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Geography and Agricultural Productivity: The Case of Latin America and the Caribbean

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I quantify the role of current land quality and geographic conditions as well as projected future climate change for agricultural productivity differences across and within Latin American and Caribbean (LAC) countries. I combine geo-spatial data on potential yields by crop and grid-cell, with a spatial accounting framework. If LAC countries produced their crops in the locations they produce them with potential yields rather than actual, the 18 percent aggregate yield deficit relative to the richest countries would be reversed to an 18 percent surplus. While there is considerable cross-country and within-country heterogeneity, overall LAC countries have favourable natural land productivity. With improved input application and cultivation practices most LAC countries can double agricultural productivity, with substantial structural change implications. Climate change will reduce average yields in most LAC countries, but because of its heterogeneous effects across regions, there is more scope for yield gains from the spatial reallocation of production than under current conditions.

KEYWORDS

Agriculture, Land Quality, Climate Change, Productivity, Spatial Allocation, Crop Choice, Latin America and Caribbean

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Geografía y productividad agrícola: El caso de América Latina y el Caribe

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Cuantifico el rol de la calidad actual de la tierra y las condiciones geográficas, así como el cambio climático futuro proyectado, para las diferencias de productividad agrícola entre y dentro de los países de América Latina y el Caribe (ALC). Combino datos geoespaciales sobre rendimientos potenciales por cultivo y celda, con un marco de contabilidad espacial. Si los países de ALC produjeran sus cultivos en los lugares donde los producen pero con rendimientos potenciales en lugar de los reales, el déficit de rendimiento agregado del 18 por ciento en relación con los países más ricos se revertiría a un superávit del 18 por ciento. Si bien existe una considerable heterogeneidad entre países y dentro de cada país, los países de ALC tienen en general una productividad natural de la tierra favorable. Con una mejor aplicación de insumos y prácticas de cultivo, la mayoría de los países de ALC pueden duplicar la productividad agrícola, con importantes implicaciones de cambio estructural. El cambio climático reducirá los rendimientos promedio en la mayoría de los países de ALC, pero debido a sus efectos heterogéneos entre regiones, hay más margen para ganancias de rendimiento a partir de la reasignación espacial de la producción que en las condiciones actuales.

KEYWORDS

Agricultura, Calidad de la Tierra, Cambio Climático, Productividad, Asignación Espacial, Elección de Cultivos, América Latina y el Caribe

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1 | INTRODUCTION

Behind the large differences in real GDP per capita across countries lie substantial differences in economic structures. Lower income countries not only engage a large share of their labor force in agriculture but are also particularly unproductive in producing farm goods relative to advanced economies (Gollin et al., 2002; Restuccia et al., 2008; Caselli, 2005). Understanding the source of the large measurable differences in real agricultural productivity across countries is a fundamental question with important implications for structural change, development, poverty reduction, sustainability and welfare.

Broadly speaking, there are two possible explanations for the agricultural productivity disparities across countries. First, they may reflect differences in production possibilities, related to the inherent geography, of land quality, climate, and topography. Geography would matter more in agriculture than any other sector of the economy because farming depends on the local biophysical environment in which it takes place. Second, agricultural productivity disparities may reflect differences in economic choices across countries, resulting from differences in institutions, frictions or constraints that affect either the operated technologies or the level and allocation of inputs. What the source of agricultural productivity differences is, is important and has different implications for policy. Most of the research in economics has focused on the second set of factors, related to economic choices and the economic or institutional environment in which they are made. Adamopoulos and Restuccia (2022) however, examine the role of land quality and geography in accounting for the differences in agricultural yields across countries.

In this paper, I study the role of current land quality and geographic conditions in understanding the observed agricultural productivity differences across countries and across sub-national administrative units within countries (states or provinces), with an emphasis on Latin America and the Caribbean (LAC). In addition, I study the implications of spatially granular climate change projections for future potential agricultural productivity differences across Latin American and Caribbean countries. Understanding the determinants of agricultural productivity is particularly important for Latin American and Caribbean countries, given that large populations still earn their living on the rural side of the economy with agriculture accounting for a sizable portion of employment and output (e.g., Bolivia, Ecuador, Guatemala, Honduras, Nicaragua, Peru); many countries are key exporters of major agricultural goods (e.g., Argentina, Brazil, Colombia, Mexico); and, there is remarkable bio-diversity and diverse agro-ecosystems not only across countries, but also across regions within countries (e.g., Amazon basin, Andean regions, Pampas, Yucatán Peninsula). Understanding the implications of climate change is particularly important, given that the challenges of food security and sustainable growth are emerging as a key policy priorities worldwide.

