Climate Change, Trade Costs, and Agricultural Trade

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Abstract: This study examines how changes in yields caused by climate change will affect the welfare of cereal grain and oilseed producers around the world. We first model how trade patterns and welfare are determined by bilateral trade costs, land endowments, and crop yields. We then estimate the parameters of this model, including crop yield distributions, the costs of accessing foreign markets, and countries' export competitiveness. We estimate the extent that trade can serve as a vehicle for adapting to climate change, and the welfare gains of liberalization in the global crops sector.

Keywords: crops, geography, grains, trade liberalization, yield variability

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Despite improvements in agronomic practices, the yields of rainfed crops are highly variable within most countries. Yield variability is largely a function of weather and may be exacerbated by widespread adoption of common high-yielding varieties and uniform agronomic practices (Anderson and Hazell, 1987). Since variation in crop yields implies variation in supplies, international trade is a natural vehicle for adapting to yield variability. When one region has a crop failure, spatial arbitrage can reallocate supplies from regions of abundance, thereby minimizing the fluctuation of prices (Randhir and Hertel, 2000; Reilly and Hohmann, 1993).

International trade already performs this role, yet the system is far less efficient than theoretically possible since trade costs are large (Anderson and van Wincoop, 2004). Relative to the general economy, market-insulating non-tariff barriers are pervasive in this sector. For example, the U.S. and Japan apply some sort of non-tariff barrier to 74% and 96% of the agricultural products that they import, respectively (Anderson and van Wincoop, 2004). Freight costs are high due to the bulkiness of agricultural products. High trade costs are also due to tariff barriers, information costs, transport time, contract enforcement costs, wholesale distribution costs, legal and regulatory costs, and barriers associated with the exchange-rate system.

By themselves, trade costs adversely affect the efficiency of world agriculture through their effect on trade flows. These inefficiencies could be worsened, however, if climate change results in greater yield variability. Recent research shows that climate change will affect not only mean yields by region but may exacerbate crop yield variability within individual countries (IPCC, 2007; Chen, McCarl, and Schimmelpfennig, 2004; Reilly, 2002). Rising temperatures may intensify climatic events such as the El Niño/Southern Oscillation (ENSO) phenomenon, which have already created large damages within the global agricultural system (Timmermann et al., 1999; Chen, McCarl, and Adams, 2001). This may lead to increased incidence of intense rainfall and flooding, as well as “dust bowl” droughts.

This study documents patterns in agricultural trade costs and models how these interact with yield variability and technology to influence economic welfare around the world. We examine the degree to which world markets are globalized versus autarkic and evaluate the extent to which trade can serve as a vehicle for adapting to potential increases in yield variability. We develop a Ricardian trade model based on the pathbreaking work of Eaton and Kortum (2002) that makes trade predictions based on the usual determinants of trade (e.g., factor endowments) but also on yield distributions and the bilateral costs of accessing foreign markets. The conceptual model provides new insights about the interaction of yield variability, technology, land resources, and trade costs in agricultural trade.

We operationalize the model by estimating an overall crop yield distribution for each country and econometrically estimating the bilateral costs of trade. This tells us about the relative competitiveness of different countries at exporting crops, as well as the aggregate barriers that exporters face. We quantify the price, trade, and welfare effects of scenarios involving changes in trade costs, production technology, yield distributions, and cropland expansion. While our model omits a direct representation of public policies, results from these counterfactuals shed light on the general types of policies that would benefit producers, exporters, and importers.

By documenting the nature of trade costs in crop agriculture, the study contributes to the broader literature on trade costs in the global economy (Anderson and van Wincoop, 2004; Hummels, 2007; Olper and Raimondi, 2007). It also contributes to a growing body of literature that examines the relationship between climate change and agricultural trade. One strand of this literature examines the value of climate forecasts in the context of trade (Sumner, Hallstrom, and Lee, 1998; Chen and McCarl, 2000). Another strand focuses on the interaction of physical and economic processes by linking atmospheric and agronomic simulation models to an economic model (Parry et al., 2004; Reilly et al., 2006; Rosegrant, Strzepek, and Msangi, 2005). A third strand of the literature focuses on how trade can act as a vehicle for adaptation to climate change (Randhir and Hertel, 2000; Reilly and Hohmann, 1993). A general conclusion from this literature is that consideration of global markets is critical for delineating winners and losers from climate change.

Our approach differs from existing studies in several ways. First, relative to the computable general equilibrium (CGE) models commonly used in the literature, we have less detail on factor input markets and employ simpler measures of welfare. However, we allow for various forms of trade costs beyond the tariff barriers typically considered within CGE models. In turn, the parsimonious structure of our model allows us to estimate a high proportion of our model's parameters. For example, we estimate bilateral trade costs using a specification derived directly from the theoretical model. We use cross-section yield data and maximum-likelihood techniques to directly estimate yield distributions by country. We also estimate national competitiveness at exporting to foreign markets.

In addition, our trading equilibrium captures stylized facts that are ignored by most existing agricultural trade models. For example, the model allows for intra-industry trade along with the fact that production of certain crops occurs in only certain countries. The approach recognizes that crop yield distributions vary by region, and that crop price differences are greater between countries that are farther apart. The approach also allows us to distinguish between comparative advantage and competitiveness in terms of model parameters.

To anticipate our main results, we find that trade costs are much higher in this sector than in manufactures trade, for example. Reduction of trade costs would result in large welfare gains for the twenty-one countries that we examine, mainly in the form of lower prices for crop buyers. Trade can also be extremely useful as a way of adapting to climate change, particularly if the latter has the effect of increasing yield variability within individual countries.

The first section below presents our conceptual framework. The following section discusses our estimation work and empirical implementation of the model. The subsequent section reports the results of several model experiments designed to represent possible future scenarios. The final section summarizes and concludes.

Conceptual Framework

We seek to link crop production and trade back to underlying factors, including yield distributions, land endowments, technology, and the bilateral costs of accessing foreign markets. We follow Eaton and Kortum’s (2002) approach to generalizing the Ricardian model beyond two countries and two commodities and introducing trade costs into the model. They examine the relationships between productivity, trade costs, and trade in the manufactures sector. A representative buyer purchases from a representative producer in the nation offering the lowest price as determined by productivity, transportation costs, and other trade impediments. Production is constant returns to scale and subject to idiosyncratic productivity shocks. The use of a probability representation of productivity allows comparative advantage to be ascribed in the context of many countries and commodities.

