Commodity Trade Matters

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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. In light of this, 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.

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1 Introduction

Globally, concerns are growing over the access of countries to critical commodities in the world market. Such pressing issues as geopolitical instability, 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 increasingly important. 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 171 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 account 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 countries. To remain at this level of granularity, we use data on production at a detailed level

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

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). 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.[4] Moreover, a low elasticity of substitution between inputs generates a low price elasticity of supply, as typically observed for commodities.[5] Commodities do not directly enter final demand but are absorbed by downstream sectors.

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

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

[3]These harmonized datasets will be made available online. Future drafts will also attempt to re-estimate the price elasticities of demand and supply for all commodities in our sample.

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

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

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. Our current simulations account for 171 commodities but only two downstream sectors (manufacturing and services) but our future calibration will account for many downstream sectors and incorporate more 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 lower elasticities of substitution. For large countries such as the US and China, gains from trade double. For the median country, gains from trade are at least four 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 costs reductions. Moreover, as trade costs decrease, we obtain a decrease in the share of commodities in world trade that mimics the decrease observed over the past decades. 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.

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).[6] 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 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

[6] 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.

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)[7].

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 predicts 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. 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.

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 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.

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

Production data. For minerals, the main source of production data is from the British Geological Survey and the US Geological Survey, which provides mineral production data at the country level from 1970 to 2014. For agriculture, the main source of agricultural data is from the Food and Agriculture Organization, 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).

Trade data. For information on trade flows, we employ BACI data, constructed by CEPII and based on UN-COMTRADE data. 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. In a future draft, we will also examine historical data from COMTRADE based on the SITC classification going back to 1970.

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. This is the most comprehensive source of yearly price data but do not cover mineral prices for countries other than the US. Additionally, we use price data for agricultural products from the FAO at the country level, employing a local currency unit to US dollar conversion correspondence from the World Bank. We complement our price data with the IMF Primary Commodity Price Series database for uranium prices, and the World Bank Commodity "Pink Sheets" for fuel (petroleum, natural gas, and coal) prices. When necessary, we also use "Non-ferrous metal data" periodical from the American Bureau of Metal Statistics, "Metal bulletin's prices & data"from Metal Bulletin Books Ltd, and the "Metals & minerals annual review" from the Mining Journal for remaining missing metal prices.

Demand and supply elasticities. FAPRI and USDA provide price elasticity estimates of supply and demand for several agricultural commodities. For other commodities, many other scattered and diverse sources and journal articles provide elasticity estimates. Examples are Russo et al. (2008) for 6 agricultural commodities produced in California; 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; 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.

Consumption data. The USDA provides data on the consumption of agricultural commodities, the US Energy Information Administration provides data on the consumption of fuels, and various other sources such as the "Non-ferrous metal data" periodical from the American Bureau of Metal Statistics, "Metals & minerals annual review" from the Mining Journal, and "Metallstatistik" from *Metallgesellschaft Aktiengesellschaft* provide consumption information for minerals, although the coverage is incomplete. When not available, we infer the consumption of primary commodities from production and trade data, as commonly done in the 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[8] 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. Even when the relative frequency of mineral end-use by NAICS downstream sector is not available, the USGS still provides information on the NAICS downstream sectors that use the commodity, just not the relative proportions across industries. In these cases, we use the relative end use frequencies across downstream sectors for minerals from GTAP, but renormalize these frequencies by removing downstream industries not mentioned as using the commodity by the USGS.

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 do not account for a large share, approximately 16 percent of the value of world trade in 2014. However, this amount has not been constant over time. Table 1 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).

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

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 F for the list of primary commodities in our study). Hence, the products in our study encompass a larger share of world trade, up to 28 percent of world trade in 2014 and 24 percent on average.

Table 1: Share of Products in World Trade

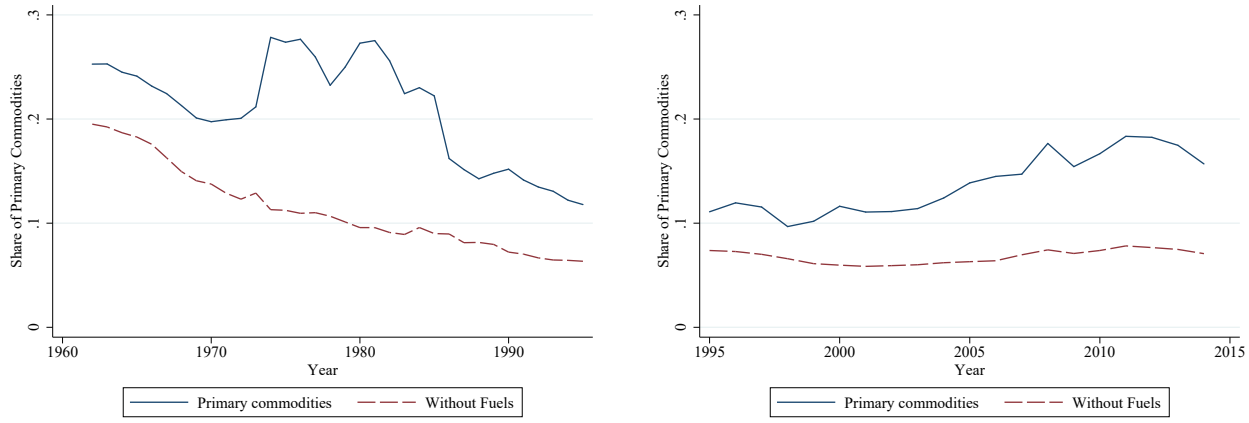
Year	Minerals	Agriculture	Fuels	Primary Commodities
1995	0.074	0.052	0.064	0.111
1996	0.070	0.052	0.078	0.120
1997	0.070	0.049	0.077	0.116
1998	0.072	0.047	0.056	0.097
1999	0.063	0.043	0.071	0.102
2000	0.065	0.036	0.095	0.116
2001	0.062	0.038	0.089	0.111
2002	0.063	0.038	0.088	0.111
2003	0.065	0.038	0.092	0.114
2004	0.071	0.035	0.106	0.124
2005	0.074	0.033	0.129	0.139
2006	0.078	0.031	0.139	0.145
2007	0.088	0.033	0.135	0.147
2008	0.089	0.036	0.172	0.177
2009	0.079	0.041	0.141	0.154
2010	0.085	0.039	0.156	0.167
2011	0.092	0.040	0.177	0.183
2012	0.092	0.040	0.181	0.182
2013	0.091	0.040	0.174	0.175
2014	0.086	0.041	0.154	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 to examine the patterns of commodity prices, hundreds of papers have estimated price or demand elasticities for the specific commodities under study, often with an emphasis on demand elasticities. We list all the papers that we have reviewed so far in Appendix Table 6 with their price elasticity estimates, and provide summary statistics in Table 2.

As described in Table 2, most estimates fall within the 0.1 and 0.5 range (in absolute values), both on the supply side and demand side. 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

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



(a) 1962-1995 (Feenstra data)

(b) 1995-2014 (BACI data)

higher elasticities, but these figures remain very low[9]. 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 all commodities, agriculture, and minerals. On average, the monthly volatility of commodity prices (standard deviation of log changes) is around 5%. The daily price deviation is about 1%. 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

[9]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	Nickel	-0.0376	(0.23 to 1.04)
Almonds	(-0.35 to -0.48)	0.19	Niobium	-0.3	
Aluminium	(-0.07 to -0.7)	(0.17 to 0.4)	Peanuts	(-0 to -0.4)	(0.04 to 0.5)
Bananas		(0.2 to 0.4)	Platinum	(-0.2 to -0.7)	
Barley	(-0.11 to -0.435)	(0.11 to 0.45)	Rapeseed	(-0.117 to -0.17)	(0.26 to 0.36)
Chromium	(-0.1 to -0.5)	(5 to 10)	Rice	(-0.01 to -0.55)	(0.01 to 0.57)
Cobalt	-0.5	< 1	Silver	-0.0423	
Cocoa	(-.01 to -.14)	(0.03 to 0.38)	Sorghum	(-0.06 to -0.49)	(0.16 to 0.53)
Coffee	-0.2	(0.1 to 0.28)	Soybeans	(-0.05 to -0.175)	(0.32 to 0.45)
Copper	(-0.2 to -0.42)	(0.1 to .453)	Sugar	(-0.06 to -0.17)	(0.055 to 0.21)
Corn	(-0.1 to -0.39)	(0.08 to 0.7)	Sunflower	(-0.083 to -0.15)	(0.15 to 0.41)
Cotton	-0.684	0.497	Tin	(-0.0968 to -0.55)	(0.3 to 1.11)
Crude Oil	-0.13	(0.1 to 0.25)	Titanium	-0.1602	
Gold	-0.4115	1.426	Tomatoes	-0.32	0.27
Vanadium	(-0.2537 to -0.3)		Tungsten	(-0.5 to -0.15)	(0.11 to 0.15)
Iron ore	-0.0865	(0.25 to 0.589)	Uranium	(-0.1 to -1.5)	(2.35 to 11.4)
Lead	(-0.1108 to -0.22)	(0.1 to 0.81)	Wheat	(-0.09 to -0.395)	(0.08 to 0.43)
Manganese	-0.1	> 1	Zinc	-0.064	(0.1 to 0.25)

Notes: The full lists of estimates and references are provided in Appendix

Table 3: Commodity Price Volatility, 1960-2005

	All commodities	Agriculture	Minerals
1960-1965	0.0493	0.0462	0.0422
1965-1970	0.0497	0.0414	0.0436
1970-1975	0.0776	0.0745	0.0667
1975-1980	0.0672	0.0593	0.0527
1980-1985	0.0618	0.0532	0.0483
1985-1990	0.0735	0.0625	0.0698
1990-1995	0.0679	0.0535	0.0541
1995-2000	0.0593	0.0502	0.0453
2000-2005	0.0603	0.0498	0.0525
2005-2007	0.0691	0.0512	0.0848

Source: Jacks et al. (2011) based on UNCTAD data. Volatility is defined as the standard deviation of monthly changes in logged prices.