Following the methodological approach of Adamopoulos and Restuccia (2022), I combine gridded micro-geography data at the pixel level from the Global Agro-Ecological Zones GAEZ v3.0 (GAEZv3.0, 2012) project of the Food and Agricultural Organization (FAO) with a spatial accounting framework that decomposes aggregate potential yield gains into a production component, a spatial component and a crop composition component. In addition to the geographic focus on Latin American and Caribbean countries, my analysis extends the work of Adamopoulos and Restuccia (2022) by: (a) conducting sub-national analysis, across states/provinces, within all the major Latin American economies; (b) estimating the effect of climate change scenarios on aggregate potential yields across these economies.

GAEZ assembles spatially detailed land quality, climate and terrain topography attributes at the 5-arc minute resolution. Picture a grid covering the entire globe where the size of a cell in the grid is about 10×10 kilometers. GAEZ combines these detailed cell-

specific geographic conditions with well established state-of-the-art crop-specific agronomic models for all major crops to estimate the maximum potential amount of output per unit of land that can be produced in that cell for that crop, what is called a *potential yield*. The GAEZ database provides crop-cell potential yields for different levels of cultivation inputs and water conditions for all cells on earth. I use two potential yields for current geographic conditions, the *low input* scenario and the *mixed input* scenario. The low input scenario assumes the lowest level of intermediate inputs and cultivation practices and assumes rainfed water supply conditions, capturing closest the natural suitability of the land in a cell for the production of a particular crop. The mixed input scenario assumes an intermediate input application and targeted cultivation practices by land quality with both irrigated and rainfed water supply conditions, what GAEZ considers a reasonable approximation of current production practices. In order to study the role of climate change I use potential yield projections from GAEZ v4.0 (GAEZv4.0, 2021), which make use of the most recent climate change scenarios predicted by climatologists, accounting for their impact on crop-cell level production conditions. I examine the predictions under two climate models for the 2050s, which involve moderate temperature increases and carbon fertilization effects.

The spatial accounting framework aggregates yields for all crops across all cells within an administrative unit. The aggregate actual yield, i.e., the total value of output per unit of harvested land, can be expressed as a weighted average across all crops and cells, where the weights are the shares of land allocated to a crop and cell. This expression can be used to construct counterfactual yields. My main counterfactual estimates the aggregate *production potential* yield, whereby the same crops are produced in the same locations but with the potential crop-cell yields rather than their actual ones, keeping the allocation of land across crops and cells to the observed one. This production potential yield can be thought of as an aggregate summary measure of the natural productivity of the land, given the current land quality and geography of the administrative unit, and the current actual distribution of production across space and crops.

In terms of actual productivity, LAC countries are closer to the richest countries in the world, than the poorest. On average, the aggregate actual yield of LAC countries is at 82 percent of that of the highest income countries. However, there is considerable variation across LAC, with the actual yield of countries like Costa Rica, Chile, Colombia, Jamaica, Peru exceeding that of rich countries, with most somewhat below, and countries like Bolivia, El Salvador, Honduras and Nicaragua well below it (although still above the poorest economies of the world).

Using the low input scenario, closest to the natural suitability of the land, the production potential yield for LAC countries is on average higher than that of both the richest (by 18 percent) and the most agriculturally productive countries (by over 30 percent) in the world. While there is heterogeneity in potential yields across LAC countries, most exceed the potential yields of the wealthier countries, especially Argentina, Dominican Republic, Guatemala, Portugal and Uruguay. These findings imply that for LAC countries, as a whole, the actual productivity deficit relative to the most productive countries is not due to natural endowment limitations. Appropriately exploiting existing biophysical conditions and geography, LAC countries have the potential to surpass the most productive countries in agricultural productivity. The variation of actual yields across LAC countries is completely uncorrelated with the variation in production potential yields. This implies that the variation in observed agricultural productivity across LAC countries is not driven by variation in land quality and geography. In relative terms, Costa Rica and Colombia produce the closest to their production potential in comparison to the rich group of countries. The findings are robust to including coffee, cocoa and tea in the analysis.