We retain this approach, but in our application we identify land instead of labor as the key factor of production. In this case the probability representation of productivity has a direct, meaningful interpretation: output per area of land (yield). The availability of direct observations on yield across countries permits us to directly estimate the parameters of this distribution instead of impute them from indirect methods. Another difference with Eaton and Kortum (2002) is that they focus on intermediate inputs trade and how manufactures fit into the broader economy, while our approach focuses on one sector: cereal grains and oilseeds, which we refer to as crops.

There are N countries indexed alternatively by i and n. In general we will index a country by i when referring to its role as a crop *producer* and by n when referring to its role as a crop *purchaser*. Each country i is endowed with a fixed amount of land specific to crops production (L_i). The yield of homogeneous crop j in country i is $z_i(j)$ and the price of cropland in country i is w_i. With constant returns to scale, the cost of producing crop j in country i is $w_i / z_i(j)$, with $z_i(j)$ being constant at this point.

To model bilateral trade we let the export country be denoted by i and the import country be denoted by n (with $i = n$ when a country buys from home). Trade costs follow the iceberg assumption, implying that delivery of one unit to country n requires d_{ni} units produced in i. We have $d_{ii} = 1$ and $d_{ni} > 1$ for any $n \neq i$. For any three countries i, k, and n, $d_{ni} \leq d_{nk} d_{ki}$.

The crops sector as a whole is modeled as a continuum of crops indexed on the unit interval $j \in [0,1]$. The representative buyer in country n has symmetric preferences over the different types of crops, and a fixed amount to spend: X_n. Utility is given by a constant elasticity of substitution function:

$$(1) \qquad U_n = \left[\int_0^1 q_n(j)^{(\sigma-1)/\sigma} dj \right]^{\sigma/(\sigma-1)},$$

where $q_n(j)$ is the quantity purchased and $\sigma > 0$ is the elasticity of substitution among crops. Country *n*'s representative purchaser maximizes U_n with respect to X_n. In a perfectly competitive international market the price that *n* pays for crop *j* from country *i* is:

$$(2) \qquad p_{ni}(j) = \frac{d_{ni} w_i}{z_i(j)}.$$

Since users in country *n* seek to buy crop *j* from the cheapest source they end up paying:

$$(3) \qquad p_n(j) = \min\{p_{n1}(j), p_{n2}(j), p_{n3}(j), ..., p_{nN}(j)\},$$

where *N* is the total number of countries.

We now introduce variability in yield, such that it is no longer a constant $z_i(j)$ (lowercase) but a random variable $Z_i(j)$ (uppercase). Since the price at which *n* can get crops from *i* depends on $Z_i(j)$, price is also a random variable, denoted $P_{ni}(j)$. As mentioned above, country *n* is supplied by the least-cost provider of crop *j*. This implies that *n* chooses the minimum from a sequence of random variables involving $Z_i(j)$. Eaton and Kortum (2002) show that in this circumstance an appropriate, underlying distribution for $Z_i(j)$ is a Fréchet Type II extreme value distribution:

$$(4) \qquad F_i(z) \; = \; \Pr\left[Z_i \le z\right] \; = \; \exp\left(-T_i z^{-\theta}\right),$$

where $T_i > 0$, $\theta > 1$, and $z > 0$. In our application T_i governs the location of the yield distributions, with higher T_i meaning higher average crop yields in country *i*. θ governs the amount of variation in the yield distributions, with a lower θ implying a broader yield distribution in each country. While T_i contributes positively to a country's absolute advantage in production, θ is a measure the degree to which comparative advantage will play a role in the analysis. A lower θ implies greater comparative advantage and higher gains from trade. Due to an assumption of identical cost and demand structures, the index for crops (j) can be dropped, and we do so whenever this is notationally convenient below.

As noted above, the price at which country i can supply country n is a random variable $P_{ni}(j)$. Its cumulative distribution function is derived by incorporating the price equation (1) into the yield distribution (4) for $p > 0$. As shown in Eaton and Kortum (2002), the probability that country i supplies country n at the lowest price is:

$$(5) \quad \Pr\left[P_{ni}(j) \ \leq \ \min\left\{P_{ns}(j); s \neq i\right\}\right] \ = \ \frac{T_i(w_i d_{ni})^{-\theta}}{\sum_{i=1}^{N} T_i(w_i d_{ni})^{-\theta}}.$$

(5) says that n's probability of buying from i is increased by higher average yields in i (T_i), lowered by trade costs between n and i (d_{ni}), and lowered by the input cost associated with land in i (w_i). Importantly, (5) can be related to the share of n's spending on crops from i. Let X_n be country n's total spending on crops, and X_{ni} be n's spending on crops from country i, with $i = n$ when a country buys from home. Summing over all sources of supply gives: $\sum_{i=1}^{N}\left(X_{ni}/X_n\right) = 1$. Due to the continuum of goods assumption, the share of n's spending on crops from i is equal to (5), which means:

$$(6) \quad \frac{X_{ni}}{X_n} = \frac{T_i(w_i d_{ni})^{-\theta}}{\sum_{i=1}^{N} T_i(w_i d_{ni})^{-\theta}}.$$

(6) relates data on trade shares back to fundamental determinants of trade, including the yield parameters (T_i and θ), bilateral trade costs (d_{ni}), and the price of cropland (w_i).

In this trading equilibrium, only certain countries will be an active producer of crop j, and they will export only to those countries for which the price received overcomes trade costs. As trade costs rise, a narrower range of crops is traded. In particular, trade adjustment occurs at the extensive margin (the subset of crops that get traded) as opposed to the intensive margin (the volume of crops traded). In the extreme of autarky, every country produces the full range of crops. Note that in a monopolistic competition model, by contrast, every country exports something to every other country. And in Armington trade models, an increase in trade would occur at the intensive margin, that is, a larger volume of trade occurs among the set of crops already traded. The Eaton and Kortum approach has some advantages in this regard.

The approach also allows for the fact that price differences are generally greater for countries that are farther apart. Following Eaton and Kortum (2002), the price index for country *n* can be written in terms of yield parameters, trade costs, and land prices:

(7) $$P_n = \gamma \left[\sum_{i=1}^{N} T_i (w_i d_{ni})^{-\theta} \right]^{-1/\theta},$$

where $\gamma = \left[\Gamma((\theta + 1 - \sigma)/\theta) \right]^{1/1-\sigma}$, with Γ being the Gamma function that is used to express certain types of definite integrals. The incorporation of bilateral trade costs allows for deviations from the law of one price to be modeled in a realistic way.

