Climate Change Impacts on Global Agricultural Trade Patterns: Evidence from the Past 50 Years

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Abstract

Climate variability affects the specialization and portfolio of production and trade in agricultural markets. Previous studies suggest that climate change has a negative impact on economic growth and production patterns, and in particular it significantly alters yields and commodity prices. This paper investigates the impacts of climate change on agricultural trade using detailed estimates of temperature and precipitation for 67 countries from 1962 to 2014. This study controls for national income, comparative advantage in land, technology and productivity, climatic zone differences, estimates of agricultural nominal rates of assistance, and trade membership. Utilizing Prais-Winsten Panel Corrected regressions, the study produces aggregate and sectoral estimates at the global, regional, and income level. Findings suggest that climate change, over the period considered, has a significant impact on agricultural exports at all levels. Rising temperature significantly reduces agricultural exports from Asia and Africa, while it benefits Australia-New Zealand. Exports of grains, oil seeds, livestock, and dairy and eggs, are found significantly vulnerable to temperature changes. Developing economies show a larger reduction in agricultural exports due to increases in temperature. The findings provide a detailed evidence of how agricultural export patterns are vulnerable to variations in climatic conditions, and they could be used in further projections considering climate change as a determinant of agricultural production and trade.

Keywords: Climate change, Temperature, Precipitation, Agricultural trade, Regional trade, Developing countries

JEL Codes: F14, F18, Q17, Q18, Q54

1. Introduction

The scientific evidence on climate change shows a significant increase in the historical levels of temperature and precipitation, and puts forward the likelihood of future increases accompanied by extreme events like floods and droughts (IPCC 2007, 235-432; 2014, 39-73; Hansen et al. 2010, 1-29; Trenberth 2011, 123–138). The impacts of climate change span across all ecosystems and human activities, and the link between climate change and economic indicators has received consideration in function of eventual resulting costs or benefits (Pearce et al. 1996, 179-224; Watson et al. 1996, 95-586; McCarthy et al. 2001, 75-486; Dell et al. 2014, 740-791; Acevedo et al. 2017, 117-177). Some recent studies suggest that climate change distorts overall international trade patterns (Jones and Olken 2010, 455-458; Li et al. 2015, 55-57). However, considering the greater sensitivity of agricultural productive activities to climate change, it is likely that agricultural trade will be affected the most. The relationship between climate change and agricultural trade is not trivial. Given the evidence on the vulnerability of agricultural yield and prices to climate change, adverse changes in agriculture-based economies could not only threaten domestic food-security but also their market share and competitiveness; which in turn could demean their economic development significantly. Against this backdrop, understanding the climate change impacts on agricultural trade is imperative; albeit empirical studies on such impacts remain limited. There are several considerations in addressing this link. Firstly, agriculture includes a range of sub-sectors and climate change could affect them differently. Second, there could be a heterogeneous geographical sensitivity in production. Moreover, impacts could be differential across developed and developing countries (i.e., agricultural trade impacts might be higher for agriculture-based economies than diversified economies).

This study aims to comprehensively explore the heterogeneous impact of climate change on agricultural trade. In particular, this paper assesses temperature and precipitation variations on total and sectoral agricultural exports at a global, regional, and economic level. This study controls for national income, comparative advantage in land, technology and productivity, climatic zone differences, estimates of agricultural nominal rates of assistance, and trade membership.

The following section discusses the literature on climate change and economics. This is followed by a description of the methodology, methods and databases used. The results are then discussed distinguishing between aggregate and sectoral levels, global and regional levels, and income classification. Lastly, concluding remarks are presented.

2. Climate and Economics

The economic impacts of climate change could be direct (i.e., on growth, income, and productivity), and indirectly channelled through ecosystems, health, and wellbeing. Lee (1957, 5-157) discussed the wider effects of climate on crop production, animal production, human health and efficiency, and industry. Investigations of the relationship between climate change and economics have gained momentum as a consequence of potential effects exposed by advanced geo-physical modelling. A recent study by the OECD indicates that the cost of climate change could range from 0.6% to 4.4% of GDP by 2060, with developing countries absorbing the blunt of these costs (OECD 2015, 17-126). Hsiang (2010, 15367-1572) suggested similar findings for Caribbean and Central American countries. Similar negative effects on income have been found by Dell et al. (2009, 1999-203) at both country and city level. The negative economic impacts of temperature variability on growth have been shown by Dell (2012, 74-90) using a large global level data. A recent study by Heal and Park (2014, 18-23) suggests that warmer-than-average years strongly relate with lower output per capita for hot-countries, and higher output per capita for cold-countries.

Cross-border activities are directly affected by climate-induced variability impacting economic growth and productivity. International trade of goods and services could be affected through the following channels: (i) changes in total and sectoral comparative advantage, (ii) increased transportation costs due to vulnerabilities of supply and distribution channels, and damage to infrastructure, and (iii) implementation of climate-related policies (WTO-UNEP, 2009; World Bank, 2010). Projection estimates of aggregate trade impacts of climate change are proposed by Dellink, et al. (2017, 18-50). They conclude that trade alone will face limitations as an adjustment mechanism to likely future changes in climate, with economies relying primarily on climate-specific or geophysical sources (i.e., developing countries) experiencing greater effects.

While projection-based estimates are numerous, empirical evidence of the past climate change impacts remains limited. Jones and Olken (2010, 455-458) found that temperature increases have a large negative impact on exports from poor countries but no impact on export from rich countries, while precipitation change has no impact on US imports but it affects its exports positively. They also estimated SITC product-wise impacts and found that temperature increases have a significant negative impact on as many as 20 different export products. Li et al. (2015, 55-57) using product-city level data suggest that temperature has a significant negative impact on both exports and imports, while precipitation has a moderate positive impacts on exports.