The country-level findings mask the sub-national heterogeneity within countries. I

assemble maps with variation in the production potential yield (low input scenario) at the cell level, indicating the intensity of the potential yield across all of LAC. Further, I estimate the production potential at the first administrative sub-national level, i.e., for states or provinces, for all major LAC countries. Overall, I find that within countries there are provinces/states with high production potential in levels, that exceed those of the country as a whole. However, there is often a weak correlation between the provinces/states where agricultural production takes place and the potential yield of those regions, with exceptions such as Argentina. While the correlation of actual yields and production potential yields across provinces/states within countries varies, for all sub-national administrative units taken together across LAC countries the correlation is 0, just like at the cross-country level. This mis-alignment of actual production and potential yields can explain why countries are not fully taking advantage of their natural endowments.

I also examine the role that inputs play in projecting land quality and geography into actual agricultural productivity. I estimate production potential yields under the mixed input scenario that assumes an intermediate application of inputs and use of cultivation practices, as well as irrigation. I find that the production potential yields under the mixed input scenario are more positively correlated with the actual yields across LAC countries, with Antigua and Barbuda being an outlier. The closer alignment of actual and potential yields across LAC indicates that the actual suitability of the land when appropriately interacted with inputs can partly account for the variation of agricultural productivity across countries. The production potential yields under the mixed input scenario are higher in levels than the actual yields for all countries. The yield gap, the ratio between the potential yield and the actual yield, is indicative of the aggregate potential yield gains that countries can achieve with more intensive input application given their internal distribution of land quality and geography, and their current allocation of harvested land across space and crops. This yield gap varies considerably across countries, but is smaller for all LAC countries relative to the less developed economies in the world. The largest potential for yield gains are for Bolivia, Honduras, Portugal (yield gap of over 3). The economies with the lowest potential yield gains, implying that they take advantage of their geography the most, are Brazil, Colombia, Costa Rica, Jamaica (yield gap of under 2). I show that these potential yield gains have substantial aggregate implications in terms of structural change and development, particularly for lower income countries.

Using the spatial accounting framework and the mixed input potential yields at the crop-cell level I also estimate the potential yield gains from the spatial reallocation of production and the change in the set of crops. I implement this through two counterfactuals. The first counterfactual estimates the *spatial potential* yield by reallocating production across cells within countries to maximize aggregate output, keeping the total amount of land allocated to each crop to the actual one in the data. The second counterfactual estimates the *total potential* yield by producing the highest value yielding crop in each cell, effectively allowing for not only a spatial reallocation of production but also a change in the composition of produced crops. I find additional gains relative to the production potential yield for all countries, particularly from the total potential. The largest gains from the spatial reallocation relative to the production potential would be experienced by Portugal (33 percent), Spain (35 percent), Ecuador (27 percent), and Peru (25 percent). The largest gains from the total potential would be experienced by Chile, El Salvador, and Uruguay.

Given the increased environmental challenges associated with extreme weather phenomena and climate change, in this paper, I also examine the effect of climate change projections by climatologists on cell-by-cell and crop-by-crop potential yields, and their implications for aggregate future potential yields, with a focus on LAC countries. Under moderate climate change scenarios, I find that aggregate production potential yields in the future are expected

to go down for most (although not all) LAC countries, relative to the potential yields with similar conditions today (mixed input scenario). However, the impact of climate change is highly heterogeneous across cells within countries, with some cells facing challenges for the cultivation of some crops while others presented with opportunities for higher yields. Taking into account the heterogeneous effect of climate change I find that there is more scope for aggregate yield benefits from the spatial reallocation of crop production across cells within countries in the future than under current climate conditions: on average across LAC countries, about 30 percent gains in the future relative to half those gains today. The potential gains from changes in the composition of crops produced (total production potential) are at 70 percent, lower than with current conditions which are at 105 percent.