We now consider the market for cropland. Supplies of cropland in each country (L_i) are taken as given and returns to cropland (w_i) are endogenous. The total domestic product derived from cropland is $w_i L_i$. This is identically equal to the sum total of country *i*'s sales around the world: $w_i L_i = \sum_{n=1}^{N} X_{ni}$. Using (6), returns to cropland can be expressed as a function of the exogenous underlying parameters:

(8) $$w_i = \frac{1}{L_i} \sum_{n=1}^{N} \left\{ X_n \left(\frac{T_i (w_i d_{ni})^{-\theta}}{\sum_{i=1}^{N} T_i (w_i d_{ni})^{-\theta}} \right) \right\}.$$

w_i can be solved for using numerical methods.

The basic model is given by equations (6), (7), and (8). The model is closed by considering trade balance and how the crop sector fits into the broader agricultural economy. We introduce a non-crop agricultural sector as a numeriare good. Total agricultural income for country *i*, denoted Y_i, equals cropland income ($w_i L_i$) plus value added in the non-crop sector. The share that crop income has of total agricultural income varies by country.

Using index *i* when discussing a country as a producer, and index *n* when discussing the same country as a buyer, total agricultural income for country *i* (Y_i) equals total agricultural spending (Y_n) for *i* = *n*. This implies that overall agricultural trade is balanced. However, trade in crops need not be balanced, which means that country *n*'s expenditure on crops (X_n) is not necessarily equal to the income derived from this sector ($w_i L_i$). The share that country *n*'s expenditure on crops (X_n) has of total agricultural spending (Y_n) is denoted α_n.

Counterfactuals are evaluated according to several criteria. One is the change in individual countries' exports and imports and overall world trade volume. Another is the change in land prices, $w_n' - w_n$, where w_n' denotes the new land price that solves (8) under the counterfactual simulation. Higher land prices are positively correlated with welfare since this reflects increases in income on the supply side. Another criterion is the change in crop prices ($P_n' - P_n$), where P_n' denotes the price that solves (7) under the counterfactual simulation. This price reflects the costs of purchasing on the demand side, and has a negative relationship with that country's welfare. A welfare measure that combines these two concepts is the change in real GDP, denoted $W_n = Y_n / P_n^{\alpha}$. For simplicity's sake a common α is used across countries. As shown in Eaton and Kortum (2002), the percentage change in real GDP can be approximated by:

(9) $$\ln \frac{W_n'}{W_n} = \left(\frac{w_n' - w_n}{w_n} \right) \frac{w_n L_n}{Y_n} - \alpha \ln \frac{P_n'}{P_n}.$$

The first and second terms on the right-hand side of (9) represent income and price effects, respectively. In a later empirical section we will use (9) to evaluate our counterfactual simulations, which involve shocks to model parameters.

Empirical Implementation

Data on bilateral crop purchases (X_{ni}) are from the GTAP (Global Trade Analysis Project) database (Dimaranan and McDougall, 2007). These data have the important advantage of being fully reconciled in a transparent manner across each exporter *i* and importer *n*. We observe the yield of crop *j* in country *i* (z_{ij}) from FAO (2007). We work with the year 2001 throughout the analysis since that is the GTAP base year. In 2001 there were 21 countries in the FAO databases that produced the following eight crops: barley, maize, oats, rice, sorghum, soybeans, wheat, and cereals nec (not elsewhere classified). To include more crops would require lowering the number of countries considered, and vice-versa. Table 1 identifies the 21 countries. While not comprehensive, this sample covers the major producers and traders of these eight grains and oilseeds. In our sample, imports from the other 20 countries as a share of total imports is 73.5% on average.

Estimation of Yield Distributions

This section describes the estimation of the parameters governing each country's productivity distribution (T_i and θ). A fundamental assumption underlying the results derived above is that the productivity distributions apply equally to each crop in a given country's crop sector. In turn, θ , which is a measure of the breadth of these productivity distributions, is assumed to not vary by crop or country. As such, T_i is basically a measure of the average productivity of a country's cropland; it is an average across crops. For these reasons we use the yields of different crops as a source of variation for estimation, as opposed, for example, to the yield of a particular crop over time.

The probability density function associated with equation (4) is:

(10) $f_{ij}(z) = \theta T_i z_{ij}^{-\theta-1} \exp(-T_i z_{ij}^{-\theta})$.

(10) can be made into an empirical likelihood function with an assumption of independence across countries (*i*) and crops (*j*):

(11) $LF = \prod_{i=1}^{N} \prod_{j=1}^{J} \theta T_i z_{ij}^{-\theta-1} \exp(-T_i z_{ij}^{-\theta})$.

(11) describes the probability of observing a particular sample of yields z_{ij} given different values of T_i and θ. To make the yields of different crops comparable, we normalize z_{ij} by *j*'s worldwide average yield ($\frac{1}{N}\sum_i z_{ij}$). This gives us eight comparable observations on yields for each of 21 countries.

The overall average yield for each country is reported in the first column of table 1. France, Zimbabwe, Italy, and the United States have the highest overall yields. The variation across countries reflects climatic conditions, soil quality, input usage (e.g., fertilizer), and management technique. Within the model, higher yields do not automatically imply greater competitiveness in international markets. One reason is that land prices (w_i) may be higher in those countries.

The second column of table 1 reports the results of maximizing the likelihood function (*LF*) using the Minos5 numerical solver. $\hat{T}_i$ ranges from 0.30 for Morocco to 2.16 for France, with $\hat{T}_{USA} = 0.99$. The results are typically very similar to the overall average yield for a country (column 1), although the range of values is larger. The yield variation parameter is $\hat{\theta} = 1.42$. This is considerably lower than the 3.60 and 8.28 values that Eaton and Kortum (2002) estimate for the manufactures sector. However, this is not surprising since crop yields are relatively heterogeneous across countries. Relative to manufactures, there are greater limits to the internationalization of agronomic knowledge (Ruttan, 2001). This is also explained by the fact that we examine a set of countries at very different stages of economic development.