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 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 North America trade. 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.

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	-1.374	-1.542	-2.072	-1.025
	[0.072]	(0.781)	(0.689)	(0.689)	(0.818)
Border effect	2.74	-4.056	-4.438	-3.756	-3.026
	[0.218]	(2.5)	(2.462)	(1.173)	(2.357)
Continguity	0.404	0.387	0.469	0.273	0.246
	[0.120]	(1.39)	(0.938)	(0.061)	(2.01)
Common Language	0.502	0.47	0.657	0.069	0.177
	[0.146]	(0.851)	(0.89)	(0.309)	(0.694)
Colonial Link	0.036	0.21	0.142	0.477	0.316
	[0.146]	(1.223)	(0.909)	(0.554)	(1.685)
In brackets:	Std Errors	Std. Dev.	Std. Dev.	Std. Dev.	Std. Dev.
Countries	94	143	143	143	143
Commodities	/	186	116	3	65

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 (186 separate commodities in column (2), less for columns (3)-(5)). As such, the numbers reported below are not standard errors, but the standard deviations of the coefficient estimates.

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 commodities). 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[10]. 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 not appear in more aggregated industry-level input-output tables.

Fact 6: Commodities are intensive in natural resources. Obviously, 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.[11]

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.

[10]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.

[11]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.

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[12] for which natural resources constitute more than 25% of GDP, where natural resources are defined as rents from agriculture, forestry, minerals, and fuels. Most of the countries that compose this table can be classified as developing, indicating that production and trade of products that use natural resources may more important to developing countries than developed countries which tend to have a comparative advantage in secondary and tertiary sectors.

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

Country	Natural Resources Income Share	Country	Natural Resources Income Share
Turkmenistan	.607	Nigeria	.320
Libya	.598	Uzbekistan	.320
Angola	.552	Liberia	.316
Papua New Guinea	.526	Iran	.306
Congo	.522	Chad	.294
Iraq	.517	Sierra Leone	.291
Kuwait	.512	Central African Rep.	.290
Equatorial Guinea	.502	Lao Peoples Dem. Rep.	.281
Saudi Arabia	.493	Brunei Darussalam	.280
Azerbaijan	.408	Ethiopia	.274
Gabon	.404	Algeria	.269
Oman	.403	Guinea-Bissau	.268
Mongolia	.394	Comoros	.267
Yemen	.351	Qatar	.255
Dem. Rep. of the Congo	.349	Kazakhstan	.253
Myanmar	.322	Burundi	.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

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 (170 primary commodities among thousands of 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

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

low-income countries. Our sample encompasses only countries with a population of more than 1 million[13], 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 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.

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 copper producer. However, the production of many commodities is actually even more concentrated geographically than copper. This includes, for instance, many agricultural products (canary seeds, cassava, garlic, etc.) and mineral products (uranium, iodine, germanium, magnesium, etc). 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.

Notably, we also find a high degree of concentration in imports of products, as shown in Table 8. The results here are more 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 exports 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, and that the largest importers are the countries with a comparative advantage in these downstream industries.

In some cases, these patterns can be partially explained by spatial allocation of natural resources necessary to produce these commodities. Although known deposits of minerals and fuels can increase with additional effort, exploration costs, and new technology, fundamentally

[13]Or countries with available population data.

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.
Chad	Petroleum and Related Products	0.885	0.953
Guinea-Bissau	Cashew Nuts	0.832	0.888
Eritrea	Uranium	0.756	0.812
Turkmenistan	Natural Gas	0.717	0.783
Mali	Gold	0.649	0.714
Venezuela	Petroleum	0.606	0.669
Timor Leste	Propane	0.458	0.773
Nigeria	Petroleum	0.454	0.620
Niger	Uranium	0.425	0.640
Myanmar	Natural Gas	0.405	0.537
Libya	Petroleum	0.343	0.522
Gabon	Petroleum	0.337	0.468
Iraq	Petroleum	0.333	0.616
Bolivia	Natural Gas	0.331	0.466
Angola	Petroleum	0.328	0.716
Sierra Leone	Diamonds	0.307	0.449
Qatar	Petroleum	0.305	0.523
Zambia	Copper	0.302	0.471
Laos	Copper	0.300	0.463
Ecuador	Petroleum	0.297	0.416

Notes: Share of top and top-three commodities in total exports by country, showing the countries with the highest concentration of exports. Source: BACI data.

these resources are highly dispersed across countries. While this peculiarity may seem limited to minerals and fuels, similarly, the land suitable for various agricultural commodities is highly dispersed across the world (see Appendix Figure 11 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 data from the FAO suggest that many countries are unsuitable for staple agricultural commodities that represent a large share of agricultural production.

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

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	Wool	China	0.653	0.819
Sorghum	USA	0.732	0.874	Iron Ores	China	0.480	0.669
Wool	Australia	0.710	0.836	Iridium & Osmium	USA	0.436	0.752
Almonds	USA	0.706	0.825	Uranium	USA	0.422	0.811
Linseed	Canada	0.671	0.794	Rare Earth Metals	Japan	0.417	0.667
Uranium	S. Africa	0.667	0.994	Raspberries, etc.	USA	0.358	0.663
Oats	Canada	0.631	0.774	Vanadium	China	0.344	0.632
Cassava	Thailand	0.629	0.868	Rhodium	USA	0.326	0.697
Garlic	China	0.620	0.834	Peas	India	0.306	0.412
Iodine	Chile	0.607	0.858	Diamonds	Belgium	0.285	0.677
Mustard Seeds	Canada	0.585	0.723	Chromium	China	0.257	0.452
Ginger	China	0.585	0.726	Iridium & Osmium	Japan	0.248	0.752
Fluorine	Israel	0.581	0.815	Rhodium	Japan	0.246	0.697
Rare Earths	China	0.556	0.848	Uranium	Canada	0.235	0.811
Figs	Turkey	0.556	0.670	Coal	Japan	0.232	0.403
Mandarins	Spain	0.554	0.696	Palladium	USA	0.230	0.564
Buckwheat	China	0.534	0.742	Molybdenum	Netherlands	0.223	0.538
Germanium	Belgium	0.530	0.936	Mushrooms	U.K.	0.218	0.444
Lentils	Canada	0.520	0.743	Beryllium	Russia	0.210	0.525
Barytes	China	0.520	0.682	Diamonds	India	0.206	0.677
Magnesium	China	0.516	0.658	Palladium	Japan	0.205	0.564
Hops	Germany	0.514	0.719	Graphite	Japan	0.201	0.410
Pineapples	Costa Rica	0.513	0.669	Petroleum	USA	0.200	0.327
Andalusite	S. Africa	0.509	0.859	Tungsten	China	0.200	0.512
Mate	Brazil	0.507	0.935	Cinnamon	Mexico	0.198	0.412

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.

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).

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:

$$D_{nk} = (P_{nk}^F / P_n^F)^{1-\sigma} \, a_{nk} E_n \tag{1}$$

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:

$$P_n^F = \left[\sum_k a_{nk} (P_{nk}^F)^{1-\sigma} \right]^{\frac{1}{1-\sigma}} \tag{2}$$

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_{ik}^F 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_{ig}^C, the cost of producing final good k in producing country i can be written as:

$$C_{ik}^F = A_{ik}^F \left[\beta_{ik,L}^F w_i^{1-\eta_k} + \sum_g \beta_{ik,g}^F (P_{ig}^C)^{1-\eta_k} \right]^{\frac{1}{1-\eta_k}} \tag{5}$$

This cost function allows for productivity terms A_{ik}^F as well as factor requirements $\beta_{ik,L}^F$ (for labor) and $\beta_{ik,g}^F$ (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:

$$D_{igk} = \beta_{ik,g}^F (P_{ig}^C / C_{ik}^F)^{1-\eta_k} \, Y_{ik}^F \tag{6}$$

where $Y_{ik}^F = \sum_n X_{nik}^F$ 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:

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

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:

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

while the price index of commodity g in destination n:

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

where C_{ig}^C 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.[14] If we denote by r_{ig} the price 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:

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

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

[14] 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 a other input (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 this commodity:

$$R_{ig} r_{ig} = \beta_{ig}^{C} (r_{ig}/C_{ig}^{C})^{1-\rho_g} \; Y_{ig}^{C} \tag{10}$$

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:

$$L_i w_i = \sum_g (1 - \beta_{ig}^{C})(w_i/C_{ig}^{C})^{1-\rho_g} \; Y_{ig}^{C} \quad + \quad \sum_k \beta_{ik,L}^{F} (w_i/C_{ik}^{F})^{1-\eta_k} \; Y_{ik}^{F} \tag{11}$$

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:

$$E_n = w_n L_n + \sum_g r_{ng} V_{ng} \tag{12}$$

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 (12).