Given the weather dependence of agricultural production systems, agriculture has been singled out as the most sensitive production activity to climate change. A vast number of studies have examined the impacts of climate change on agriculture, looking at yield effects and price forecasting. Different simulation-based studies forecast that global warming would significantly reduce production, yields, and economic surpluses in the US agricultural sector across crops, regions and farms (Adams, 1989, 1272-1279), Adams et al. (1995, 147-167) (Kaiser et al. 1993, 387-398). Similar modelling used by Mendelsohn et al. (1994, 753–771) also suggests a substantial loss in the values of US agricultural land and farms due to warming. In a more detailed approach, Schlenker and Roberts (2009, 15594–15598) predict the nonlinear impacts of temperature increases on the US Corn and Soybean yields and find that yields increase with temperature increases up to a threshold, however, yields experience a much steeper fall when they rise over that threshold. The vulnerability of US agricultural crop yields is also discussed by Feng et al. (2010, 14257–14262). Antle (1995, 741-746) suggests that most of the warming impacts are felt by tropical and sub-tropical countries, mainly the developing ones. Mendelsohn and Dinar (1999, 277–293) provide evidence that developing countries, like India and Brazil, are likely to experience significant crop yield shocks from warming. Schlenker and Lobell (2010, 1-80) also suggests large shocks in several crop yields in developing countries. Using a unique farmer-managed field level data, Welch et al. (2010, 14562–14567) finds that rice yields in six major tropical and subtropical Asian countries show large but contrasting responsiveness to minimum and maximum temperature levels. Using an extensive FAO panel data of all countries in the world, Lobell et al. (2011, 616-620) shows that yields of major agricultural crops like maize, rice, wheat, and soybean are significantly reduced by changes in temperature and precipitation both at the global and regional levels. Research on agricultural sensitivity has been complemented by studies looking at how climate change induces reduction in non-agricultural productivity, industrial output, industrial value added, and labour supply., Hsiang 2010, 15367-1572; Dell et al. 2012, 74-90; Lee et al. 2014, 504-513).

Climate variability may significantly change countries' agricultural trade competitiveness. Reilly et al. (1994, 24-36) advocate that a country's net economic effect of climate change will depend as much on its role in agricultural trade as on the impacts of the changed climate on crop yields. Juliá and Duchin (2007, 393–409) find that, using projected estimates of agricultural trade impacts, adaptation is critical to satisfy future demand, access to food may decrease in some regions of the world, and that relying solely on trade as a mechanism for the adjustment of agriculture to likely future changes in climate is concerning.

Stevanović et al. (2016, 1-9) forecast that by 2100, climate change impacts on global agricultural may reach an annual loss of 0.3% of global GDP, with a magnification of these effects in the presence of trade-restrictive policies. Jones and Olken (2010, 457-458) assess the impact of climate shocks on exports by using a simplified formulation of the change in exports dependent on changes in temperature and precipitation. Looking at US imports for four agricultural SITC 2-digit sectors, and 18 manufacturing products, they find that temperature increases negatively affect the exports of cereals and preparations, dairy and eggs, although positively affect exports of dyes and hides. This limited provision of agricultural sub-sectoral trade impacts of climate change is prevalent in the literature, with a vacuity of studies addressing the link between climate change and agricultural trade in a comprehensive manner.

To fil this void, we evaluate temperature and precipitation variations on total and sectoral agricultural exports at a global, regional and economic level; while controlling for income, comparative advantage in land, technology and productivity, climatic zone differences, estimates of agricultural nominal rates of assistance, and trade membership.

3. Methodology

Using the 2-digit SITC category, we extract world exports data for six agricultural sub-sectors for 102 countries from the United Nations Comtrade database for the period from 1962 to 2014. The agricultural product categories are: (i) grains, (ii) oil-seeds-nuts-kernels (iii) fruits and vegetables, (iv) tropical crops, (v) livestock, and (vi) dairy products and eggs. Detail on the sub-sectoral definitions is provided in appendix table A1. We generate world's 'total agricultural exports' (*agriexp*) by summing up these selected sub-sectoral agricultural exports for each country. The exports data is deflated to remove inflationary effects. We use historical temperature and precipitation data, with yearly averages of monthly near surface temperature and precipitation constructed from the National Center for Environmental Prediction (NCEP), NOAA/National Center for Atmospheric Research, USA real analysis[1]. The NCEP Real analysis is a spatially resolved dataset compiled from ground stations, satellites, aircraft, and marine observational systems. Country averages were constructed by identifying 2.5 x 2.5 degree grid cells within each country, and then averaging over all grid cells. To control for economy size, domestic demand and national income, we use GDP per capita (*GDPpc*) while for resource and factor endowment we incorporate arable land per capita (*aralandpc*) from the World Bank's World Development Indicators (WDI) database. To capture technological progress, innovation and improvement in productivity of factors of production, we use data on agricultural Total Factor Productivity (TFP) growth (*tfpgr_ag*) published by the US Department of Agriculture. To capture farm-level policies, we use nominal rates of assistance to total agriculture (*nra_ag*) collected from the World Bank's estimates of distortions to agricultural incentives (Anderson and Valenzuela 2008; Anderson and Nelgen 2013). In consideration to trade policies, we construct a dummy variable with respect to GATT-WTO membership accession (1 from the year of accession and 0 before that) for each country. Because the formation of GATT-WTO and its accession by the countries is considered as an event that largely changed the course of international trade, the accession dummy inclusion also captures this structural break in trade history. Detail on the variables and the data summary are provided in appendix table A5 and A6. In addition to the control variables, we further control for 'time' fixed effects (years) and 'climate-zone' fixed effects in our analysis. Dell et al.'s (2014, Appendix Table 1) review of related empirical literature suggests that many studies have not controlled for fixed-effects, while others have done it using different cross-section unit levels (e.g., city, country, region). Controlling for fixed-effects across climate zones enables us to produce

[1] We acknowledge Dr. David Newth from Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) for his generous temperature and precipitation data support contribution.

consistent estimates by accounting for fixed-heterogeneity biases due to the different nature of climate faced by different countries and regions. Following Belda et al. (2014, 3-4), we classify countries into four major climate zones (CZ): (i) Tropical (*torp*), (ii) Sub-tropical (*subtorp*), (iii) Temperate (*temp*), and (iv) Polar and Subpolar (*pol_subpol*).

Using the variables identified above, we formulate the following basic relationship:

$$Agricultural\ Exports = f(GDPpc, aralandpc, tfpgr\_ag, nra\_ag, WTO\_mem, temp, prec, climezone)$$

Subsequently, we propose the following estimation structure:

$$\mathrm{lnagriexp_{it}} = \alpha_\mathrm{i} + \beta_1\mathrm{lnGDPpc} + \beta_2\mathrm{aralandpc_{it}} + \beta_3\mathrm{tfpgr\_ag_{it}} + \beta_3\mathrm{nra\_ag_{it}} + \beta_4\mathrm{WTO\_mem_{it}} + \beta_6\mathrm{temp_{it}} + \beta_7\mathrm{prec_{it}} + \beta_8\mathrm{trop_{dum_{it}}} + \beta_9\mathrm{subtrop_{dum_{it}}} + \beta_{10}\mathrm{pol\_subpoldum_{it}} + \sum_{i=1}^{n} Y_i + \mu_\mathrm{it} \quad \text{------- (Eq.1)}$$

$$\mathrm{lnagriexp_{its}} = \alpha_\mathrm{i} + \beta_1\mathrm{lnGDPpc} + \beta_2\mathrm{aralandpc_{it}} + \beta_3\mathrm{tfpgr_{ag_{it}}} + \beta_3\mathrm{nra_{ag_{it}}} + \beta_4\mathrm{WTO_{mem_{it}}} + \beta_6\mathrm{temp_{it}} + \beta_7\mathrm{prec_{it}} + \beta_8\mathrm{trop_{dum_{it}}} + \beta_9\mathrm{subtrop_{dum_{it}}} + \beta_{10}\mathrm{pol\_subpoldum_{it}} + \sum_{i=1}^{n} Y_i + \mu_\mathrm{it} \quad \text{------- (Eq. 2)}$$

Where, *lnagriexp* is natural log converted agricultural exports, *i* denotes country, *t* denotes year, *s* for sub-sector, Y_i denotes year fixed-effects, α is constant, and μ captures residuals.