In all that follows, we do not work with these crops individually but an aggregate of all eight crops. The eight crops were distinguished only for estimation of (11). The X_{nn} and X_{ni} data discussed below are based on an aggregation carried out using the GTAP software. We were careful in our aggregation to include only those crops and countries that correspond directly between the FAO and GTAP data. There are two exceptions. We estimate T_i for Ethiopia and the Ukraine using FAO yield data. However, the GTAP database does not distinguish Ethiopia or the Ukraine as individual countries. Rather, their production and trade are included within GTAP groupings *XSS* (Rest of Sub-Saharan Africa) and *XSU* (Rest of former Soviet Union), respectively. These include the country of question plus neighboring ones that have only partial information (Dimaranan and McDougall, 2007).

Estimation of Trade Costs

In this section we estimate bilateral trade costs in conjunction with a country's competitiveness at exporting crops. Our gravity model approach takes a more explicit approach to trade frictions than in Armington models, for example, and allows us to calculate trade frictions between specific country pairs. Once we have our estimate of trade costs (d_{ni}) we use it to impute land area and prices for the particular crops and countries in our sample.

Using the trade equation (6), we follow Eaton and Kortum (2002) and normalize (X_{ni} / X_n) by the home sales of a buyer (X_{nn} / X_n) to get:

(12) $$\frac{X_{ni}}{X_{nn}} = \frac{T_i(w_i d_{ni})^{-\theta}}{T_n w_n^{-\theta}} = \frac{T_i}{T_n}\left(\frac{w_i}{w_n}\right)^{-\theta} d_{ni}^{-\theta}.$$

Now take the log:

(13) $$\ln\left(\frac{X_{ni}}{X_{nn}}\right) = \ln\frac{T_i}{T_n} - \theta\ln\frac{w_i}{w_n} - \theta\ln d_{ni}.$$

To make this more useful we adopt a measure of competitiveness, $S_i \equiv \ln T_i - \theta \ln w_i$, which corresponds (roughly) to yield adjusted for land costs. We substitute S_i into (13) to get:

(14) $$\ln\left(\frac{X_{ni}}{X_{nn}}\right) = -\theta \ln d_{ni} + S_i - S_n .$$

In estimating (14) the S_i can be captured as country source dummies. With $\hat{T}_i$ and $\hat{\theta}$ from (11), we will subsequently be able to recover w_i.

Since we cannot directly observe $\ln d_{ni}$, we proxy for it with variables typically employed in gravity equations. Distance is accounted for using six dummy variables (d_k, k = 1,…,6) representing different intervals of Great Circle distance between capitals. For example, d_1 represents a distance of 375 miles or less, and d_2 represents a distance of 375 to 750 miles. We also account for whether two countries share a border (b), share membership in a trade agreement (e_h), and have a common language (l). Finally, we include an overall sourcing effect (m_n) that proxies for openness to trade. Substituting these in for $\ln d_{ni}$ in (14) gives:

(15) $$\ln\left(\frac{X_{ni}}{X_{nn}}\right) = S_i - S_n - \theta m_n - \theta d_k - \theta b - \theta l - \theta e_h + \theta \xi_{ni}^2 + \theta \xi_{ni}^1 ,$$

where ξ_{ni}^2 and ξ_{ni}^1 are error terms accounting for two-way and one-way trade to capture reciprocity in geographic barriers (Eaton and Kortum, 2002). To avoid the dummy variable trap there is no overall intercept, and the coefficients on ($S_i - S_n$) as well as the coefficients on $-\theta m_n$ are restricted to sum to zero.

Table 2 reports the results of estimating (15) with Generalized Least Squares and 420 observations [$420 = (21 \times 21) - 21$]. The overall fit of the estimated equation is good, with an adjusted R^2 of 0.71. Looking at the top part of table 2, we see that most explanatory variables have p-values close to zero and thus are statistically non-zero.

The negative coefficients on the $-\theta d_h$ variables indicate that trade costs increase with distance. The positive coefficients on the border, language, NAFTA, and EU variables indicate that these reduce trade costs. The coefficients on the $-\theta m_n$ variables, which give an indication of openness to imports, are reported further down the left half of table 2. Positive values of $-\theta m_n$ imply greater openness, while negative values of $-\theta m_n$ imply greater restrictiveness. With $-\theta m_n$ estimates equal to 5.45 and 3.42, respectively, the U.S. and France are the most open. With $-\theta m_n$ estimates equal to −4.64 and −3.94, respectively, Zimbabwe and Bulgaria are the least open.

The middle two columns of table 2 report the percentage effect of a trade impediment on trade costs. If we denote an estimated parameter by $\hat{d}$, the implied percentage effect on cost is calculated as $100\left(e^{-\hat{d}/\hat{\theta}}-1\right)$. Using our $\theta = 1.42$ estimate, we see that destinations within 375 miles add 5,104% to costs, for example, while sharing a border and language reduce trade costs by 34% and 56%, respectively. In the lower section of table 2 we see that shipping to Argentina would reduce costs by 86%, all else the same.

The trade costs in this sector are much higher than what Eaton and Kortum (2002) report for the manufactures sector. This is mainly because they use a higher estimate of θ (8.28). To understand the role that θ plays in our estimates, we report alternative trade cost effects for $\theta = 8.28$ (table 2). As expected, this lowers trade cost estimates by an order of magnitude, yet trade costs are still higher for crops than for manufactures (Eaton and Kortum, p. 1765). Another study to which we can compare our results is Riezman, Whalley, and Zhang (2006), who measure the extent of globalization in the overall economy. While they find a fairly high degree of integration in tradable sectors at large, the international crops sector that we study is relatively thin and unintegrated.

The rightmost three columns of table 2 report estimates of a country's competitiveness (S_i), which are also estimated as part of (15). Recall that competitiveness is increased by yields and reduced by land prices. The United States is the most competitive country in 2001 (5.09), followed by Argentina, another large exporter (3.84). Peru and Zimbabwe are the least competitive, at -3.37 and -3.21, respectively.

With our definition of competitiveness, $S_i \equiv \ln T_i - \theta \ln w_i$, and our estimates of S_i, T_i, and θ, we can back out an estimate of country *i*'s cropland price:

$$(16) \qquad \hat{w}_i = \exp\left([\ln \hat{T}_i - \hat{S}_i]/\hat{\theta}\right).$$

These values are reported in the third column of table 1. Note, for example, that average land costs are much higher in Italy than in the U.S. This gives the U.S. greater competitiveness (table 2) despite the fact that Italy's productivity distribution lies to the right of that of the U.S. (table 1).