This paper contributes to a large literature in macroeconomics and development trying to understand the role of agriculture for structural change and the process of economic development (Kuznets, 1966; Gollin et al., 2007; Caselli, 2005; Restuccia et al., 2008). An important question in this literature is understanding what accounts for the large productivity differences in agriculture across countries and between agriculture and non-agriculture within countries. The vast majority of the macro-development literature on the determinants of agricultural productivity has focused on the role of several frictions, institutions, policies constraining economic choices in agriculture, both across countries as well as within countries: intermediate inputs (Restuccia et al., 2008); farm size (Adamopoulos and Restuccia, 2014); spatial transport connectivity (Sotelo, 2020; Adamopoulos, 2025); land misallocation (Adamopoulos et al., 2022); selection (Lagakos and Waugh, 2013); idiosyncratic agricultural risk Donovan (2021); trade risk (Adamopoulos and Leibovici, 2024); capital intensity (Chen, 2020), among many others. None of this literature however has considered the role of land quality. As in Adamopoulos and Restuccia (2022), I study the role of current land quality conditions and geography for agricultural productivity using a spatial accounting framework and high-resolution geospatial data. I add to this by focusing on agricultural productivity differences across LAC countries, and extend the work by studying the role of land quality and geography at the sub-national level (across states/provinces) within LAC countries, and by considering the effect of climate change on potential future agricultural productivity.

There is an economics and agronomic literature that studies the role of individual geographic attributes, such as temperature, rainfall, soil quality, and topography on crop yields (Levine and Yang, 2014; Schlenker and Roberts, 2009; Cassman, 1999; Kravchenko and Bullock, 2000). Instead, the analysis here accounts for all geographic attributes that impact the biological growth of crops, summarized through potential yields. There is an earlier literature on cross-country growth analyses that use aggregate land quality indices or geography measures (Gallup et al., 1999; Sachs, 2003; Wiebe, 2003). In contrast here, I utilize the explicit spatial nature of the micro-geography data in GAEZ using an accounting framework, to aggregate up to various administrative levels, namely the country and sub-national levels.

It is well documented that temperature and climate change are associated with economic outcomes, at the micro, macro and spatial level (Nordhaus, 2006; Dell et al., 2009, 2012; Hsiang et al., 2017; Somanathan et al., 2021; Desmet and Rossi-Hansberg, 2024). There is however no other sector that is affected more directly by climate change than the agricultural sector (Cruz, 2024). Rising temperatures reduce crop yields, especially beyond some threshold, giving rise to non-linear effects (Schlenker and Roberts, 2009; Calzadilla et al., 2013; Burke et al., 2015; Zhao et al., 2017). To cope with climate change in agriculture the literature has examined several adaptation and mitigation strategies: adjusting agricultural inputs (Jagnani et al., 2021); changing patterns of production and trade (Costinot et al., 2016); sectoral reallocation (Nath, 2024); internal migration (Gröger and Zylberberg, 2016);

long-run adaptation (Burke and Emerick, 2016), among others. Here I examine how the high-resolution spatial effects of climate change are expected to affect aggregate agricultural productivity. In addition, taking into account the effect of climate change on future yields by crops and cell, I show that reshuffling agricultural production across space (within countries) and shifting farming to less affected crops, can mitigate the impact of global warming in LAC countries.

The rest of the paper proceeds as follows. In Section 2, I briefly examine the sectoral structure of LAC countries and describe the gridded data I use in the analysis. In Section 3, I present the spatial accounting framework. Section 4 presents the aggregate potential yields across countries. Section 5 covers the sub-national analysis across LAC countries, and Section 6 examines the role of climate change on future aggregate yields. I conclude in Section 7.

2 | DATA

I first examine the sectoral structures and incomes of Latin American and Caribbean economies, along with Portugal and Spain (LAC for short) and then present the spatial micro-geography data.

2.1 | Sectoral Composition: LAC Countries

Before considering the role of geography and land quality for agricultural productivity across LAC countries, I report data for the sectoral composition of their economies and their relative aggregate income. Table 1 displays the share of employment in agriculture (first column), the share of agricultural value added in GDP (second column), and real GDP per capita, PPP in constant 2021 international \$ (third column). All data are from the *World Development Indicators* of the World Bank for the year 2010.¹ I report the data by LAC country, their average as well as for Canada, the United States and the top (20 percent richest) and bottom (20 percent poorest) quintiles of the world real GDP per capita distribution. The fourth column reports the ratio of each country's real GDP per capita relative to the 20 percent richest countries.