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).[15]

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

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:

$$\widehat{E}_i = e_{iL}\hat{w}_i + \sum_g e_{ig,R}\hat{r}_{ig} \tag{13}$$

$$\widehat{P^F_n} = \left[\sum_k \alpha_{nk}\widehat{P^F_{nk}}^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \tag{14}$$

$$\widehat{P^F_{nk}} = \left[\sum_i \lambda^F_{nik}(\widehat{C^F}_{ik}\widehat{d_{nik}})^{-\theta_k}\right]^{-\frac{1}{\theta_k}} \tag{15}$$

$$\widehat{P^C_{ng}} = \left[\sum_i \lambda^C_{nig}(\widehat{C^C}_{ig}\widehat{d_{nig}})^{-\theta_g}\right]^{-\frac{1}{\theta_g}} \tag{16}$$

$$\widehat{D_{nk}} = \left(\frac{\widehat{P^F_{nk}}}{\widehat{P^F_k}}\right)^{1-\sigma}\widehat{E_n} \tag{17}$$

$$\widehat{D_{ng}} = \sum_k d_{nkg}\left(\frac{\widehat{P^C_{ng}}}{\widehat{C^F_{nk}}}\right)^{1-\eta_k}\widehat{Y^F_{nk}} \tag{18}$$

$$\widehat{Y^F}_{ik} = \sum_n \pi^F_{nik}(\widehat{C^F}_{ik}\widehat{d_{nik}})^{-\theta_k}(\widehat{P^F}_{nk})^{\theta_k}\ \widehat{D_{nk}} \tag{19}$$

$$\widehat{Y^C}_{ig} = \sum_n \pi^C_{nig}(\widehat{C^C}_{ig}\widehat{d_{nig}})^{-\theta_g}(\widehat{P^C}_{ng})^{\theta_g}\ \widehat{D_{ng}} \tag{20}$$

$$\widehat{C^F_{ik}} = \left[\varphi_{ik,L}\hat{w}_i^{1-\eta_k} + \sum_g \varphi_{ik,g}(\widehat{P^C_{ig}})^{1-\eta_k}\right]^{\frac{1}{1-\eta_k}} \tag{21}$$

$$\widehat{C^C_{ig}} = \left[\varphi_{ig,R}\hat{r}_{ig}^{1-\rho_g} + \varphi_{ig,L}\hat{w}_i^{1-\rho_g}\right]^{\frac{1}{1-\rho_g}} \tag{22}$$

$$\hat{r}_{ig} = (\hat{r}_{ig}/\widehat{C^C_{ig}})^{1-\rho_g}\ \widehat{Y^C_{ig}} \tag{23}$$

$$\hat{w}_i = \sum_g s^L_{ig}(\hat{w}_i/\widehat{C^C_{ig}})^{1-\rho_g}\ \widehat{Y^C_{ig}} \ + \ \sum_k s^L_{ik}(\hat{w}_i/\widehat{C^F_{ik}})^{1-\eta_g}\ \widehat{Y^F_{ik}} \tag{24}$$

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:

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

changes in log.

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

$$\alpha_{nk} = a_{nk} \left(\frac{P_{nk}^F}{P_n^F} \right)^{1-\sigma}.$$

- 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):

$$\lambda_{nik}^F = \frac{X_{nik}^F}{D_{nk}} = \frac{(C_{ik}^F d_{nik})^{-\theta_k}}{{P_{nk}^F}^{-\theta_k}} \qquad \text{and} \qquad \lambda_{nig}^C = \frac{X_{nig}^C}{D_{ng}} = \frac{(C_{ig}^C d_{nig})^{-\theta_g}}{{P_{ng}^C}^{-\theta_g}}.$$

- 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):

$$\pi_{nik}^F = \frac{X_{nik}^F}{Y_{ik}^F} \qquad \text{and} \qquad \pi_{nig}^C = \frac{X_{nig}^C}{Y_{ig}^C}.$$

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

$$\varphi_{ik,L}^F = \frac{{A_{ik}^F}^{1-\eta_k} \beta_{ik,L}^F w_i^{1-\eta_k}}{{C_{ik}^F}^{1-\eta_k}} \qquad \text{and} \qquad \varphi_{ik,g}^F = \frac{{A_{ik}^F}^{1-\eta_k} \beta_{ik,g}^F (P_{ig}^C)^{1-\eta_k}}{{C_{ik}^F}^{1-\eta_k}}.$$

- 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_{ik}^L and s_{ig}^L.

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 (12). 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:

$$\widehat{P_{ik}^F} = \widehat{\lambda_{iik}^F}^{-\frac{1}{\theta_k}} \widehat{C_{ik}^F} \qquad ; \qquad \widehat{P_{ig}^C} = \widehat{\lambda_{iig}^C}^{-\frac{1}{\theta_g}} \widehat{C_{ig}^C} \tag{25}$$

where λ_{iik}^F and λ_{iik}^C 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:

$$\widehat{C_{ik}^F} = \widehat{\varphi_{ik,L}}^{-\frac{1}{1-\eta_k}} \hat{w}_i \qquad \widehat{C_{ik}^F} = \widehat{\varphi_{ik,g}}^{-\frac{1}{1-\eta_k}} \widehat{P_{ig}^C} \qquad ; \qquad \widehat{C_{ig}^C} = \widehat{\varphi_{ig,R}}^{-\frac{1}{1-\eta_k}} \widehat{r_{ig}} \tag{26}$$

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

$$\widehat{P_i^F} = \widehat{\alpha_{ik}}^{-\frac{1}{1-\sigma}} \widehat{P_{ik}^F} \tag{27}$$

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

$$GT_i^L = \widehat{P_i^F} = \left[\sum_k \alpha_{ik} \widehat{P_{ik}^F}^{1-\sigma} \right]^{\frac{1}{1-\sigma}} = \left[\sum_k \alpha_{ik} \widehat{\lambda_{iik}^F}^{-\frac{1-\sigma}{\theta_k}} \widehat{\varphi_{ik,L}}^{-\frac{1-\sigma}{1-\eta_k}} \right]^{\frac{1}{1-\sigma}} \tag{28}$$

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:

$$GT_{ig}^R = \frac{\widehat{P_i^F}}{\widehat{r_{ig}}} = \widehat{\alpha_{ik}}^{-\frac{1}{1-\sigma}} \widehat{\lambda_{iik}^F}^{-\frac{1}{\theta_k}} \widehat{\varphi_{ik,g}}^{-\frac{1}{1-\eta_k}} \widehat{\lambda_{iig}^C}^{-\frac{1}{\theta_g}} \widehat{\varphi_{ig,R}}^{-\frac{1}{1-\rho_g}} \tag{29}$$

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

$$\widehat{r_{ig}} = (\widehat{\varphi_{ik,g}}/\widehat{\varphi_{ik,L}})^{\frac{1}{1-\eta_k}} \widehat{\lambda_{iig}^C}^{\frac{1}{\theta_g}} \widehat{\varphi_{ig,R}}^{\frac{1}{1-\rho_g}} \tag{30}$$

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 (15) to (20) can then be replaced by the following set of equations:

$$\widehat{P_{nk}^F} = (\lambda_{nnk}^F)^{-\frac{1}{\theta_k}}\widehat{C_{nk}^F} \tag{31}$$

$$\widehat{P_{ng}^C} = (\lambda_{nng}^C)^{-\frac{1}{\theta_g}}\widehat{C_{ng}^C} \tag{32}$$

$$\widehat{Y_{nk}} = \left(\frac{\widehat{P_{nk}^F}}{\widehat{P_k^F}}\right)^{1-\sigma}\widehat{E_n}\,\frac{D_{nk}}{Y_{nk}} \tag{33}$$

$$\widehat{Y_{ng}} = \frac{D_{ng}}{Y_{ng}}\sum_k d_{nkg}\widehat{Y_{nk}^F}\left(\frac{\widehat{P_{ng}^C}}{\widehat{C_{nk}^F}}\right)^{1-\eta_k} \tag{34}$$

while other equations (13), (14) and (21) to (24) 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:

$$\hat{r}_{ig} = \left(\lambda_{ig}^{-\frac{1-\eta}{\theta_g}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k d_{nkg} \frac{\widehat{Y_{ik}^F}}{\widehat{C_{ik}^F}^{1-\eta}} \right)^{\frac{1}{\eta}} \tag{35}$$

and thus the change in income, using equation (13). 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_{ik}^F 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 (22), $\widehat{C_{ig}^C}^{1-\eta} = \varphi_{ig,L} + \varphi_{ig,R} \hat{r}_{ig}^{1-\eta}$, we can then also obtain production costs for commodity g and downstream industry k:

$$\widehat{C_{ik}^F}^{1-\eta} = \varphi_{ik,L} + \sum_g \varphi_{ik,g} \varphi_{ig,L} \lambda_{ig}^{-\frac{1-\eta}{\theta_g}} + \frac{E_i \widehat{C_{ik}^F}^{1-\eta}}{Y_{ik}^F \widehat{Y_{ik}^F}} \sum_g e_{ig} \left(\lambda_{ig}^{-\frac{1-\eta}{\theta_g}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k d_{nkg} \frac{\widehat{Y_{ik}^F}}{\widehat{C_{ik}^F}^{1-\eta}} \right)^{\frac{1}{\eta}} \tag{36}$$