Using the result from (16) and data on X_{ni}, baseline cropland estimates can be backed out of the land market identity that relates total production (exports plus production for domestic consumption) and land costs:

$$(17) \qquad \hat{L}_i = \frac{\sum_{n=1}^{N} X_{ni}}{\hat{w}_i}.$$

These values are reported in the fourth column of table 1. Finally, we need to estimate α_n, which is the share that spending on crops (X_n) has of all agricultural spending (Y_n). We first calculate this for individual countries using the GTAP data, then find a unified α by taking a GDP-weighted average. We get $\hat{\alpha} = 0.21$.

Counterfactual Simulations

The model is defined by equations (6), (7), and (8). We solve for baseline levels of the endogenous variables P_n, X_{ni}, and w_i using the procedure of Eaton and Kortum (2002). The counterfactual simulations involve shocks to trade costs (d_{ni}), yield distributions (T_i and θ), and cropland (L_i). Results are reported in tables 3-6.

Role of Yield Variability (θ)

We first consider changes in yield variability. Since the climate change literature makes few if any specific predictions in this regard, we take the simple route of considering a hypothetical 30% decrease in θ (from $\theta = 1.42$ to $\theta = 0.99$). This implies that productivity draws include more extreme lows and highs. This accounts for the possibility that one region has a poor crop while another region has a bumper crop, in which case there would be larger potential gains from trade.

The broadening of the yield distributions leads to an increase in overall world trade of 109%. The impacts on net welfare, crop prices, and returns to cropland are reported in columns 1-3 of table 3. The net welfare results are mixed, with ten of the countries having a net welfare gain. In some cases the rise in net welfare is driven primarily by a rise in the returns to cropland. For example, the U.S. has the most competitive crops sector (coefficient on S is 5.09), and as it responds to new opportunities in foreign markets it experiences a 6.5% rise in the returns to land. Increased foreign demand also drives up crops prices in the U.S., but this is too small (1.1%) to offset the positive welfare benefits of rising cropland prices. U.S. net welfare increases 1.4%.

Some of the countries that experience rises in land prices do not have high competitiveness, however. Bulgaria, Hungary, and Romania are not especially competitive in the crops sector (table 2), but their returns to cropland and their crop prices increase because they are relatively closed to imports (coefficients on $-\theta m$ in table 2 are all highly negative). In Bulgaria and Romania the rise in crop prices outstrips the rise in land prices, and net welfare falls by 2.9% and 3.7%, respectively.

Some countries with a fairly high level of competitiveness, such as China, do not experience an increase in land prices because they are relatively open to imports, which takes pressure off their crops sector. Crop prices in China fall by 9.5%, which contributes to a 1.3% increase in net welfare. The largest declines in crop prices are in Italy and Greece, which have falls of 56.2% and 54.1%, respectively. This happens because they are reasonably open to imports (coefficients on $-\theta m$ are 0.65 and –0.27, respectively) and their crop sectors are not especially competitive.

Twelve of the 21 countries have an increase in crop prices. Of those with an increase in prices, the average rise is 15%. For this reason 11 of the countries have a small decrease in overall welfare, with the maximum decline being 5.5% (Russia). Russia's crop sector is not particularly competitive (coefficient on S is -0.01), and it is not especially open to imports (coefficient on $-\theta m$ is –0.61), so its crop prices rise by 21.3% while returns to cropland fall by 4.0%.

So greater dispersion in yields around the world leads to a doubling of trade volumes. But what if trade was kept from expanding? Weather-induced yield variability has long been a rationale for trade restrictions in crop agriculture. For this reason we consider a simultaneous increase in yield variability and protectionism (trade costs). In particular, what if there was a 30% increase in yield variability (as considered above) but also rising protectionism, such that overall trade volume stays fixed?

Columns 4-6 of table 1 indicate what would happen in this scenario. The change from $\theta = 1.42$ to $\theta = 0.99$ with a simultaneous rise in trade barriers implies that potentially large gains from trade are missed. Fourteen of the countries experience a decline in net welfare. This is generally due to a rise in crop prices, which happens in 17 of the 21 countries. The median change in crop price is 15.1% (Brazil), with a maximum increase of 31.7% in Russia.

The adverse effect of rising crop prices is typically offset to some extent by rising land prices, which means that land-owners benefit at the expense of crop buyers. Thus while Mexico experiences a substantial rise in crop prices (23.0%), this is moderated by the fact that land prices also rise (16.1%). Mexico has a net welfare change of −2.3%.

Seven countries actually experience a net welfare benefit despite the rise in protectionism in conjunction with rising yield variability. The U.S. has a slight increase in welfare (0.2%) because crop prices fall to a greater extent (5.5%) than land prices fall (4.1%). This is due to slackening foreign demand associated with rising protectionism elsewhere. Spain also has an increase in welfare (0.5%), but for a completely different reason. Rising protectionism means it relies more heavily on its crops sector, causing cropland prices rise by 13.5%. This offsets a 7.0% rise in crop prices.

To sum up this section, the first scenario suggests that a broadening of countries' yield distributions is not highly detrimental so long as trade is free. Indeed, with higher levels of yield variability the gains from trade are that much higher; what is critical is that countries remain open to trade. The second scenario shows that the typical country will get hurt if trade barriers rise in concert with yield variability.

Importance of Trade Costs (d_{ni})

We now measure the degree that the world crops sector is globalized, and calculate the potential gains from further trade liberalization. We first examine what happens if each country would go to autarky. In the model this is accomplished by letting d_{ni} go to infinity for $n \neq i$, and setting $d_{ni} = 1$ whenever $n = i$. In this case world trade decreases 100%, and countries must produce whatever they consume. Specialization according to comparative advantage is no longer possible. This provides a (reverse) measure of the gains from trade.

The first column of table 4 reports welfare changes from going to autarky. As might be expected, every country suffers a small loss in net welfare (in Bulgaria and Ukraine the losses round to zero). Yet while the maximum fall in welfare is 10.6% (Spain), the median reduction in welfare is only 0.7% (Australia). This suggests that in terms of net welfare, the current level of globalization in world crops markets is similar to a state of autarky; international crop markets, on the whole, are very thin.