On average, LAC countries are only at 29 percent of the richest countries in terms of GDP per capita, which is roughly in the middle of the distribution, and well below the other countries in North America. This average confounds the variation across LAC countries, with Portugal and Spain being at 60 and 70 percent of the richest countries, while Bolivia, Honduras and Nicaragua at about 10 percent. The share of employment in agriculture, a measure of the extent of structural change in a country, varies significantly across LAC countries from 30 percent and above in Bolivia, Guatemala, Honduras, Nicaragua to 4 and 6 percent in Spain and Argentina respectively. To put these numbers into perspective, in high income countries like Canada and the United States the agricultural employment share is under 2 percent while in the poorest countries in the world this is over 60. Similar conclusions are drawn by looking at the output share of agriculture. Most major LAC countries, in terms of their sectoral structure, are in the fourth quintile of the income distribution.

¹Due to missing or inaccurate data the agricultural employment and output shares for Argentina are from the Groningen Growth and Development Centre's *Economic Transformation Database* (de Vries et al., 2021) for the year 2010, and Antigua and Barbuda's agricultural employment share is from the Food and Agricultural Organization for the year 2013 (FAO, 2015).

TABLE 1 Role of Agriculture and GDP per capita

	Agr. Empl. Share (%)	Agr. VA Share (%)	Real GDP pc (PPP, int \$)	Real GDP pc Rel. to Rich 20%
North America				
Canada	1.8	1.5	52474.6	0.86
Mexico	14.6	3.1	20052.6	0.33
United States	1.7	1.0	59799.3	0.98
Central America				
Belize	18.5	8.8	11868.4	0.19
Costa Rica	12.4	6.5	18668.3	0.30
El Salvador	20.8	7.0	8648.9	0.14
Guatemala	33.5	11.2	9828.4	0.16
Honduras	36.5	11.6	5396.1	0.09
Nicaragua	29.6	17.0	5654.4	0.09
Panama	17.4	3.6	22739.1	0.37
Caribbean				
Antigua and Barbuda	21.0	1.2	25831.8	0.42
Bahamas	3.3	1.1	32702.0	0.53
Cuba	18.6	3.6		
Dominican Republic	12.4	6.1	14853.6	0.24
Jamaica	17.7	5.3	9654.1	0.16
South America				
Argentina	6.0	7.8	28056.3	0.46
Bolivia	31.7	10.4	7571.7	0.12
Brazil	11.5	4.1	18062.2	0.29
Chile	10.1	3.5	24148.3	0.39
Colombia	18.5	6.3	14012.0	0.23
Ecuador	27.9	8.3	11651.3	0.19
Guyana	21.4	28.5	10374.4	0.17
Paraguay	25.6	13.0	12738.6	0.21
Peru	28.0	6.8	12061.2	0.20
Uruguay	11.6	7.2	24960.7	0.41
Venezuela	8.5	5.4		
Europe				
Portugal	11.2	1.9	36670.0	0.60
Spain	4.2	2.4	42657.0	0.70
LAC countries	18.2	7.4	17869.2	0.29
Rich 20% of all countries	3.2	2.0	61312.2	1.00
Poor 20% of all countries	58.3	25.7	2596.0	0.04

Notes: Data from the World Bank's *World Development Indicators* for the year 2010, except for Argentina's agriculture shares (GGDC) and Antigua and Barbuda's agricultural employment share (FAO).

2.2 | Global Agro-Ecological Zones (GAEZ) Data

I use spatial micro-geography data from the Global Agro-Ecological Zones project, GAEZ v3.0 (GAEZv3.0, 2012), of the Food and Agricultural Organization (FAO) and the International Institute for Applied Systems Analysis (IIASA). GAEZ provides gridded datasets on a rich set of current land quality and geographic characteristics at the 5-arc minute resolution. The spatial unit of observation is a cell or pixel in this grid that is roughly 10 by 10 kilometers, with the mapping from arc minutes to square kilometers depending on the latitude. GAEZ offers a cell-by-cell characterization of the conditions relevant for agricultural production in terms of: a) soil attributes (e.g., depth, fertility, drainage, texture, chemical composition); b) climate attributes (e.g., temperature, sunshine hours, precipitation, humidity, and wind speed); c) terrain attributes (e.g., elevation, slope). This information is used to identify local biophysical constraints and limitations across cells.

GAEZ feeds the cell-specific information on geographic characteristics into well-established state-of-the-art agronomic models for each crop, that account for science-based biophysical growing requirements for each crop. A key output of this procedure is the estimation of a potential yield for each crop for each cell, which captures the highest output per hectare that can be attained in the cell given: the crop's growing requirements; the cell's characteristics; and assumptions about water supply conditions and cultivation practices. In sum, potential yields encapsulate the importance of location-specific land quality and geography for the production of particular crops. The crop-specific agronomic model parameters are based on well tested field and lab experiments by agricultural research institutes, reflecting the latest state of scientific knowledge (rather than estimated from reduced-form regressions).