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 (31), (33), (13) and (14) 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.[16]

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

$$\hat{r}_{ig} = \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{e_{iL}}{\Lambda_i^{1-\sigma}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k \frac{d_{nkg} D_{ik}^F}{Y_{ik}^F} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}} \right)^{\frac{1}{\sigma}} \tag{37}$$

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

where Λ_i is defined as:

$$\Lambda_i^{1-\sigma} \equiv \sum_k \alpha_k \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}} \left[\varphi_{ik,L} + \sum_g \varphi_{ik,g} \varphi_{ig,L} \lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \right] \tag{38}$$

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:*

$$GT_i \;=\; \left[\left(\frac{\Lambda_i}{e_{iL}} \right)^{\frac{1-\sigma}{\sigma}} + \sum_g e_{ig,R} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \, \frac{D_{ig}^C}{Y_{ig}^C} \, \sum_k \frac{d_{nkg} D_{ik}^F}{Y_{ik}^F} \lambda_{ik}^{-\frac{1-\sigma}{\theta_k}} \right)^{\frac{1}{\sigma}} \right]^{\frac{\sigma}{1-\sigma}} \tag{39}$$

if we assume that $\rho_g = \eta_k = \sigma$, where Λ_i is defined as above (equation 38).

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 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:

$$\widehat{P^F}_i \;=\; \Lambda_i \left[1 + \sum_g \frac{e_{ig,R}}{e_{iL}} \hat{r}_{ig} \right]^{\frac{1}{1-\sigma}} \tag{40}$$

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 37) 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:

$$GT_i \;=\; \lambda_{iM}^{-\frac{1}{\theta_M}} \left[e_{iL} \left(\frac{\varphi_{iM,L} + \sum_g \varphi_{iM,g}\varphi_{ig,L}\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}}}{e_{iL}} \right)^{\frac{1}{\sigma}} + \sum_g e_{ig,R} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{E_i}{Y_i^F} \frac{D_{ig}^C}{Y_{ig}^C} \right)^{\frac{1}{\sigma}} \right]^{\frac{\sigma}{1-\sigma}} \tag{41}$$

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.

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[17] 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:

[17] 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.

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 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.[18] 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 20 and 30% for most commodities, and close to the ones obtained with our baseline strategy.

[18] 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.

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 0.5 for both η_k and ρ_g, which generate price elasticities of demand and supply close to 0.5. This is a conservative choice. As documented in Figure 2 and Appendix Figure 6, this is generally 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) do not play a key 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 $\sigma = 0.5$ 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 (13)-(24) to simulate partial trade costs changes and equations (13), (14), (21)-(24) and (31)-(34) to simulate full Autarky.

5.1 Gains from trade relative to Autarky

Aggregate gains from trade We show in Figure 2 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 15, we show that we obtain similar results to

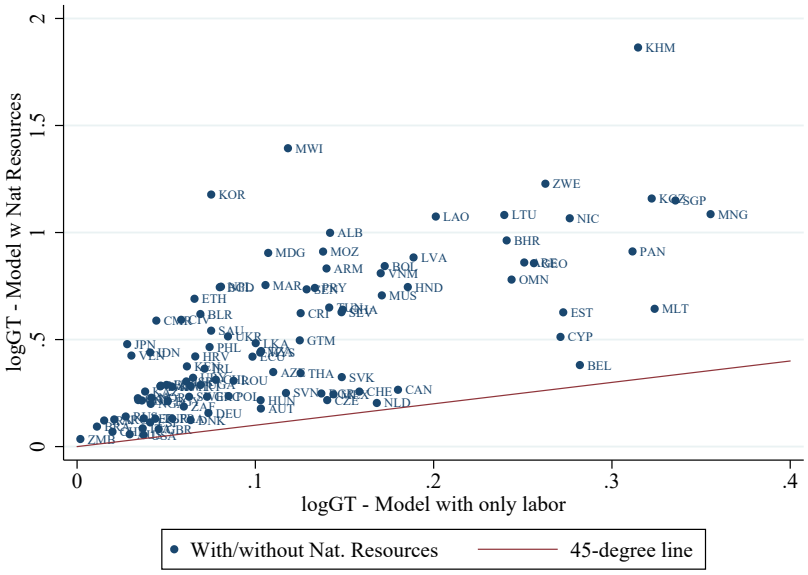


Figure 2: Gains from trade relative to model with only labor

those in Figure 2: the difference between the two models is now even slightly larger, since trade in final goods alone yields lower gains.

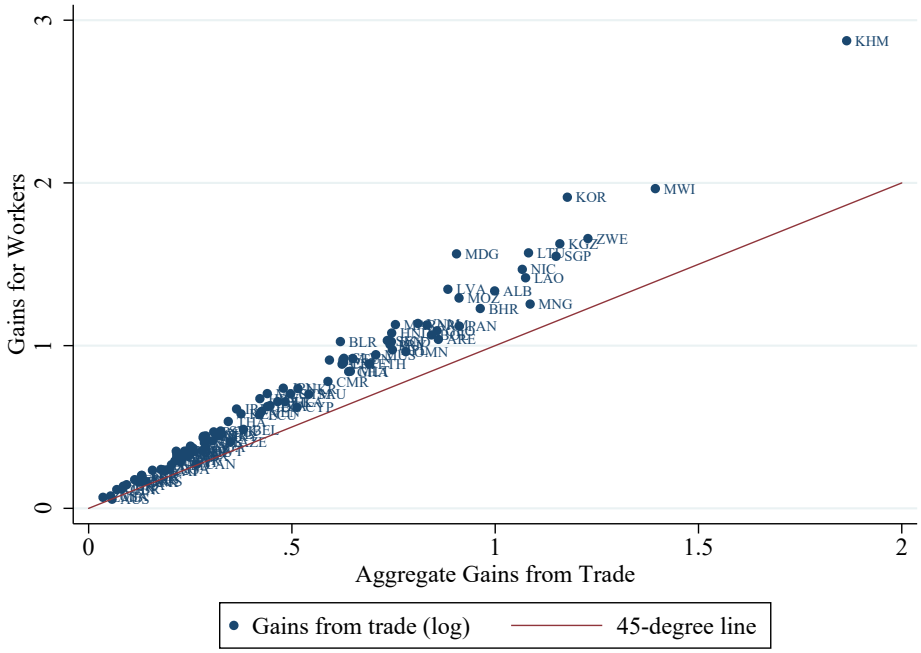
Heterogeneous gains from trade Panel (a) of Figure 3 compares the gains from trade for workers and Natural resources relative to the aggregate gains from trade. First, we can see that workers fare better in our model as a country opens to trade, reflecting a decrease in the cost of commodity sourcing 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).

In Panel (b) of Figure 3, 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.

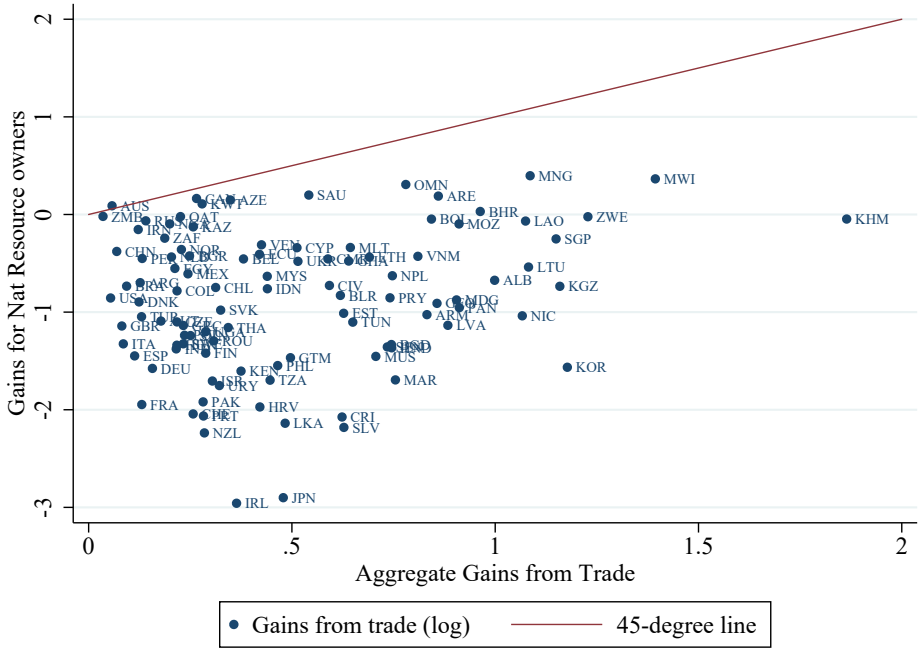
Role of supply and demand elasticities. As noted in the theory section, gains from trade in primary commodities depend on supply and demand elasticities. To illustrate the role of

Figure 3: Heterogeneous gains from trade

(a) Workers vs aggregate gains from Trade



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



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 4, we examine the gains from trade for our model if we assume $\eta_k = \rho_g = 0.95$ (almost Cobb-Douglas) and $\eta_k = \rho_g = 1.5$ (which is close to most estimates of the elasticity of substitution between skilled and unskilled labor, e.g. Katz and Murphy, 1992). 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 (here 1.5), gains from trade are essentially identical to the single-factor model and considerably smaller than in our baseline model.