We estimate equation (1) for the World and equation (2) for the six agricultural sectors separately. We further estimate equation (1) individually for eight geographical regions: (i) USA and Canada, (ii) Central America, (iii) Latin America (iv) Western Europe/EU-15, (v) ETE-Central Asia, (vi) Africa, (vii) Asia and (viii) Australia and New Zealand. Finally, we produce estimates for High-income countries (HICs) and Developing countries (DVCs) (upper middle-income, lower middle-income, and lower income) separately. A list of countries by region and income groups (i.e. economic status following the 2014 definition of the World Bank lending groups) is shown in appendices table A2 and A3.

Given the unavailability of a full set of data for all variables across all regions and years, we check for model correctness and appropriate estimation method selection for each sample group (method selection results are given in appendix table A7). Based on these tests, we elect to carry out our estimations using Prais-Winsten Panel Corrected standard errors regressions. We produce estimates for 67 countries.

4. Results and discussion

This section firstly discusses world aggregate results, followed by sub-sectoral results. Results by region and economic level are discussed afterwards.

4.1 World aggregate level

When considering global exports of total agriculture, we find that GDP per capita is significant and positive, consistent with the development-led export hypothesis of trade. Arable land per capita is also significant and positive, consistent with the factor-endowment postulate of trade. We find that agricultural policy interventions, as measured by nominal rates of assistance, has significant and negative effects on agricultural exports, which provides empirical support of the general distortion and anti-trade properties of farm-policy interventions, discussed by Anderson (2009, 10). WTO accession and total factor productivity growth appear to have no significant effect. Climate zone fixed-effects show significant and positive signs as expected. Having controlled for all these factors, we find that increases in temperature have a significant negative effect on agricultural exports. A one degree Celsius increase in temperature reduces agriculture exports by about 1.6%. However, the effect of precipitation increases appears insignificant.

In light of these results, it is plausible that the negative effects of climate change, i.e. increases in temperature, over the last five decades, may have offset the positive effects of trade liberalization through WTO agreements and the growth in total factor productivity through technological developments and improvements in the quality of resources (e.g., agricultural inputs).

4.2 Sub-sectoral estimations

When considering sub-sectoral estimations, GDP per capita is consistently significant and positive for all six agricultural sub-sectors. Arable land per capita also shows a similar sensitivity, except for fruits and vegetables and topical crops. TFP shows significant and positive effects for livestock and oil-seeds-nuts-kernels. Otherwise, the effects of TFP growth is nullified, which supports the result on aggregate agricultural exports. WTO accession shows no significant effect on any of the agricultural sub-sectors, consistent with the results on aggregate total exports. Conforming to the aggregate exports effects, agricultural NRA appears to have significant distortion effects in all sub-sectoral agricultural exports except for dairy and eggs.

[Table - 1: Sub-sectoral estimation result on world agricultural exports]

With respect to the climate variables, we find significant and negative effects of increased temperature on the exports of four major agricultural sub-sectors: grains, oil-seeds-nuts-kernels, livestock, and dairy and eggs. It is relevant to consider that these four sub-sectors are the major sources of global food supply. Therefore, our findings indicate that increased temperature has large negative effects on the exports of products which are main sources of global food-supply, alongside the confirmation of no effects on tropical crops and fruits and vegetables. Results suggest that a one percentage-point increase in temperature reduces exports of grain by 6.7%, oil-seeds-nuts-kernels by 7.6%, livestock by 7.0%, and dairy and eggs by 5.7%. The magnitude of these effects appears large and roughly of similar size. On the other hand, precipitation shows significant and negative effects only for the exports of oil seeds, nuts and kernels. The insignificance of the other five sub-sectors is in line with the lack of sensitivity of total agricultural exports to precipitation changes. Overall, we find that oil-seeds-nuts-kernels are susceptible to both temperature and precipitation changes. Our results on cereals and dairy and eggs are consistent with earlier findings of Jones and Olken (2010, 455-458).

4.3 Regional estimations

The regional estimation results are shown in Table 2. GDP per capita appears significant and positive for four regions: Central America, Latin America, EU-15, and Africa. However, it appears negative for US-Canada and Australia-New Zealand. This might be due to the fact that the world has seen accelerated economic growth driven by non-agricultural sectors, i.e. manufacturing and industrial sectors; thereby, diverting resources from agricultural to non-agricultural sectors leading to reduction in relative agricultural share in production and exports. The argument can further be validated by looking at the results of arable land per capita. While arable land per capita appears significant and positive for two regions, consistent to the previous results; it is negative for four regions - Latin America, Central America, EU-15, and Africa. Given the natural progression of the world economy, this exhibit negative sensitivity appears meaningful. Our data shows that arable land per capita has been decreasing while at the same time, due to technological improvements and innovations in crop varieties have led to increase in total agricultural production and trade (See figure A8 and A9 in appendix). From 1961 to 1999, about 71% of growth in agricultural crops production has been due to yield growth while the other 29% comes from the harvestable land expansion (Bruinsma (ed.) 2003, 124-127). These facts essentially indicate a practical negative relationship between agricultural exports and arable land per capita. Note that in our estimations we explore the effective and robust relationship between arable land per capita and agricultural exports by separating out technology and innovation effects through TFP growth. The overall explanation also supplements the earlier discussion on the competitive use of resources for non-agricultural economic activities. We find a very limited evidence on the significance of TFP growth; significant and positive only for the EU-15 region. Regional effects of WTO accession appear mixed as its effects are negative in Asia and Latin America while positive for Central America and Africa, consistent with the literature. Agricultural farm-policies reflected through NRA shows evidence of significant distortion of agricultural exports for Asia and Latin America - the two major agricultural suppliers in the global market.