The changes in net welfare do, however, mask much larger changes in crop and land prices (table 4, columns two and three). For example, Spain has 92.8% increase in crop prices, and a 54.6% increase in land prices as pressure is put on the crops sector. In turn, twelve of the 21 countries experience an increase in cropland prices. In these countries, which might be considered "natural importers," the price of cropland gets bid up as the crops sector is forced to meet domestic requirements. U.S. land prices fall by 17.2%, which indicates a major contraction of this sector. However, the U.S. experiences only a 0.4% drop in net welfare since crop prices for consumers fall by 16.5%.

We now consider the extreme opposite of the above experiment: the total elimination of trade barriers. In this case we set $d_{ni} = 1$ for all $n \neq i$ and $n = i$ to create a situation of "zero gravity." The volume of world trade increases 1593%. Every country faces a drop in land prices except for Argentina, Australia, Brazil, Hungary, and the U.S. The effect is quite striking. Since their crop sectors expand under free trade they might be called "natural exporters." Zimbabwe has the largest increase in welfare, at 115.7%. This is not surprising given that it is the least open country, with a coefficient on $-\theta m$ of -4.64, and one of the least competitive countries, with a coefficient on S of -3.21 (table 2). The U.S. has the smallest increase in welfare (26.5%) since the U.S. is already both quite open and competitive and has relatively less to gain from further reduction in trade costs (table 2). The U.S. has 31.7% higher crop prices, which is bad for buyers, but exports increase by 1490%, and the returns to land almost double (95.5%).

We now consider a less extreme possibility reported in columns 4-6 of table 5. We let geographic barriers fall such that world trade doubles in volume (a 100% increase). Every country has a welfare increase, due mainly to falling crop prices, but it is small overall. The median welfare change is 1.6% (Australia), and the maximum is 9.7% (Spain). Since existing world trade volumes are fairly small to begin with, a doubling of trade volume doesn't result in a large change in countries' net welfare. On the other hand, the net welfare results mask much larger changes in crop prices. Countries such as Greece, Italy, and Spain experience large drops in crop prices, which benefits crop buyers in those countries.

The approach of this section enables calculation of an elasticity of trade volume with respect to trade cost. Upon conducting a variety of simulations (some not reported here) we find that a 1% reduction in trade costs increases world trade volumes by 1.5-2.5%. This is quite elastic, but in line with findings for the manufactures sector by Eaton and Kortum (2002), who report a trade volume/trade cost elasticity of 2-3.

Technological Advancement (T_i)

As noted in an earlier section, there are important limits to the internationalization of knowledge in the crop sector (Ruttan, 2001). A technique that works well in one region may not work well in another region due to large differences in soil and climate. However, trade can be a vehicle by which to spread the benefits of innovation.

In our model an improvement in overall yields for a given country *i* corresponds to an increase in T_i. We consider the effect of a hypothetical 30% increase in T_{USA}. The results are reported in the left three columns of table 6. A major effect of the change is a 5.2% increase in world trade volume. U.S. welfare increases 4.1%, due mainly to a

15.6% drop in crop prices, but also to a 2.9% increase in land prices as the U.S. crop sector benefits from increased technical prowess. U.S. exports increase by 15.9% while imports fall by 17.5%. All other countries have a fall in crop prices, which benefits consumers. This happens because they increase their imports, from 1.0% up to 17.4% (not reported in the table). Only one country (Argentina) has a welfare decrease, and it is slight, at 0.1%. This happens because Argentina is a close competitor for the U.S. (it has the second highest competitiveness coefficient) and because geographically it is of a comparable distance to key Asian and European export markets. The welfare of every other country increases, but less so for countries with higher import restrictions. Overall, the results suggest that trade can transfer the benefits of an innovation in one nation to other nations. However, the benefits are reduced greatly by trade costs.

Changes in Acreage (L_i)

In this final scenario we use the model to consider the fact that certain countries of the world have scope to increase their area planted to some of the crops that we consider in our analysis. As an illustration of how this might affect global patterns of trade and production, we consider a hypothetical 30% expansion of acreage in Brazil. Table 6 reports the effects on welfare, crop prices, and returns to land. The largest impact is in Brazil, of course. Crop prices drop by 22.8% in Brazil and land prices drop 23.4%. The overall welfare gain in Brazil is 5.6%. Overall world trade increases by 0.4%, with Brazil’s exports increasing by 38.3% (not reported in the table). The effects are fairly minor for other countries. The U.S. experiences a small, 0.5% drop in exports, and a larger, 6.5% rise in imports. However, due to the large size of the U.S. crops sector, U.S. welfare is essentially unaffected.

Summary and Conclusions

This study examines trade and welfare outcomes in the crops sector with respect to crop yield distributions, land endowments, and bilateral impediments to trade. Drawing on the novel approach of Eaton and Kortum (2002), the model explains intra-industry trade along with the fact that production of certain crops occurs in only certain countries. It also generates estimable equations regarding how open countries are to imports and how competitive they are in world markets. Our econometric work shows that trade costs are much higher in this sector than for those in the manufactures sector, for example, or in the general economy. The U.S. stands out, however, as one of countries most open to imports, and as one of the most competitive countries in the crops sector.

We evaluate the potential of international trade to serve as a vehicle for adapting to increased yield variability, which may occur as a result of future climate change. We characterize this possibility as a broadening of countries' individual yield distributions from which yield draws are made. We find that despite the existence of high trade costs, the global trading system is currently flexible enough to adapt to rising yield variability. If a 30% increase in yield variability would happen, for example, world trade would need to expand by 109%, but the welfare of the typical country is little changed. In short, trade can offset the potentially adverse effects of increased yield variability.

Since there is a long history of countries implementing trade restrictions in response to the randomness of agricultural production, we also consider what would happen if protectionism would rise in the wake of increased yield variability. If more extreme yields occur but world trade volumes remain fixed, most of the 21 countries in our sample would experience adverse welfare effects. The primary reason lies in large increases in crop prices, which occur in 17 of the 21 countries that we investigate. So while the earlier scenario suggests that a broadening of countries' yield distributions need not have highly adverse consequences, protectionism would reinforce the overall loss in welfare for the average country in our sample.

We also examine the role of geography in agricultural trade, and find that world trade volumes increase by roughly 1.5-2.5% for a 1% reduction in trade costs. This highly elastic response may be related to the fact that the international crops sector remains fairly autarkic overall. If world trade in crops were to shut down completely, the typical country would experience surprisingly little welfare change, at least on net. If, at the other extreme, there would be a hypothetical total elimination of trade barriers, world trade volumes would increase nearly 16-fold, and welfare would increase 72.1% in the median country. These gains would accrue mainly to crop buyers in the form of lower prices. Overall, our results suggest that the crops sector is far from being globalized, and that small reductions in trade costs would lead to sizable welfare gains.