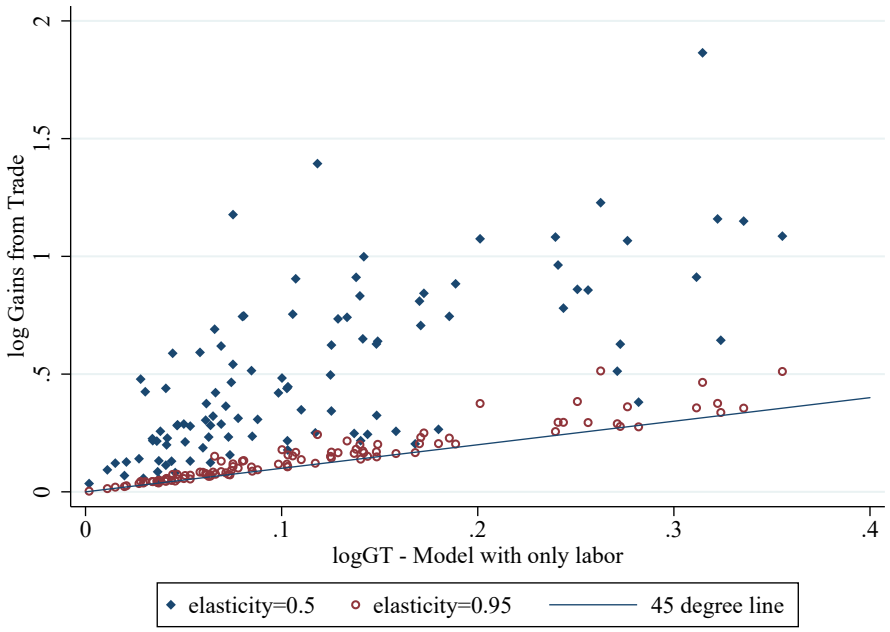


Figure 4: Gains from Trade (Aggregate) for Different Elasticities of Substitution

While resource owners often experience negative gains from trade (panel (b) of Figure 3), this result does not hold for larger elasticities of substitution. In Figure 5, 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

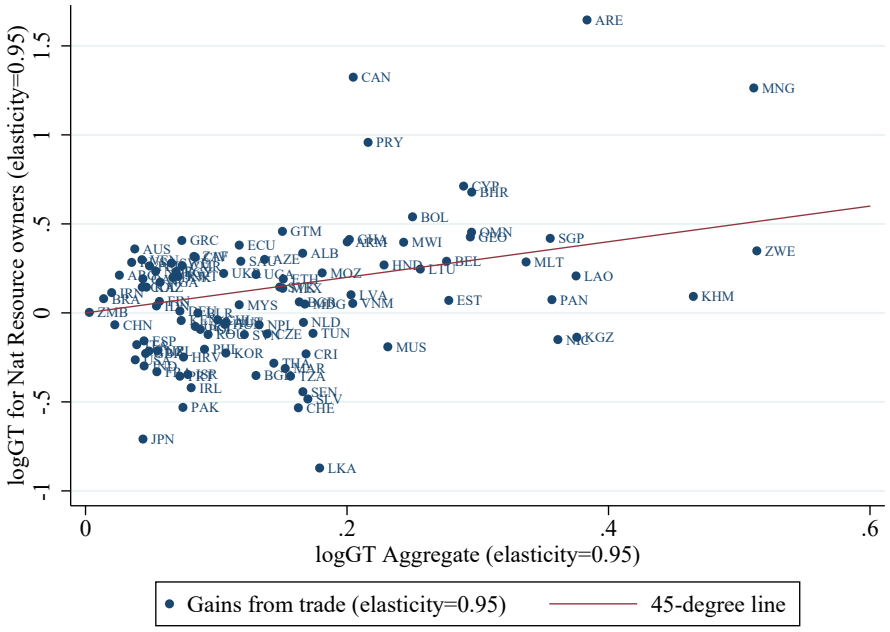


Figure 5: Gains from Trade for Resource Owners for Different Elasticities of Substitution

easily employ labor to substitute for limited natural resources, thereby decreasing the marginal product and returns to natural resources.

The trade elasticity for commodities plays a more muted role in explaining the gains from trade in commodities. Figure 6 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). 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 7.

First, as documented in panel (a) of Figure 7, 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 resources and gain access to various commodities that cannot be produced domestically.

Next, in panel (b) of Figure 7, we plot the gains from trade against a country's share

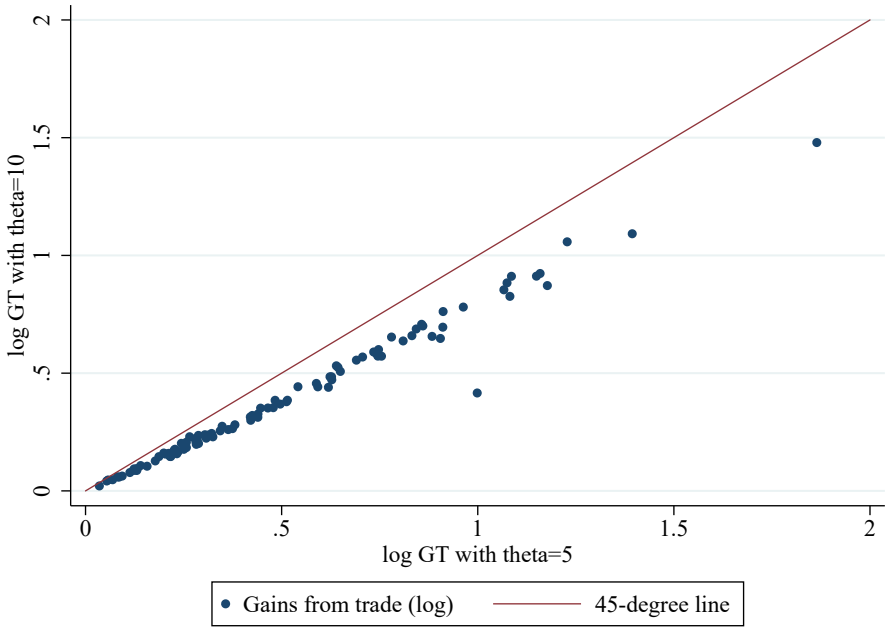


Figure 6: Gains from Trade with Higher Trade Elasticity for Commodities: $\theta_g = 10$

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 they have a comparative advantage in. 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.

Finally, panel (c) plots the correlation between the gains from trade and the size of manufacturing to total GDP in each country. The correlation is significant both in the model with resources and the model with only labor, but the gains from trade are larger for countries with more manufacturing in the model with resources.