The estimated potential yields, for the year 2000, are reported for different water supply conditions (irrigated, rainfed, total) and type of cultivation practices (low, intermediate, high, mixed).² I focus my analysis on two scenarios: (a) the *low input* scenario, with rainfed water supply conditions and the low level of cultivation practices, meant to capture the natural suitability of the land for the production of different crops; (b) the *mixed input* scenario that assumes total water supply conditions and mixed level of inputs, which assumes high inputs on the best land, intermediate inputs on moderately suitable land, and low inputs on marginal land, a scenario GAEZ considers a reasonable representation of current cultivation conditions. I use potential yields for baseline historical climate conditions (1960-1990). In the main analysis, I focus on 18 major crops and commodity groups,³ and examine the robustness to including cocoa, tea and coffee, which are high value cash crops.

The GAEZ database also provides at the 5 arc-minute resolution, for the year 2000, data on crop choice, actual production, actual area cultivated, and actual yield, i.e., tonnes of production per hectare of the crop actually planted. The actual production data for each cell are estimated using a flexible iterative rebalancing methodology that sequentially down-scales regional agricultural production statistics. The actual production data at the cell level are available for all major crops.

To aggregate the cell-level information provided by GAEZ to administrative units, countries and states or provinces, I use shape files from the World Borders data set of

²Low level of inputs (traditional management), assumes subsistence based farming, labor intensive techniques, no application of nutrients, chemicals, and pesticides. Intermediate level of inputs (improved management), assumes partly market oriented farming, improved varieties with hand tools and/or animal traction, some mechanization, medium labor intensity, use of some fertilizer, chemicals, and pesticides. High level of inputs (advanced management) assumes mainly market oriented farming, high yield variety seeds, fully mechanized with low labor intensity, optimum application of nutrients, chemicals, and pesticides as well as disease and weed control.

³The crops are: wheat, rice, maize, sorghum, millet, other cereals (barley, rye, oat, and other minor cereals), tubers (white potato, sweet potato), roots (cassava, yam and cocoyam), sugarcane, sugarbeets, pulses (chickpea, cowpea, dry pea, grams, pigeon-pea), soybean, sunflower, rapeseed, groundnut, oilpalm, olive, cotton.

“Thematic Mapping” for countries and shape files from “GADM” for sub-national units.⁴

2.3 | Climate Change Data

I use the updated future potential yields from GAEZ v4.0 (GAEZv4.0, 2021) based on the latest climate change projections of the Intergovernmental Panel of Climate Change (IPCC) in its fifth Assessment Report (AR5). GAEZ v4.0 provides climate change-based projections of future potential yields by crop and cell for the entire world, based on different climate models, Representative Concentration Pathways (RCPs), water supply conditions, with and without CO₂ fertilization. Different climate models use different parameterizations of climate processes. Different RCPs, developed by climatologists, represent different greenhouse gas concentration trajectories over time, leading to different levels of global warming by the year 2100. An RCP’s radiative forcing value (measured in W/m²) captures the energy flow over a surface area due to greenhouse gas concentrations, leading to a warming effect. With CO₂ fertilization higher levels of carbon dioxide (CO₂) in the atmosphere can be used in the process of photosynthesis by plants, potentially enhancing crop yields, with variation by crop and location. I use future potential yields for the 2050s (period 2041-2070) by crop and cell from two climate models, GFDL-ESM2M (climate model “M1” below) and IPSL-CM5A-LR (climate model “M2” below), with CO₂ fertilization and with only rainfed water supply, in order to obtain cleaner effects of climate change. For both climate models, I use an intermediate balanced RCP, RCP4.5 (radiating forcing value of 4.5 W/m²), achievable under moderate emission mitigation measures. All future projections of potential yields due to climate change are provided by GAEZ v4.0 only for the a high level of inputs, under the implied assumption that by that time agricultural practices would reflect everywhere what is considered high input application and practices today. Overall, the projected potential yields take into account how different expected temporal patterns of warming and precipitation will affect the growth cycle of different crops in each spatial pixel.