[Table - 2: Regional estimation result on world agricultural exports]

With respect to the climate variables, we find that the two major agricultural producing regions, namely, Asia and Africa, experience significant large negative effects on trade with increases in temperature. While a one degree-Celsius increases in temperature reduces agricultural exports by 4.8% for Africa, the effect is more than three-times larger at 14.4% for Asia. This puts into evidence the vulnerability of agricultural exports from these two regions to increases in temperature. While most of the economies in these regions are largely dependent on agriculture, most of the world's developing and least developed countries also belong to these two regions. There is an abundant body of literature identifying that people's lives, resources, and possessions in these two regions are most vulnerable to rapidly increasing temperature, and extreme weather, causing agricultural lands to become barren, or permanently lost with rising sea-levels, altering agricultural production and trade patterns (IPCC 2007, 235-432:2014, 39-73). In contrast, while rising temperature distorts agriculture in those regions, it can benefit temperate countries. We find that a degree-Celsius increase in temperature increases agricultural exports for Australia-New Zealand by as much as 8.3%.

We also find significant and negative effects of precipitation for Asia and Latin America, while positive in ETE-Central Asia. We find that a 1 mm increase in precipitation decreases agricultural exports by 0.1% in both Asia and Latin America. High levels of precipitation may cause significant losses in production and yield through untimely and heavy rainfall of long duration, increased frequency and duration of flooding, and widespread diseases of agricultural produce. We find that Asia is susceptible to increases in both temperature and precipitation levels.

4.4 Estimations by economic levels

Estimations of grouped countries according to economic levels are presented in Table 3. GDP per capita and arable land per capita are more or less consistent to the arguments provided earlier. TFP growth appear to have large positive effects only in high income countries, suggesting that developed economies have effectively gained from productivity improvement, mainly through technological development and innovation in agriculture. Agriculture in poorer economies often is largely labour-intensive, and cannot readily adopt advanced technology and innovation due to economic limitations. WTO accession shows mixed results, similar to the previous estimates. Consistent to the earlier evidence and arguments, agricultural NRA shows significant and negative effects on agricultural exports regardless of economic status. It is important to note that its effect is about twice larger for developing countries than high-income countries.

[Table - 3: Results by economic levels on world agricultural exports]

We find consistent estimates of temperature and precipitation effects on agricultural exports. Increases in temperature reduces agricultural exports for both high-income and developing economies. One degree Celsius increase in temperature reduces agriculture exports by 5.6% in developed economies, and by 12.6% in developing. Analysing further the developing economies we find that the lower middle-income and lower income countries are more susceptible to increased temperature. We find that a one degree-Celsius temperature increase reduces agricultural exports by a magnitude of 22.8% in lower middle-income countries and 39.1% in lower income countries. This indicates that middle-income countries experience no significant effects, while poor economies face a higher risk on their agricultural exports. We also find that increases in precipitation levels have negative effects on the exports of developing economies. A significant and negative effect is prevalent in lower middle-income and lower-income economies. These results are consistent with previous studies on the higher vulnerability of poor economies to climate change (e.g., Mendelsohn et al., 2006, Mendelsohn 2008; Jones and Olken, 2010, 455-458; Dell et al., 2012, 74-90).

5. Conclusion

We find that climate variations have significant impacts on agriculture exports globally. At a sub-sector level, we find that grains, oil seeds, livestock, and dairy and eggs, are significantly vulnerable to increases in the level of temperature. At regional levels, we identify that exports from the two major agriculture producing regions – Asia and Africa are most susceptible to rising temperature, while Australia-New Zealand benefit from it. Our findings provide further evidence that exports from both developed and developing economies are affected by the effects of increasing temperature, however, developing economies are considerably more vulnerable than high-income countries. We also find that changes in the levels of precipitation have no significant effects at the global level, however, precipitation is significant and negative for oil seeds at the sub-sectoral level, and Asia and Latin America.

Our results are wide-ranging as we control for climate-zone geo-differential fixed-effects, gravity effects, land endowment, WTO membership and agricultural nominal rates of assistance. Based on the exposed significant evidence of diverse sensitivities of trade to climate change, in order to build agricultural supply resilience to climate variations it is necessary to devise differentiated policy frameworks across sub-sectors, regions and economic levels.

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Table - 1: Sub-sectoral estimation result on world agricultural exports

Explanatory Variables	*Total Agriculture* (Equation 1)	Agricultural Sub-sectors (Equation 2)					
		Grains	*Oil seeds, nuts and kernels*	*Fruits and vegetables*	*Topical crops*	*Livestock*	*Dairy and eggs*
GDP pc (log)	0.855*** (0.056)	1.097*** (0.109)	0.563*** (0.120)	0.921*** (0.087)	0.838*** (0.074)	1.195*** (0.104)	1.639*** (0.168)
Arable land pc	0.401*** (0.096)	1.135*** (0.136)	1.660*** (0.263)	-0.155 (0.104)	-0.269* (0.150)	1.044*** (0.127)	0.639*** (0.166)
TFP growth	0.023 (0.197)	0.501 (0.545)	1.014* (0.533)	-0.049 (0.283)	0.102 (0.300)	0.772* (0.425)	0.393 (0.580)
WTO Mem	-0.010 (0.081)	0.290 (0.237)	0.010 (0.240)	0.090 (0.107)	0.171 (0.121)	0.152 (0.199)	0.183 (0.242)
NRA Agri	-0.164*** (0.048)	-0.408*** (0.124)	-0.384** (0.154)	-0.181** (0.080)	-0.204*** (0.058)	-0.289*** (0.109)	-0.164 (0.146)
Temp	-0.016** (0.008)	-0.067*** (0.023)	-0.076*** (0.026)	-0.005 (0.011)	-0.009 (0.010)	-0.070*** (0.020)	-0.057** (0.025)
Precip	0.000 (0.000)	-0.002 (0.001)	-0.002** (0.001)	0.000 (0.000)	0.000 (0.000)	0.000 (0.001)	-0.001 (0.001)
Trop Dummy	2.943*** (0.311)	1.992*** (0.692)	4.616*** (0.978)	2.957*** (0.481)	3.958*** (0.420)	1.538** (0.636)	1.477* (0.802)
Sub-trop Dummy	2.211*** (0.272)	2.607*** (0.485)	3.808*** (0.791)	2.769*** (0.395)	1.930*** (0.350)	2.657*** (0.481)	1.738*** (0.619)
Temp Dummy	1.675*** (0.171)	1.467*** (0.238)	2.479*** (0.511)	2.473*** (0.223)	1.139*** (0.178)	2.538*** (0.247)	1.564*** (0.278)
Constant	12.518*** (0.590)	8.751*** (1.065)	10.152*** (1.325)	9.565*** (0.903)	10.595*** (0.820)	6.362*** 1.009	2.688* (1.636)
R^2	0.956	0.696	0.607	0.886	0.909	0.764	0.600
No. of Observations	2436	2423	2420	2435	2409	2342	2370
No. of Countries	67	67	67	67	67	67	67