5.2 Sensitivity to alternative specifications

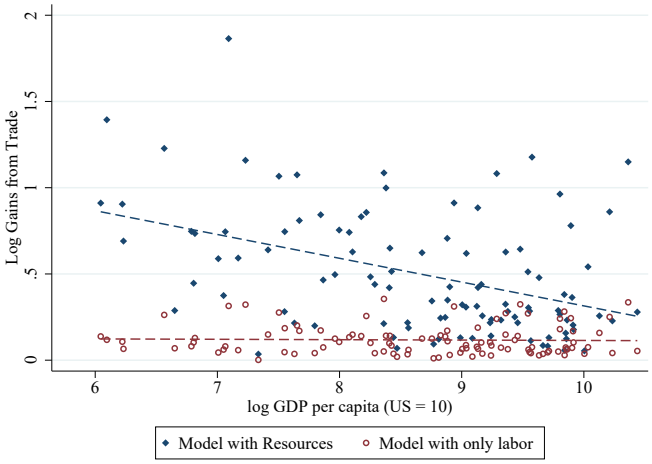
Aggregation of downstream sectors In Figure 8, we compare the gains from trade from our baseline model with services and multiple downstream sectors to a model with services but only one downstream sector, manufacturing. We find that the gains from trade are larger with only one manufacturing sector. 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

Figure 7: Determinants of the gains from trade, compared with labor-only model

(a) Gains from Trade and Per Capita Income

Baseline model:
$corr(\log GT_i, \log w_i) = -0.434^{***}$

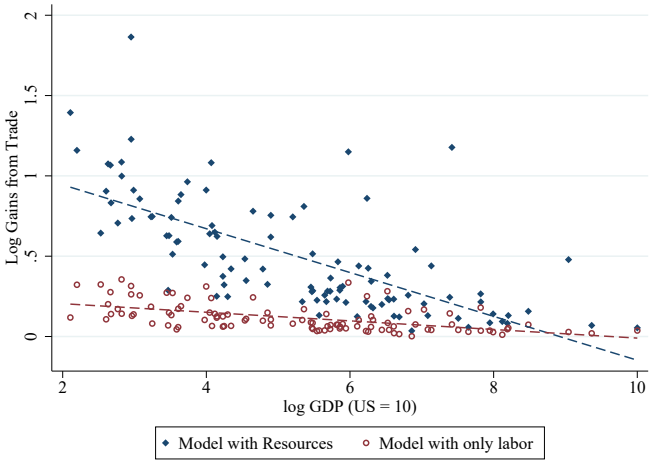
Single-factor model:
$corr(\log GT_i, \log w_i) = -0.048$



(b) Gains from Trade and Market Size

Baseline model:
$corr(\log GT_i, \log E_i) = 0.694^{***}$

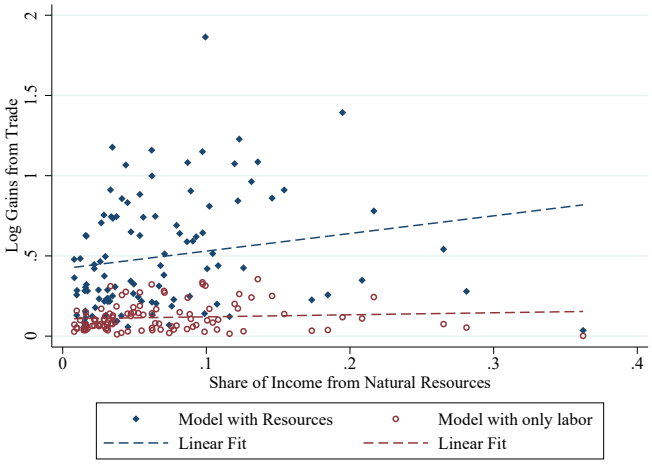
Single-factor model:
$corr(\log GT_i, \log E_i) = -0.559^{***}$



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

Baseline model:
$corr(\log GT_i, \log e_{iR}) = 0.194^{**}$

Single-factor model:
$corr(\log GT_i, \log e_{iR}) = 0.091$



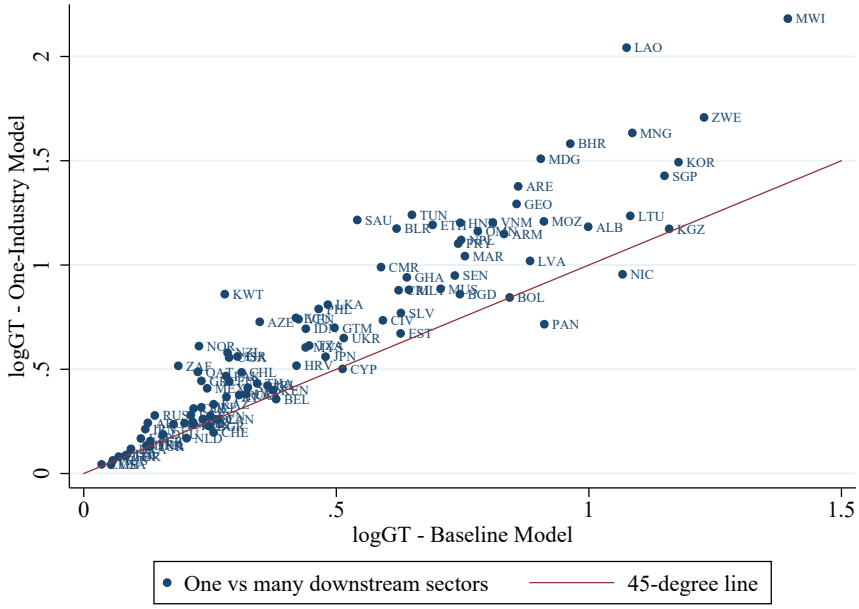


Figure 8: Gains from Trade in a Model with only one Downstream Sectors

final good requires all commodities and is more difficult to replace.

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 much larger gains from trade than both the Cobb-Douglas and the single-industry specifications.

Other years We compare for instance the gains from trade in a model calibrated with 2007 data vs. 2012 data in the single-downstream sector model. We find larger gains in 2012 than 2007, which is likely explained by the larger share of commodities in total trade in 2012 than 2007, although this growth is mostly driven by fuels.

Choke prices With Cobb-Douglas production functions or with CES and elasticities below unity, losses from switching to Autarky are potentially infinite when a country has a positive demand in a commodity but no natural resources associated with that commodity.

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. We incorporate this insight by considering an alternative production

function allowing for substitution with labor at higher prices:

$$C_{ik}^F = A_{ik}^F \left[\beta_{ik,L}^F w_i^{1-\eta_k} + \sum_g \beta_{ik,g}^F \left(P_{ig}^{1-\eta_k} - (1-\eta_k) P_{ig} (a_g w_i)^{-\eta_k} \right) \right]^{\frac{1}{1-\eta_k}}$$

This cost function yields an upper bound $P_{ig} \leq a_g w_i$ and necessarily finite gains from trade. Work in progress: future draft will incorporate estimates of a_g as well as counterfactual simulations based on this production function. In the meanwhile, the next robustness check also deal with extreme cases with small production (and thus possibly large price hikes in Autarky).

Extreme dependence In Figure 16 in Appendix E, we plot the gains from trade in a calibration where demand is set to zero whenever production is zero or tiny relative to demand and imports (whenever domestic trade shares λ_{iig} are smaller than 0.005). Even if we omit extreme cases where production is too small, we find gains from trade that still largely exceed the ones computed from a model without natural resources (X-axis in Figure 16).

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). A sizable difference starts appearing when trade costs changes are fairly large (50% changes) as seen in Figure 9.

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, the gains from trade for labor in a model with primary commodities are 10-20% larger (on average across countries) than in standard models with higher substitution or no natural resources.

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.

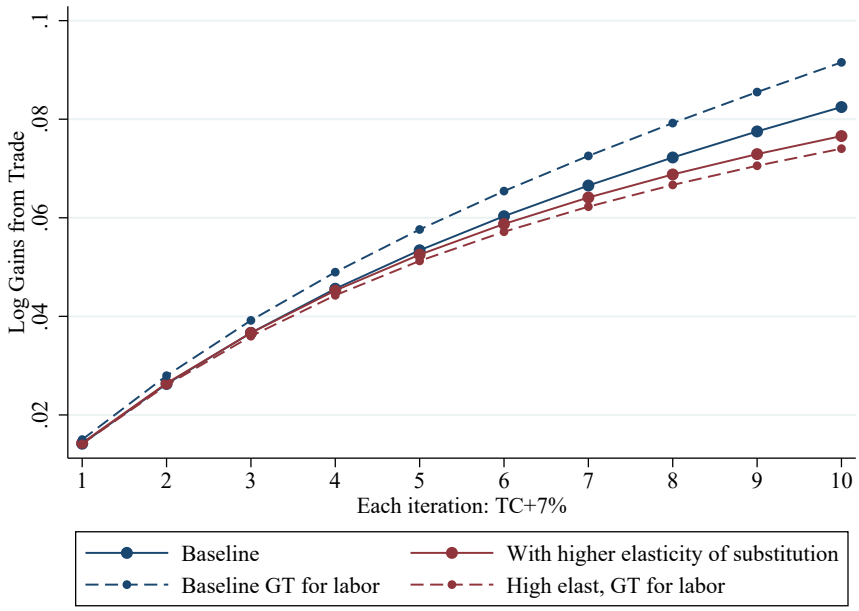


Figure 9: Gains from trade – increasing trade costs by 7% at each iteration

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

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

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:

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

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:

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

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 10. Once tariff revenues are accounted for, one can see in Figure 10 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.