Table 1. Baseline Parameters

Country	Simple average crop yield ($\bar{z}_i$)	Estimated yield parameter ($\hat{T}_i$)	Estimated land price ($\hat{w}_i$)	Estimated cropland ($\hat{L}_i$)
Argentina	1.04	0.74	0.05	143,273
Australia	1.01	0.89	0.31	5,471
Brazil	0.77	0.60	0.08	91,821
Bulgaria	0.87	0.70	1.84	3,912
China	1.12	1.06	0.17	264,445
Ethiopia	0.59	0.32	0.27	35,088
France	1.88	2.16	0.43	9,925
Greece	1.13	0.98	5.85	110
Hungary	1.17	1.10	3.47	233
Italy	1.55	1.62	3.03	1,528
Mexico	1.05	0.85	1.26	3,659
Morocco	0.43	0.30	0.70	3,453
Peru	0.65	0.43	5.94	173
Romania	0.82	0.44	1.44	1,871
Russia	0.56	0.31	0.43	12,140
South Africa	0.70	0.44	0.55	1,995
Spain	1.21	1.06	2.70	1,012
Ukraine	0.72	0.44	0.40	78,211
United States	1.23	0.99	0.03	1,112,677
Uruguay	0.86	0.48	2.92	192
Zimbabwe	1.66	0.42	5.20	53

Notes: Overall average yield corresponds to the eight crops, each value normalized by the average world yield for that crop. Maximum likelihood estimate of θ is 1.42 (degree of homogeneity in yield across countries and commodities).

Table 2. Bilateral Trade Equation

Source of barrier		Estimate	p-value	% effect on cost $\theta = 1.42$	% effect on cost $\theta = 8.28$		Estimate	p-value
Dist [0,375]	$-\theta d_1$	–5.61	0.00	5,104	97			
Dist [375,750]	$-\theta d_2$	–6.18	0.00	7,642	111			
Dist [750,1500]	$-\theta d_3$	–7.26	0.00	16,456	140			
Dist [1500,3000]	$-\theta d_4$	–8.26	0.00	33,492	171			
Dist [3000,6000]	$-\theta d_5$	–9.81	0.00	100,125	227			
Dist [6000,max]	$-\theta d_6$	–10.38	0.00	149,083	250			
Border	$-\theta b$	0.59	0.19	–34	–7			
Language	$-\theta l$	1.17	0.00	–56	–13			
NAFTA	$-\theta e_1$	1.45	0.31	–64	–16			
EU	$-\theta e_2$	1.21	0.05	–57	–14			
Mercosur	$-\theta e_3$	–0.70	0.46	63	9			
Country:		Destination country				Source country		
Argentina	$-\theta m_1$	2.75	0.00	–86	–28	S_1	3.84	0.00
Australia	$-\theta m_2$	1.99	0.00	–75	–21	S_2	1.54	0.00
Brazil	$-\theta m_3$	2.38	0.00	–81	–25	S_3	2.99	0.00
Bulgaria	$-\theta m_4$	–3.94	0.00	1,509	61	S_4	–1.22	0.00
China	$-\theta m_5$	1.81	0.00	–72	–20	S_5	2.54	0.00
Ethiopia	$-\theta m_6$	1.73	0.00	–70	–19	S_6	0.73	0.06
France	$-\theta m_7$	3.42	0.00	–91	–34	S_7	1.96	0.00
Greece	$-\theta m_8$	–0.27	0.65	21	3	S_8	–2.52	0.00
Hungary	$-\theta m_9$	–1.13	0.05	122	15	S_9	–1.67	0.00
Italy	$-\theta m_{10}$	0.65	0.28	–37	–8	S_{10}	–1.09	0.01
Mexico	$-\theta m_{11}$	–0.53	0.38	45	7	S_{11}	–0.49	0.22
Morocco	$-\theta m_{12}$	0.61	0.30	–35	–7	S_{12}	–0.70	0.07
Peru	$-\theta m_{13}$	–3.75	0.00	1,305	57	S_{13}	–3.37	0.00
Romania	$-\theta m_{14}$	–2.17	0.00	361	30	S_{14}	–1.34	0.00
Russia	$-\theta m_{15}$	–0.61	0.29	53	8	S_{15}	–0.01	0.99
South Africa	$-\theta m_{16}$	1.11	0.05	–54	–13	S_{16}	0.02	0.96
Spain	$-\theta m_{17}$	1.19	0.04	–57	–13	S_{17}	–1.35	0.00
Ukraine	$-\theta m_{18}$	–2.21	0.00	375	31	S_{18}	0.49	0.20
United States	$-\theta m_{19}$	5.45	0.00	–98	–48	S_{19}	5.09	0.00
Uruguay	$-\theta m_{20}$	–3.84	0.00	1,395	59	S_{20}	–2.25	0.00
Zimbabwe	$-\theta m_{21}$	–4.64	0.00	2,533	75	S_{21}	–3.21	0.00

Notes: Estimated by Generalized Least Squares using 2001 data and 420 observations. Adjusted $R^2 = 0.71$.

Table 3. The Gains from Trade: Broadening of Countries' Yield Distributions

Country	θ decreases by 30%; trade volume allowed to expand			θ decreases by 30%; trade volumes fixed at current levels		
	Net welfare	Crop prices	Returns to land	Net welfare	Crop prices	Returns to land
Argentina	1.7	33.2	28.4	–1.6	10.5	2.5
Australia	1.8	–1.2	7.1	–0.2	5.7	4.6
Brazil	–1.5	13.6	6.4	–2.9	15.1	1.8
Bulgaria	–1.9	12.0	3.2	–2.2	10.8	0.8
China	1.3	–9.5	–3.7	0.7	–3.8	–0.8
Ethiopia	–5.0	15.7	–7.6	–6.7	28.5	–2.2
France	11.0	–51.3	–0.5	5.4	–29.9	–4.4
Greece	10.1	–54.9	–12.6	1.0	2.3	9.4
Hungary	4.9	8.6	25.9	1.7	6.2	12.3
Italy	10.5	–56.2	–10.8	3.3	–7.5	10.1
Mexico	3.5	–19.0	–3.8	–2.3	23.0	16.1
Morocco	–3.4	8.1	–8.0	–6.6	27.4	–3.1
Peru	–2.1	–1.5	–12.7	–4.8	22.1	–0.2
Romania	–3.7	25.7	8.0	–4.9	24.7	2.0
Russia	–5.5	21.3	–4.0	–7.1	31.7	–1.1
South Africa	–0.7	–5.1	–9.7	–4.4	20.9	0.8
Spain	10.1	–51.5	–8.0	0.5	7.0	13.5
Ukraine	–4.9	22.2	–0.2	–5.2	23.4	–0.5
United States	1.4	1.1	6.5	0.2	–5.5	–4.1
Uruguay	–1.6	6.0	–1.9	–4.9	29.9	8.3
Zimbabwe	–4.2	16.0	–3.4	–5.3	23.9	–0.5