*Significance level: ***1%, **5%, *10%. Figures in parenthesis indicate HAC adjusted standard errors. Estimates for climate-zone fixed effects reported, however, for year fixed effects not reported.*

Source: Authors' estimations

Table - 2: Regional estimation result on world agricultural exports

Explanatory Variables (Equation 1)	*US & Canada*	*Latin America*	*Central America*	*EU-15*	*ETE -Central Asia*	*Asia*	*Africa*	*Australia & New Zealand*
GDP pc (log)	-2.088** (0.879)	0.953*** (0.313)	1.642*** (0.225)	1.893*** (0.092)	-0.110 (0.141)	0.022 (0.088)	1.053*** (0.057)	-2.676*** (0.810)
Arable land pc	0.252 (0.329)	-2.345*** (0.404)	-1.145** (0.524)	-0.542*** (0.193)	1.202** (0.510)	2.854*** (0.372)	-4.028*** (0.607)	0.025 (0.148)
TFP growth	0.335 (0.487)	-0.067 (0.451)	0.605 (0.571)	0.273** (0.113)	-0.086 (0.267)	0.620 (0.648)	-1.955 (1.894)	-0.320 (0.860)
WTO Mem	-	-0.220* (0.123)	0.796*** (0.119)	-	0.082 (0.156)	-0.349*** (0.116)	0.647*** (0.202)	-
NRA Agri	-0.143 (0.321)	-0.416** (0.166)	-0.204 (0.168)	0.070 (0.050)	0.108 (0.091)	-0.261** (0.123)	-0.430 (0.280)	0.287 (0.597)
Temp	-0.014 (0.042)	-0.014 (0.013)	-0.005 (0.020)	0.003 (0.009)	-0.038 (0.025)	-0.048*** (0.012)	-0.144*** (0.039)	0.083*** (0.025)
Precip	0.005 (0.003)	-0.001** (0.001)	0.000 (0.001)	0.000 (0.000)	0.004* (0.002)	-0.001*** (0.000)	-0.002 (0.003)	-0.001 (0.002)
Trop Dummy	-	1.354*** (0.318)	0.642 (0.429)	-	-	1.158*** (0.247)	1.725*** (0.134)	-
Sub-trop Dummy	-	3.502*** (0.335)	-	-	-	-1.174*** (0.312)	-	-
Temp Dummy	1.911*** (0.489)	-	-	2.179*** (0.065)	0.923*** (0.252)	-	-	-
Constant	41.646*** (7.978)	13.321*** (2.457)	8.168*** (1.997)	1.645* (0.878)	20.083*** (1.584)	19.912*** (0.7088)	17.494*** (1.092)	46.196*** (7.404)
R^2	0.998	0.983	0.999	0.984	0.979	0.973	0.486	0.974
No. of Observations	102	251	58	629	246	564	498	88
No. of Countries	2	5	2	14	12	14	16	2

*Significance level: ***1%, **5%, *10%. Figures in parenthesis indicate HAC adjusted standard errors. Estimates for climate-zone fixed effects reported, however, for year fixed effects not reported.*

Source: Authors' estimations

Table - 3: Results by economic levels on world agricultural exports

Explanatory Variables (Equation 1)	***Developed Economies (HICs)***	**Developing Economies (DVCs)**			
		All DVCs	*UMICs*	*LMICs*	*LICs*
GDP pc (log)	1.766*** (0.089)	1.231*** (0.107)	-1.937*** (0.217)	0.889*** (0.299)	1.221** (0.521)
Arable land pc	1.250*** (0.106)	0.142 (0.519)	4.560*** (0.506)	-2.842*** (0.821)	-0.570 (2.247)
TFP growth	0.686*** (0.231)	0.211 (0.756)	0.970 (0.904)	-0.335 (1.598)	0.643 (4.115)
WTO Mem	0.017 (0.138)	0.100 (0.169)	0.545** (0.241)	-0.739** (0.339)	3.298*** (0.951)
NRA Agri	-0.284*** (0.078)	-0.544** (0.215)	0.422 (0.277)	-0.104 (0.383)	-2.199** (0.965)
Temp	-0.056*** (0.014)	-0.126*** (0.021)	-0.020 (0.027)	-0.228*** (0.049)	-0.391*** (0.103)
Precip	-0.001 (0.001)	-0.003*** (0.001)	0.001 (0.001)	-0.008*** (0.001)	-0.020*** (0.007)
Trop Dummy	-	1.162** (0.471)	0.760 (0.844)	-0.062 (1.064)	0.225 (0.735)
Sub-trop Dummy	0.289 (0.433)	1.591*** (0.366)	2.541*** (0.770)	-0.823 (0.950)	-
Temp Dummy	1.925*** (0.166)	0.853** (0.359)	0.747 (0.654)	-	-
Constant	1.089 (0.777)	8.667*** (0.754)	28.533*** (1.682)	15.567*** (1.981)	18.829*** (3.983)
R^2	0.872	0.648	0.696	0.627	0.671
No. of Observations	1,166	1,257	477	593	187
No. of Countries	30	37	13	17	7

*Significance level: ***1%, **5%, *10%. Figures in parenthesis indicate HAC adjusted standard errors. Estimates for climate-zone fixed effects reported, however, for year fixed effects not reported.*