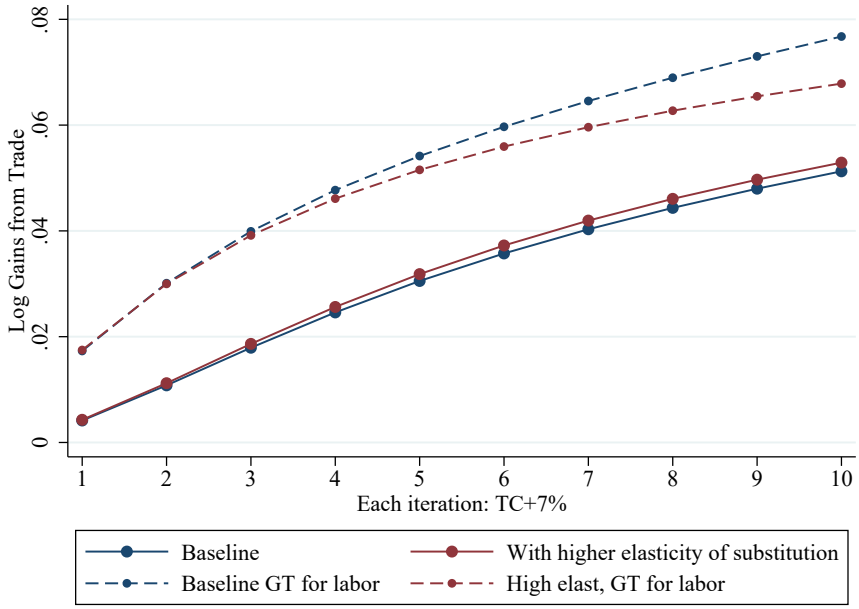


Figure 10: Gains from trade – increasing trade costs by 7% at each iteration

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 larger than in standard model, 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

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:

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

We obtain the equation in the text after noticing that $\varphi^F_{ik,L} = \frac{{A^F_{ik}}^{1-\eta_k} \beta^F_{ik,L} w_i^{1-\eta_k}}{{C^F_{ik}}^{1-\eta_k}}$ and $\varphi^F_{ik,g} = \frac{{A^F_{ik}}^{1-\eta_k} \beta^F_{ik,g} (P^C_{ig})^{1-\eta_k}}{{C^F_{ik}}^{1-\eta_k}}$ 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:

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

- Demand for commodity g in destination i, is:

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

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

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

$$X^F_{nik} = (C^F_{ik} d_{nik})^{-\theta_k} (P^F_{nk})^{\theta_k} \; D_{nk}$$

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:

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

where π^C_{nig} 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:

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

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:

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

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

- Income from specific factor g:

$$R_{ig} r_{ig} = \beta^C_{ig} (r_{ig} / C^C_{ig})^{1-\rho_g} \; Y^C_{ig}$$

where $Y^C_{ig} = \sum_n X^C_{nig}$ denotes the production of commodity g in country i.

- Income from labor:

$$L_i w_i = \sum_g (1 - \beta^C_{ig}) (w_i / C^C_{ig})^{1-\rho_g} \; Y^C_{ig} \quad + \quad \sum_k \beta^F_{ik,L} (w_i / C^F_{ik})^{1-\eta_k} \; Y^F_i$$

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:

$$\begin{aligned}
\hat{r}_{ig} &= \widehat{C_{ig}^C}^{-\frac{1-\sigma}{\sigma}} \widehat{Y_{ig}^C}^{\frac{1}{\sigma}} && (42)\\
&= \lambda_{ig}^{-\frac{1-\sigma}{\theta_g \sigma}} \widehat{P_{ig}^C}^{-\frac{1-\sigma}{\sigma}} \widehat{Y_{ig}^C}^{\frac{1}{\sigma}} && (43)\\
&= \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k d_{nkg} \frac{\widehat{Y_{ik}^F}}{\widehat{C_{ik}^F}^{1-\sigma}} \right)^{\frac{1}{\sigma}} && (44)
\end{aligned}$$

The change in the cost of commodity g is then:

$$\begin{aligned}
\widehat{C_{ig}^C}^{1-\sigma} &= \varphi_{ig,L} + \varphi_{ig,R} \hat{r}_{ig}^{1-\sigma} && (45)\\
&= \varphi_{ig,L} + \varphi_{ig,R} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k d_{nkg} \frac{\widehat{Y_{ik}^F}}{\widehat{C_{ik}^F}^{1-\sigma}} \right)^{\frac{1-\sigma}{\sigma}} && (46)
\end{aligned}$$

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:

$$\begin{aligned}
\widehat{P_{ig}^C}^{1-\sigma} &= \varphi_{ig,L} \lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} + \varphi_{ig,R} \lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \hat{r}_{ig}^{1-\sigma} && (47)\\
&= \varphi_{ig,L} \lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} + \varphi_{ig,R} \lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k d_{nkg} \frac{\widehat{Y_{ik}^F}}{\widehat{C_{ik}^F}^{1-\sigma}} \right)^{\frac{1-\sigma}{\sigma}} && (48)
\end{aligned}$$

and:

$$\begin{aligned}
\widehat{Y_{ig}^C} &= \widehat{C_{ig}^C}^{1-\sigma} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k d_{nkg} \frac{\widehat{Y_{ik}^F}}{\widehat{C_{ik}^F}^{1-\sigma}} \right) && (49)\\
&= \varphi_{ig,L} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{\widehat{Y_{ik}^F}}{\widehat{C_i^F}^{1-\sigma}} \frac{D_{ig}^C}{Y_{ig}^C} \right) + \varphi_{ig,R} \left(\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} \frac{D_{ig}^C}{Y_{ig}^C} \sum_k d_{nkg} \frac{\widehat{Y_{ik}^F}}{\widehat{C_{ik}^F}^{1-\sigma}} \right)^{\frac{1}{\sigma}} && (50)
\end{aligned}$$

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

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

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

$$\widehat{C_{ik}^F}^{1-\sigma} = \varphi_{ik,L} + \sum_g \varphi_{ik,g}\varphi_{ig,L}\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}} + \sum_g \frac{E_i e_{ig,R}\hat{r}_{ig}^{\frac{1}{\sigma}}}{Y_{ik}^F} \frac{d_{nkg}}{\sum_h d_{nhg}\widehat{Y_{ih}^F}\widehat{C_{ih}^F}^{\sigma-1}}$$

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

$$\begin{aligned}
Y_{ik}^F\widehat{Y_{ik}^F} &= \frac{Y_{ik}^F\widehat{Y_{ik}^F}}{\widehat{C_{ik}^F}^{1-\sigma}}\left[\varphi_{ik,L} + \sum_g \varphi_{ik,g}\varphi_{ig,L}\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}}\right] + E_i\sum_g e_{ig,R}\hat{r}_{ig}^{\frac{1}{\sigma}} \frac{d_{nkg}\widehat{Y_{ik}^F}\widehat{C_{ik}^F}^{\sigma-1}}{\sum_h d_{nhg}\widehat{Y_{ih}^F}\widehat{C_{ih}^F}^{\sigma-1}} \\
&= \frac{\widehat{E_i}D_{ik}^F}{\widehat{P_i^F}^{1-\sigma}}\lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}\left[\varphi_{ik,L} + \sum_g \varphi_{ik,g}\varphi_{ig,L}\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}}\right] + E_i\sum_g e_{ig,R}\hat{r}_{ig}^{\frac{1}{\sigma}} \frac{d_{nkg}\widehat{Y_{ik}^F}\widehat{C_{ik}^F}^{\sigma-1}}{\sum_h d_{nhg}\widehat{Y_{ih}^F}\widehat{C_{ih}^F}^{\sigma-1}}
\end{aligned}$$

and summing across industries, we get:

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

which can be rewritten:

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

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:

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

Hence:

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

where Λ_i is defined as:

$$\Lambda_i^{1-\sigma} \equiv \sum_k \alpha_k\lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}\left[\varphi_{ik,L} + \sum_g \varphi_{ik,g}\varphi_{ig,L}\lambda_{ig}^{-\frac{1-\sigma}{\theta_g}}\right] \tag{51}$$

Plugging it back into 44, and using again $\frac{\widehat{Y_{ik}^F}}{\widehat{C_{ik}^F}^{1-\sigma}} = \frac{D_{ik}^F}{Y_{ik}^F}\frac{\widehat{E_i}}{\widehat{P_i^F}^{1-\sigma}}\lambda_{ik}^{-\frac{1-\sigma}{\theta_k}}$, we obtain an analytical expression for the

change in income for natural resources:

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

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:

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

Finally, we obtain that the gains from trade are:

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

C - Survey of Elasticity Estimates

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)

Notes: Here, SR indicates a short run elasticity estimate, and LR indicates a long run elasticity estimate. 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 construct our elasticity estimate table in the main section.