3 | SPATIAL ACCOUNTING FRAMEWORK

I combine the potential yields from GAEZ with the spatial accounting framework developed in Adamopoulos and Restuccia (2022), which allows me to aggregate up yields from the cell-crop level resolution to any administrative unit level. This section describes the general setup of the framework, how aggregation occurs across crops and locations, and the counterfactual experiments I run through this framework.

3.1 | Setup

There is a fixed number of administrative units indexed by $i \in \mathcal{I} \equiv \{1, 2, \dots, I\}$. These units could be countries or states/provinces within a country. Each administrative unit i has a finite number J_i of grid cells of fixed size. Grid cells are indexed by $j \in \mathcal{J}_i \equiv \{1, 2, \dots, J_i\}$. Each grid cell can produce any of C crops, indexed by $c \in \mathcal{C} \equiv \{1, 2, \dots, C\}$.

Cells differ in the productivity of the land across crops, captured by the crop-specific *potential* yield or land productivity (tonnes per hectare) of each cell. The potential yield from producing crop c , in grid cell j , in unit i , is given by $\hat{y}_{ji}^c$. That is, for each cell j in unit i there are C such land productivity numbers.

⁴Available through http://thematicmapping.org/downloads/world_borders.php and <https://gadm.org/data.html> for sub-national units.

The actual crops produced in a cell may differ from the crops in which the cell has the highest potential yield. Denote by q_{ji}^c the real output (in tonnes) and by ℓ_{ji}^c the amount of cultivated land in hectares of crop c , cell j , and unit i . I denote by y_{ji}^c the *actual* yield which is just the ratio of real output to land, $y_{ji}^c = q_{ji}^c / \ell_{ji}^c$.

To aggregate the value of crops in a location i use international prices p^c of each crop which are common across cells and administrative units.

3.2 | Aggregation

I denote with upper case letters aggregate variables. L_i is the amount of land used in agricultural production in administrative unit i , given by,

$$L_i = \sum_{c \in \mathcal{C}} \sum_{j \in J_i} \ell_{ji}^c.$$

I denote by Q_i the amount of real agricultural output produced in administrative unit i , given by,

$$Q_i = \sum_{c \in \mathcal{C}} \sum_{j \in J_i} p^c q_{ji}^c,$$

Given these aggregates, I define the actual aggregate yield Y_i by the ratio of aggregate real output to land used in the unit, that is,

$$Y_i = \frac{Q_i}{L_i} = \frac{\sum_{c \in \mathcal{C}} \sum_{j \in J_i} p^c y_{ji}^c \ell_{ji}^c}{L_i} = \sum_{c \in \mathcal{C}} \sum_{j \in J_i} p^c y_{ji}^c \frac{\ell_{ji}^c}{L_i}. \quad (1)$$

The aggregate yield is a weighted average of the yields in every crop and location in a given country. Equation (1) is the key equation in the accounting analysis as it provides the basis for assessing the key determinants of low agricultural productivity in poor countries, that is, whether the differences in aggregate yields arise from low actual yields of each crop in each location (i.e., low y_{ji}^c), from not producing in the highest yielding locations across space, or from the low yielding crop mix in each location.

3.3 | Counterfactuals

I construct three counterfactual aggregate potential yields for each administrative unit i , by exploiting the set of potential yields by crop at the cell level j and the spatial distribution of production by crop across cells. The counterfactuals incorporate the three potential channels of productivity variation connected with land quality: production potential, spatial potential, and total potential.

Production potential

The main counterfactual assesses the impact of producing at the potential yield for each crop and each location. This counterfactual can be mapped in equation (1) by simply replacing the actual yield y_{ji}^c for each crop for each cell by its potential counterpart $\hat{y}_{ji}^c$. Hence, in this counterfactual only the crop-cell yields change, while the weights represented by the shares of cultivated land of crops across location are kept constant ℓ_{ji}^c / L_i to their actual ones. The

aggregate yield in this counterfactual is defined as,

$$Y_i^{pp} = \sum_{c \in \mathcal{C}} \sum_{j \in J_i} p^c \hat{y}_{ji}^c \frac{\ell_{ji}^c}{L_i}.$$

If the variation in actual yields is not related to the variation in the production potential counterfactual, then geography and land quality are not important determinants of actual yield gaps across administrative units.