Source: Authors' estimations

APPENDIX

Table A1: Agricultural sectors considered

SITC Code	Sector	Breakdowns
00	Live animals	001 - Live animals other than Fish and aquatic or marines: Bovine animals, live Sheep and goats, live Swine, live Poultry, live (i.e., fowls of the species Gallus domesticus, ducks, geese, turkeys and guinea-fowls), Horses, asses, mules and hinnies, Live animals, n.e.s.
01	Meat and meat preparations	011 - Meat of bovine animals, fresh, chilled or frozen 012 - Other meat and edible meat offal, fresh, chilled or frozen (except meat and meat offal unfit or unsuitable for human consumption) 016 - Meat and edible meat offal, salted, in brine, dried or smoked; edible flours and meals of meat or meat offal 017 - Meat and edible meat offal, prepared or preserved, n.e.s.
02	Dairy products and birds' eggs	022 - Milk and cream and milk products other than butter or cheese 023 - Butter and other fats and oils derived from milk 024 - Cheese and curd 025 - Eggs, birds', and egg yolks, fresh, dried or otherwise preserved, sweetened or not; egg albumin
04	Cereals and cereal preparations (Grains)	041 - Wheat (including spelt) and meslin, unmilled 042 - Rice 043 - Barley, unmilled 044 - Maize (not including sweet corn), unmilled 045 - Cereals, unmilled (other than wheat, rice, barley and maize) 046 - Meal and flour of wheat and flour of meslin 047 - Other cereal meals and flours 048 - Cereal preparations and preparations of flour or starch of fruits or vegetables
05	Vegetables and fruits	054 - Vegetables, fresh, chilled, frozen or simply preserved (including dried leguminous vegetables); roots, tubers and other edible vegetable products, n.e.s., fresh or dried 056 - Vegetables, roots and tubers, prepared or preserved, n.e.s. 057 - Fruit and nuts (not including oil nuts), fresh or dried 058 - Fruit, preserved, and fruit preparations (excluding fruit juices) 059 - Fruit juices (including grape must) and vegetable juices, unfermented and not containing added spirit, whether or not containing added sugar or other sweetening matter
06	Sugars, sugar preparations and honey	061 - Sugars, molasses and honey 062 - Sugar confectionery
07	Coffee, tea, cocoa, spices, and manufactures thereof	071 - Coffee and coffee substitutes 072 - Cocoa 073 - Chocolate and other food preparations containing cocoa, n.e.s. 074 - Tea and maté 075 – Spices
22	Oil-seeds, nuts, kernels and oleaginous fruits	221- Oil-seeds, oil nuts, and oil kernels 222 - Oil-seeds and oleaginous fruits of a kind used for the extraction of "soft" fixed vegetable oils (excluding flours and meals) 223 - Oil-seeds and oleaginous fruits, whole or broken, of a kind used for the extraction of other fixed vegetable oils (including flours and meals of oil-seeds or oleaginous fruit, n.e.s.)

Source: UN Comtrade Database

Table A2: Regions and Countries considered

North America	South America	Western Europe/EU-15	ETE and Central Asia	Africa	Asia	Oceania	Central America
Canada	Argentina	Austria	Belarus	Botswana	Bahrain	Australia	Costa Rica
United States of America	Bolivia	Belgium	Bulgaria	Cameroon	Bangladesh	New Zealand	El Salvador
	Brazil	Denmark	Croatia	Côte d'Ivoire	Cambodia		Guatemala
	Chile	Finland	Cyprus	Egypt	China		Honduras
	Colombia	France	Czech Republic	Ethiopia	Georgia		Mexico
	Ecuador	Germany	Czechoslovakia	Ghana	Hong Kong		Nicaragua
	Paraguay	Greece	Estonia	Kenya	India		Panama
	Peru	Ireland	Hungary	Madagascar	Indonesia		
	Uruguay	Italy	Latvia	Malawi	Iran		
	Venezuela	Luxembourg	Lithuania	Mauritius	Israel		
		Netherlands	Malta	Morocco	Japan		
		Portugal	Norway	Mozambique	Kazakhstan		
		Spain	Poland	Nigeria	Korea		
		Sweden	Romania	Senegal	Kuwait		
		United Kingdom	Russia	South Africa	Kyrgyzstan		
			Slovakia	Tanzania	Malaysia		
			Slovenia	Tunisia	Nepal		
			Switzerland	Uganda	Oman		
			Ukraine	Zambia	Pakistan		
				Zimbabwe	Philippines		
					Qatar		
					Saudi Arabia		
					Singapore		
					Sri Lanka		
					Thailand		
					Turkey		
					Vietnam		

Source: Authors' definitions

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Table A3: List of Countries by Economic Level (Income Class)

High Income		Upper Middle Income	Lower Middle Income	Low Income
Australia	Kuwait	Argentina	Bangladesh	Ethiopia
Austria	Latvia	Belarus	Bolivia	Madagascar
Bahrain	Lithuania	Botswana	Cambodia	Malawi
Belgium	Luxembourg	Brazil	Cameroon	Mozambique
Canada	Malta	Bulgaria	Côte d'Ivoire	Nepal
Chile	Netherlands	China	Egypt	Senegal
Croatia	New Zealand	Colombia	El Salvador	Tanzania
Cyprus	Norway	Costa Rica	Ghana	Uganda
Czech Republic	Oman	Ecuador	Guatemala	Zimbabwe
Czechoslovakia	Poland	Georgia	Honduras	
Denmark	Portugal	Iran	India	
Estonia	Qatar	Kazakhstan	Indonesia	
Finland	Saudi Arabia	Malaysia	Kenya	
France	Singapore	Mauritius	Kyrgyzstan	
Germany	Slovakia	Mexico	Morocco	
Greece	Slovenia	Panama	Nicaragua	
Hong Kong	Spain	Paraguay	Nigeria	
Hungary	Sweden	Peru	Pakistan	
Ireland	Switzerland	Romania	Philippines	
Israel	United Kingdom	Russia	Sri Lanka	
Italy	United States of America	South Africa	Tunisia	
Japan	Uruguay	Thailand	Ukraine	
Korea		Turkey	Vietnam	
		Venezuela	Zambia	

Source: World Bank Definition of Country Lending Groups, 2014

Table A4: List of Countries by Climatic Zone

Tropical	Sub-tropical	Temperate	Polar
Cambodia	Argentina	Australia	Canada
Cameroon	Bahrain	Austria	Finland
Colombia	Bangladesh	Belarus	Norway
Costa Rica	Bolivia	Belgium	Russia
Côte d'Ivoire	Brazil	Botswana	Sweden
Ecuador	Egypt	Bulgaria	
El Salvador	Honduras	Chile	
Ethiopia	Hong Kong	China	
Ghana	Israel	Croatia	
Guatemala	Kuwait	Cyprus	
India	Mexico	Czech Republic	
Indonesia	Morocco	Czechoslovakia	
Kenya	Oman	Denmark	
Madagascar	Pakistan	Estonia	
Malawi	Paraguay	France	
Malaysia	Peru	Georgia	
Mauritius	Qatar	Germany	
Mozambique	Saudi Arabia	Greece	
Nepal	South Africa	Hungary	
Nicaragua	Tunisia	Iran	
Nigeria	Zambia	Ireland	
Panama	Zimbabwe	Italy	
Philippines		Japan	
Senegal		Kazakhstan	
Singapore		Korea	
Sri Lanka		Kyrgyzstan	
Tanzania		Latvia	
Thailand		Lithuania	
Uganda		Luxembourg	
Venezuela		Malta	
Vietnam		Netherlands	
		New Zealand	
		Poland	
		Portugal	
		Romania	
		Slovakia	
		Slovenia	
		Spain	
		Switzerland	
		Turkey	
		Ukraine	
		United Kingdom	
		United States of America	
		Uruguay	