Commodity	PED	PES	Location	Citation
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)
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)

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

D - List of primary commodities under consideration

Table 9: List of primary commodities under consideration

Allspice	Eggplant	Other minerals
Almonds	Fava Beans	Other nuts nes
Aluminium	Felspar	Other oil seeds, nes
Andalusite, kyanite and sillimanite	Ferro-manganese	Other seeds, nes
Anise	Figs	Palladium
Antimony	Fluorine; bromine	Palm Oil
Apples	Fluorspar	Papayas
Apricots	Foraged plants, nes	Peaches
Arsenic	Garlic	Peanut
Asbestos	Germanium	Pears
Asparagus	Ginger	Peas
Avocados	Gold	Peppercorns
Balata	Grain sorghum	Petroleum
Bananas	Grapefruit	Pineapples
Barley	Grapes	Pistachio
Barytes	Graphite	Plants for perfume
Beans, nes	Green tea	Platinum
Beeswax	Guavas, mangoes	Platinum
Beryllium	Gypsum	Plums
Birds Eggs	Hazelnuts	Poppy seed
Bismuth	Honey	Potassium chloride
Borax	Hops	Potatoes
Boron; tellurium	Iodine	Processed ramie
Brazil nuts	Iridium, osmium and ruthenium	Rapeseed
Brussels sprouts	Iron	Rare-earth metals
Buckwheat	Kieselguhr, Tripolite	Raspberries, blackberries, etc.
Cabbage, lettuce	Lead	Rhodium
Cacao	Lead	Rice
Cadmium	Leeks	Roots and tubers, nes
Calcium phosphates	Leguminous vegetables, nes	Rye
Canary seed	Lemons and limes	Saffron
Carrots and turnips	Lentils	Salt
Cashew nuts	Linseed	Sand and Gravel
Cassava	Magnesite	Seasame
Cauliflowers	Magnesium	Selenium
Cement	Maize seed	Silk-worm cocoons
Cement clinkers	Mandarins	Silver
Cherries	Manganese	Soybeans
Chestnuts	Mate	Spinach
Chickpeas	Melons	Steel
Chromium	Mercury	Strawberries
Cinnamon	Mica	Strontium and barium
Citrus fruit, nes	Milk and cream	Sugar
Cloves	Millet	Sunflower seed
Coal	Molybdenum	Sweet potatoes
Cobalt	Mushrooms	Talc
Coconuts	Mustard seed	Tin
Coffee	Natural gas	Titanium
Cotton	Natural rubber latex	Tobacco
Cotton seed	Nickel	Tomatoes
Cucumbers	Nickel	Tungsten
Dates	Niobium, tantalum and vanadium	Uranium
Diamonds	Nutmeg	Vanilla
Dried beans	Oats	Vermiculite, perlite and chlorites
Dried pepper	Onions	Walnuts
Durum wheat	Oranges	Zinc
Edible roots	Other cereals	Zirconium

E - Additional Figures

Figure 11: Crop suitability for cotton (green = high potential yield)

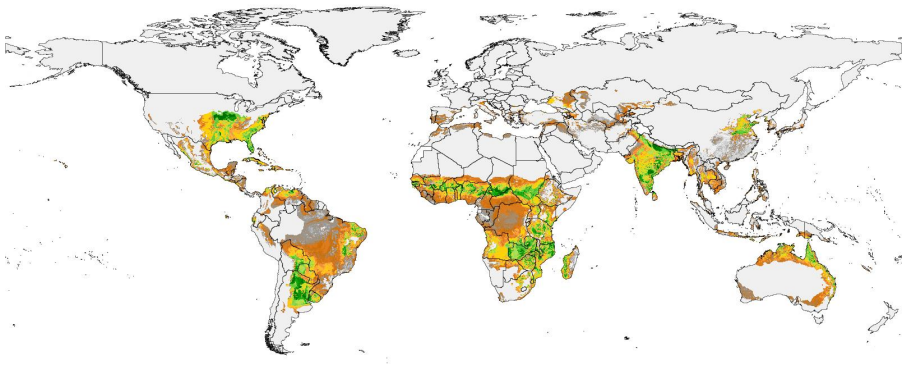
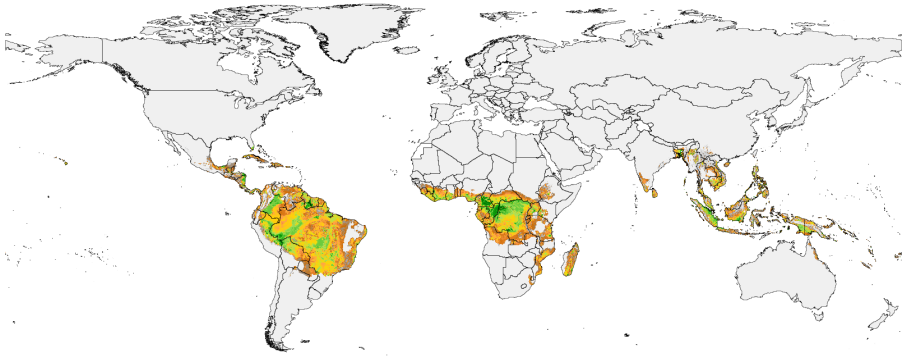


Figure 12: Crop suitability for coffee



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 13: Crop suitability for maize; source: GAEZ

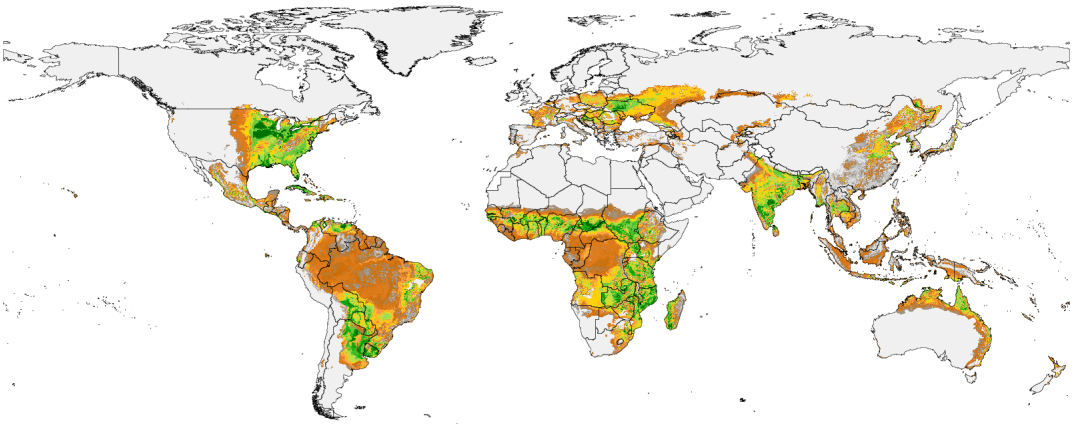
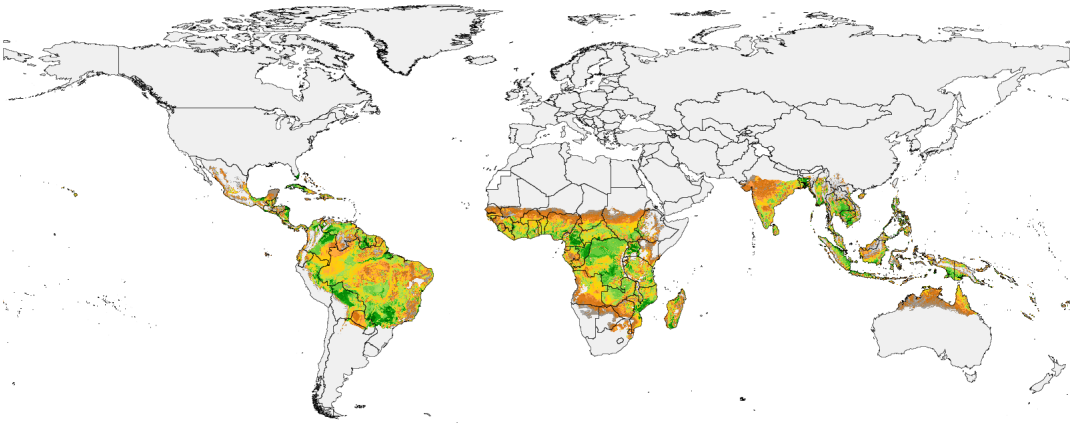


Figure 14: Crop suitability for dryland rice; source: GAEZ



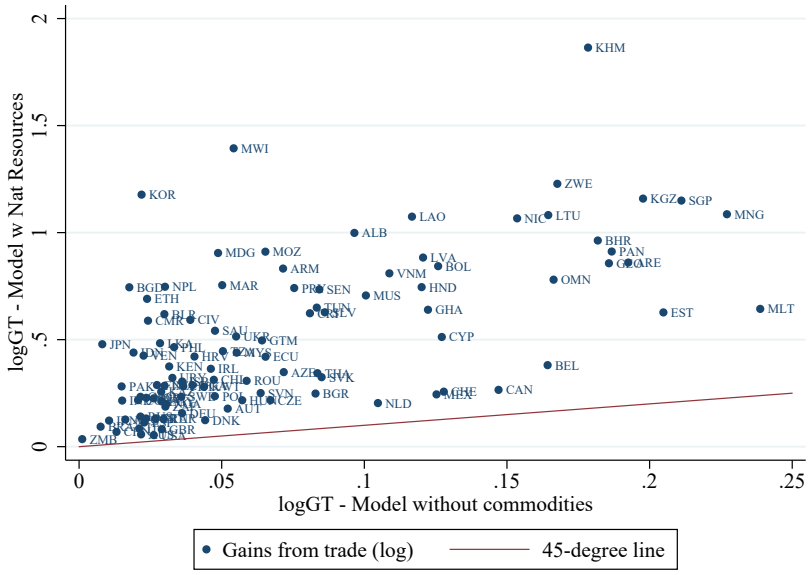


Figure 15: Gains from trade relative to gains from trade in manufacturing only



Figure 16: Comparison to model with labor only – excluding commodities in small production