Note: The 30% decrease in θ implies that yield outcomes are more heterogeneous across countries. In columns 1-3 world trade changes by 109%; it does not change in columns 4-6.

Table 4. The Gains from Trade: A Move to Autarky

Country	Percentage changes		
	Net welfare	Crop prices	Returns to land
Argentina	–1.3	–35.6	–36.0
Australia	–0.7	6.3	3.2
Brazil	–0.5	0.7	–1.4
Bulgaria	0.0	–2.0	–2.1
China	–0.1	1.4	0.9
Ethiopia	–0.3	2.8	1.4
France	–3.8	–7.7	–23.0
Greece	–7.6	72.2	44.5
Hungary	–0.5	–9.2	–11.1
Italy	–6.3	60.9	36.7
Mexico	–6.4	63.3	39.8
Morocco	–0.7	3.1	–0.4
Peru	–1.4	17.0	10.9
Romania	–0.1	–5.1	–5.7
Russia	–0.3	1.9	0.4
South Africa	–1.7	18.9	11.8
Spain	–10.6	92.8	54.6
Ukraine	0.0	–1.0	–1.1
United States	–0.4	–16.5	–17.2
Uruguay	–3.1	33.9	21.5
Zimbabwe	–0.2	2.1	1.3

Note: Overall world trade volume decreases 100%.

Table 5. The Gains from Trade: Lowering Geographic Barriers

	Percentage changes					
	Baseline to zero gravity			Baseline to doubled trade		
Country	Net welfare	Crop prices	Returns to land	Net welfare	Crop prices	Returns to land
Argentina	63.0	–26.3	131.2	3.0	25.9	27.6
Australia	63.1	–243.6	40.8	1.6	–11.7	–4.7
Brazil	43.4	–115.0	65.1	0.9	–1.0	3.1
Bulgaria	72.1	–395.2	–88.2	0.1	1.4	1.6
China	30.3	–193.5	–72.0	0.3	–3.6	–2.2
Ethiopia	52.3	–256.8	–17.8	0.8	–7.3	–3.9
France	47.8	–239.3	–17.5	5.5	–27.5	–1.9
Greece	101.8	–512.5	–93.6	9.3	–64.0	–35.1
Hungary	89.2	–409.5	0.7	1.4	–1.3	4.8
Italy	76.1	–399.8	–101.0	7.8	–56.6	–31.5
Mexico	68.5	–353.6	–71.4	7.3	–53.9	–32.2
Morocco	73.1	–353.1	–18.0	1.8	–13.2	–5.1
Peru	112.6	–595.5	–151.1	2.4	–24.3	–15.4
Romania	76.9	–379.7	–27.9	0.5	2.3	4.1
Russia	63.2	–326.5	–42.1	0.8	–6.6	–2.8
South Africa	74.8	–352.2	–9.1	3.0	–28.1	–16.5
Spain	76.3	–384.5	–70.3	9.7	–61.6	–30.3
Ukraine	48.3	–284.9	–87.3	0.1	1.1	1.4
United States	26.5	31.7	95.5	1.0	11.2	13.1
Uruguay	97.6	–487.0	–56.5	3.8	–33.3	–20.2
Zimbabwe	115.7	–600.5	–102.0	0.5	–5.7	–3.4

Notes: The zero gravity scenario in columns 1-3 implies no trade costs. In this case world trade increases by 1593%. The doubled-trade scenario implies that world trade increases by 100%.

Table 6. The Gains from Trade: Alternative Scenarios

	Percentage changes					
	Technology diffusion: T_{USA} increases by 30%			Cropland expansion: L_{BRA} increases 30%		
Country	Net welfare	Crop prices	Returns to land	Net welfare	Crop prices	Returns to land
Argentina	–0.1	–1.0	–1.0	0.0	–0.9	–0.8
Australia	0.1	–1.7	–1.1	0.0	–0.1	–0.1
Brazil	0.0	–0.5	–0.4	4.8	–19.4	–19.9
Bulgaria	0.0	–0.1	–0.1	0.0	0.0	0.0
China	0.0	–0.2	–0.2	0.0	0.0	0.0
Ethiopia	0.0	–0.5	–0.4	0.0	–0.1	–0.1
France	0.2	–2.8	–1.7	0.0	–0.5	–0.3
Greece	0.4	–3.0	–1.9	0.1	–0.6	–0.3
Hungary	0.0	–0.8	–0.6	0.0	–0.1	–0.1
Italy	0.2	–2.1	–1.4	0.0	–0.4	–0.2
Mexico	1.0	–8.0	–5.1	0.0	–0.1	–0.1
Morocco	0.1	–1.2	–0.8	0.0	–0.2	–0.2
Peru	0.1	–0.6	–0.4	0.1	–0.7	–0.4
Romania	0.0	–0.3	–0.3	0.0	0.0	0.0
Russia	0.0	–0.3	–0.2	0.0	0.0	0.0
South Africa	0.3	–2.9	–1.8	0.0	–0.3	–0.2
Spain	0.3	–2.6	–1.6	0.1	–0.5	–0.3
Ukraine	0.0	–0.1	–0.1	0.0	0.0	0.0
United States	4.1	–15.6	2.9	0.0	–0.2	–0.1
Uruguay	0.0	–0.4	–0.3	0.0	–0.4	–0.3
Zimbabwe	0.0	–0.4	–0.3	0.0	0.0	0.0

Notes: World trade increases by 5.2% in the leftmost scenario. World trade increases by 0.4% in the rightmost scenario.

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