Source: Authors' definitions

Table A5: List of Variables and Data Sources

Variable (*notation*)	Explanation/Controlling for	Source*
Agricultural Exports (*agriexp*)	Country-wise annual aggregate agricultural exports (US$ corrected for inflationary process)	United Nations Comtrade Database
GDP per capita (*GDPpc*)	Economic activity/level (US$)	WDI (the World Bank)
Arable land per capita (*aralandpc)*	Resource and factor endowments (hectare)	WDI (the World Bank)
Total Factor Productivity in agricultural sector (*tfpgr_ag*)	Productivity improvement in all factors of production (land, labour and capital) (per cent growth rate)	United States Department of Agriculture (USDA)
Agricultural Nominal Rate of Assistance (*NRA_ag*)	Farm policy interventions	Anderson and Valenzuela (2008); Anderson and Nelgen (2013), World Bank
Temperature (*temp*)	Yearly average of monthly near surface temperature (degree Celsius)	NCEP, NOAA/NCAR, USA[1]
Precipitation (*prec*)	Yearly average of monthly precipitation (millimetres); real analysis.	NCEP, NOAA/NCAR, USA[1]
Climate Zone (*dummies)*	Clime Zone-wise fixed effects for: Topical, Subtropical, Temperate, and polar and subpolar zones.	Belda *et al.* (2014)

***Sources:** *World Development Indicators (WDI), agdistortions World Bank, National Center for Environmental Prediction (NCEP), National Center for Atmospheric Research (NOAA/NCAR), World Trade Organization (WTO).*

Table A6: Descriptive Statistics

	Obs	Mean	Std. Dev.	Min	Max
Total Agricultural Exports					
World	4,272	4.23	9.25	0.00	118.00
Grains	4,196	0.99	3.01	0.00	41.20
Oil-seeds-nuts-kernels	4,080	0.31	1.59	0.00	26.00
Fruits and vegetables	4,217	0.97	2.22	0.00	22.90
Tropical crops	4,186	0.79	1.68	0.00	24.20
Livestock	3,985	0.85	1.98	0.00	18.90
Dairy and eggs	4,051	0.45	1.22	0.00	11.20
US & Canada	108	34.20	27.40	4.10	118.00
Latin America	527	3.81	7.86	0.00	65.20
Central America	347	1.63	2.52	0.20	18.00
EU-15	770	9.29	10.80	0.11	55.50
ETE-Central Asia	569	1.58	2.34	0.00	17.50
Africa	746	0.77	0.95	0.00	5.88
Asia	1,100	1.97	3.51	0.00	29.90
Australia-New Zealand	105	9.41	5.30	2.63	24.90
HIC	2,008	6.48	12.10	0.00	118.00
UMIC	930	3.84	6.72	0.00	65.20
LMIC	1,020	1.35	2.13	0.00	24.80
LIC	314	0.31	0.37	0.01	2.95
GDP Per Capita					
World	4,559	10424.68	13720.58	83.33	87772.69
US & Canada	106	29401.01	8626.60	14428.35	46405.25
Latin America	530	3433.29	1904.98	598.08	9853.53
Central America	368	2955.63	1952.24	820.20	8521.89
EU-15	779	27465.43	13154.04	4262.56	87772.69
ETE-Central Asia	508	15385.49	16530.99	1123.41	69094.75
Africa	953	1259.90	1486.29	113.71	7116.59
Asia	1,225	7257.30	10505.92	83.33	62168.77
Australia-New Zealand	90	24444.96	6013.29	13952.13	37867.77
HIC	1,882	22443.29	14325.19	584.35	87772.69
UMIC	1,126	3510.99	1856.91	83.33	8864.74
LMIC	1,157	1024.51	653.95	234.17	3953.42
LIC	394	378.55	205.61	113.71	850.06

Source: Authors' estimations

Table A6: Descriptive Statistics (Continued)

	Obs	Mean	Std. Dev.	Min	Max
Arable Land per Capita					
World	4,781	0.32	0.38	0.00	3.50
US & Canada	104	1.22	0.53	0.48	2.21
Latin America	520	0.35	0.24	0.03	1.10
Central America	364	0.22	0.12	0.05	0.61
EU-15	704	0.27	0.14	0.06	0.60
ETE-Central Asia	635	0.35	0.22	0.00	0.89
Africa	1,040	0.31	0.17	0.03	0.90
Asia	1,311	0.17	0.28	0.00	2.20
Australia-New Zealand	103	1.68	1.12	0.10	3.50
HIC	1,997	0.34	0.51	0.00	3.50
UMIC	1,128	0.35	0.32	0.03	2.20
LMIC	1,188	0.26	0.17	0.03	0.90
LIC	468	0.30	0.14	0.08	0.88
Agricultural TFP Index					
World	4,965	99.90	25.33	6.11	236.73
US & Canada	104	98.33	23.69	70.27	145.36
Latin America	520	97.40	22.88	52.97	178.78
Central America	364	109.58	29.56	39.61	206.08
EU-15	728	93.83	24.06	50.88	167.84
ETE-Central Asia	762	99.51	18.04	56.76	164.45
Africa	1,040	101.89	19.94	53.73	185.47
Asia	1,343	100.48	31.66	6.11	236.73
Australia-New Zealand	104	98.21	20.46	68.44	143.45
HIC	2,019	96.24	27.47	6.11	236.73
UMIC	1,236	100.67	24.60	39.61	202.26
LMIC	1,242	102.94	24.51	53.73	209.87
LIC	468	105.60	15.73	81.41	171.58

Source: Authors' estimations

Table A6: Descriptive Statistics (Continued)

