodine	Chile	0.573	0.449
Cloves	Indonesia	0.860	0.752	Tobacco	China	0.571	0.345
Cucumbers	China	0.832	0.693	Fluorspar	China	0.567	0.358
Mushrooms	China	0.827	0.687	Mandarins	China	0.560	0.327
Melons	China	0.784	0.617	Lithium	Australia	0.555	0.346
Pears	China	0.767	0.591	Almonds	USA	0.548	0.319
Spices	India	0.735	0.554	Arsenic	China	0.548	0.374
Niobium	Brazil	0.732	0.553	Citruses	China	0.544	0.367
Strontium	China	0.730	0.567	Barytes	China	0.543	0.326
Celery	China	0.720	0.524	Flax	China	0.537	0.335
Graphite	China	0.707	0.529	Mate	Brazil	0.537	0.427
Tungsten	China	0.703	0.510	Cinnamon	Indonesia	0.536	0.386
Lettuce	China	0.693	0.499	Sillimanite	S. African C.U.	0.536	0.371
Peppers	China	0.692	0.486	Cotton seeds	China	0.530	0.323
Plums	China	0.674	0.460	Peanuts	China	0.529	0.322
Brussel sprouts	China	0.668	0.453	Poppy seeds	Czech Rep.	0.527	0.318
Hazelnuts	Turkey	0.652	0.455	Beans	China	0.520	0.288
Chickpeas	India	0.652	0.440	Gallium	China	0.517	0.304
Peaches	China	0.648	0.430	Legumes nec	India	0.509	0.282
Seeds	India	0.641	0.429	Walnuts	China	0.508	0.299

Notes: Share of production (in quantities) from the largest producer for each commodity in the year 2007. Second column is the Herfindahl-Hirschman index, where a number above 0.25 indicates a high concentration of production. Source: Authors' calculations, using country level FAO and BGS production data.