	Obs.	Mean	Std. Dev.	Min.	Max.
Temperature					
World	5,353	16.98	7.50	2.80	29.26
US & Canada	106	6.27	2.93	2.80	10.10
Latin America	530	20.32	5.19	6.87	26.25
Central America	371	23.93	1.54	18.49	25.99
EU-15	795	9.81	2.77	3.58	15.30
ETE-Central Asia	954	9.41	3.33	2.87	18.84
Africa	1,060	23.18	2.73	16.26	29.26
Asia	1,431	19.24	7.35	4.23	28.17
Australia-New Zealand	106	15.91	5.59	9.20	22.57
HIC	2,332	12.65	6.58	2.80	28.06
UMIC	1,272	17.92	6.81	3.97	26.41
LMIC	1,272	22.24	5.13	5.71	28.35
LIC	477	21.55	6.09	4.23	29.26
Precipitation					
World	5,353	82.57	54.94	2.11	307.33
US & Canada	106	52.30	7.26	40.49	67.27
Latin America	530	117.85	50.52	31.14	278.80
Central America	371	161.96	52.16	45.48	279.97
EU-15	795	68.46	16.89	35.45	127.71
ETE-Central Asia	954	56.64	14.50	27.16	116.15
Africa	1,060	69.02	37.92	2.11	255.40
Asia	1,431	85.87	72.37	2.23	307.33
Australia-New Zealand	106	88.78	48.18	22.36	164.86
HIC	2,332	64.40	38.06	2.23	243.58
UMIC	1,272	98.10	67.39	11.09	307.33
LMIC	1,272	103.29	63.40	2.11	271.73
LIC	477	74.71	22.78	28.94	155.06

Source: Authors' estimations

Table A7: Diagnostics for the estimations (P-values reported)

Test Name	**Heteroskedasticity** *Modified Wald*	**Cross Section Dependence** *Pesaran*	**Autocorrelation (AR1)** *Wooldridge*	**Chosen Method**
World	0.000	0.000	0.017	PCSE (AR1)
Asia	0.000	0.000	0.000	PCSE (AR1)
ETE-Central Asia	0.000	0.031	0.002	PCSE (AR1)
EU 15	0.000	0.000	0.000	PCSE (AR1)
Latin America	0.000	0.000	0.001	PCSE (AR1)
Africa	0.000	0.071	0.299	PCSE
US & Canada	0.856	0.000	0.061	PCSE (AR1)
Central America	0.999	0.888	0.190	PCSE (Independent)
Australia & New Zealand	0.943	0.000	0.123	PCSE
High Income Countries	0.000	0.000	0.000	PCSE (AR1)
Developing Countries	0.000	0.000	0.002	PCSE (AR1)
Upper Middle Income Countries	0.000	0.000	0.000	PCSE (AR1)
Lower Middle Income Countries	0.000	0.000	0.342	PCSE
Lower Income Countries	0.001	0.002	0.077	PCSE (AR1)
Grains	0.000	0.000	0.000	PCSE (AR1)
Oil seeds, nuts and kernels	0.000	0.000	0.000	PCSE (AR1)
Fruits and vegetables	0.000	0.000	0.000	PCSE (AR1)
Tropical Crops	0.000	0.000	0.000	PCSE (AR1)
Livestock	0.000	0.000	0.000	PCSE (AR1)
Dairy and Eggs	0.000	0.000	0.000	PCSE (AR1)
Grains	0.000	0.000	0.000	PCSE (AR1)

Source: Authors' estimations

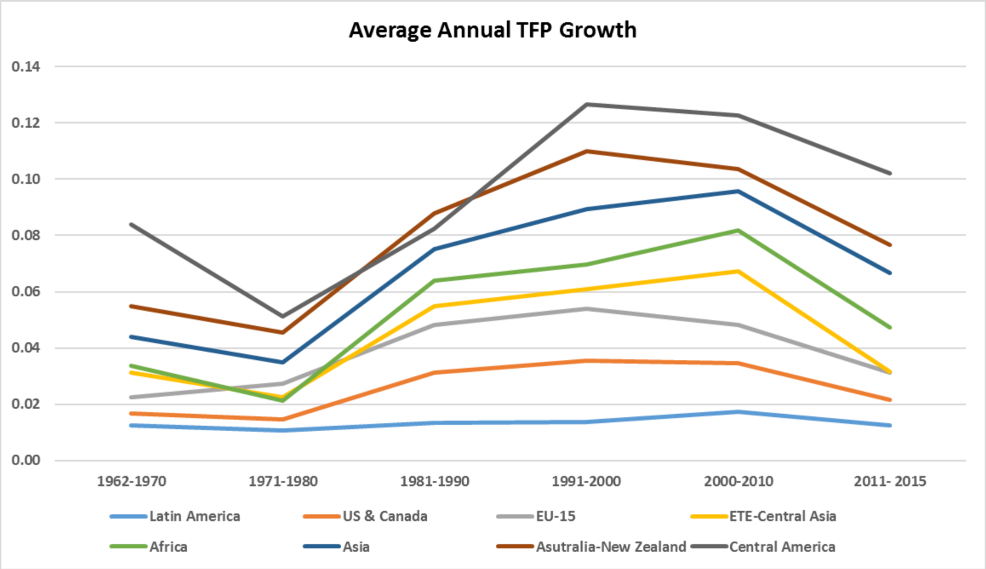

Figure A8: Average Arable Land per Capita by Decade;

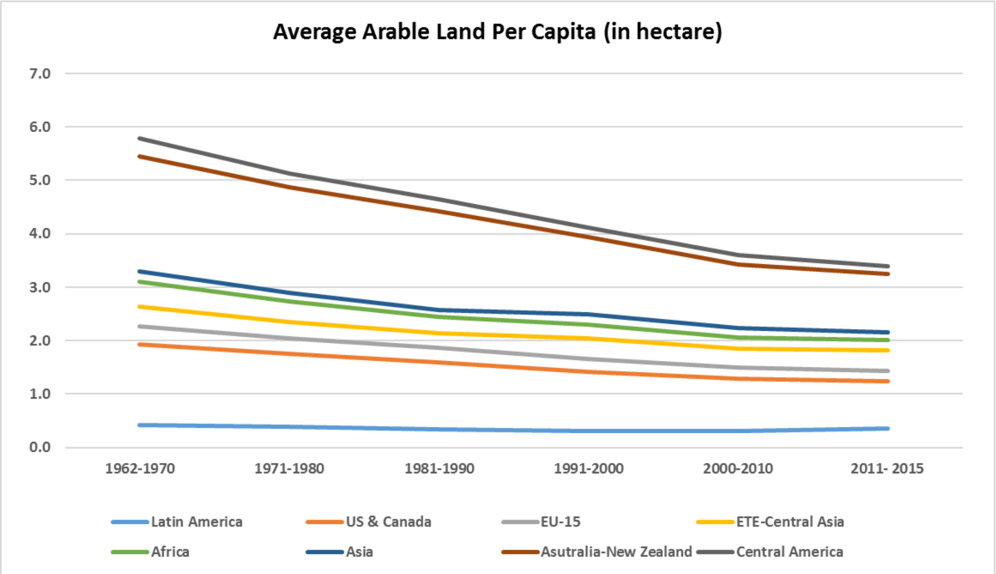

Figure A9: Average Annual Total Factor Productivity Growth by Decade