Spatial potential

Here I assess the extent to which reallocation of agricultural production of the different crops to the most productive locations across space within an administrative unit can raise aggregate output. This counterfactual combines the production potential with a reallocation of crops across space to the most suitable locations. In particular, I allow production to be re-allocated so that each crop is produced in the cells where it realizes the highest potential yields, keeping constant the amount of cultivated land for that crop in the country to the actual level, i.e., $L_i^c = \sum_{j \in J_i} \ell_{ji}^c$. This allocation problem is non-trivial, as some cells within a country may exhibit higher potential productivity for all crops, while the amount of land that can be allocated to a given crop is limited as is the amount of land of a cell. I reallocate the production of crops to cells according to *comparative advantage* in potential yields of the different crops, i.e., where the relative potential return for each crop is the highest. Formally, this involves solving a large-scale linear programming problem for each administrative unit, given by,

$$\max_{\{\ell_{ji}^c\}} \sum_{c \in \mathcal{C}} \sum_{j \in J_i} p^c \hat{y}_{ji}^c \ell_{ji}^c, \quad (2)$$

subject to

$$\sum_{c \in \mathcal{C}} \ell_{ji}^c \leq L_{ji}, \quad j = 1, 2, \dots, J_i; \quad (3)$$

$$\sum_{j \in J_i} \ell_{ji}^c \leq L_i^c, \quad c = 1, 2, \dots, C; \quad (4)$$

$$\ell_{ji}^c \geq 0, \quad j = 1, 2, \dots, J_i; \quad c = 1, 2, \dots, C. \quad (5)$$

The objective is to maximize the total amount of output across all cells and crops, subject to three sets of constraints. The first set of constraints restricts that land allocated to the production of the different crops cannot exceed what is available in each cell. The second set of constraints indicates that land allocated to crop c over all cells cannot exceed the total in the data. The third set of constraints allows for the possibility that not all crops are produced in all cells.

Total potential

The last counterfactual is to assess the extent to which administrative units may not be producing the highest yielding mix of crops in each location given their land endowment characteristics. This counterfactual involves computing the aggregate yield in each country

by picking the crop in each location that maximizes output. Formally, I solve for ℓ_{ji}^c in equation (2) subject to only the first and third set of constraints, that is equations (3) and (5). This counterfactual involves production potential, reallocation of crops across space, and changes in crop choices in order to maximize aggregate output. The difference between this counterfactual and the production potential counterfactual represents the contribution to the aggregate yield of crop-mix choices and the spatial reallocation of production.

4 | CROSS-COUNTRY RESULTS

I first present the production-potential results under low inputs in Section 4.1, that capture the natural suitability of the land. Section 4.2 presents the production-potential yields under the mixed input scenario, to illustrate the role of complementary inputs, and Section 4.3 shows the gains from reallocation across space and crops. Section 4.4 shows the aggregate implications for structural change of the production-potential yields under mixed inputs.

4.1 | Natural Land Suitability

I calculate for each country aggregate output per hectare (actual yield) for the year 2000, using output and harvested land data by crop and cell within countries, and FAO international crop prices (Geary-Khamis international dollars, GK \$ henceforth). In the first column of Table 2 I report the actual yield for individual Latin American and Caribbean countries along with Portugal and Spain, as well as the average across these countries (LAC). In addition, to facilitate comparisons with other countries, I report values for the two other North American economies, Canada and the United States, as well as the average across the 10 percent richest and 10 percent poorest across all countries in Adamopoulos and Restuccia (2022). The second column in Table 2 reports the ratio of each country's actual yield to that of the 10 percent richest economies in the world, as higher income countries tend to have higher agricultural productivity. On average, LAC countries are closer in actual yield to the richest rather than the poorest set of countries. Nevertheless, the average actual yield across LAC countries exhibits an 18 percent deficit relative to the richest countries. This average masks considerable variation across LAC countries. Chile, Colombia, Costa Rica, Jamaica, Guyana and Peru are all more productive than the high income countries. However, Antigua and Barbuda, Nicaragua, Honduras have a yield at 50 percent or less than the richest group.

In the third column of Table 2 I report the value in GK \$ of the counterfactual production potential yield under the low input scenario. The aggregate production potential yield is constructed by replacing the observed yields by crop in each cell with the potential yields estimated by GAEZ under rainfed and low farming inputs case. As noted above, the low input production potential captures more closely the natural suitability of the land for the production of different crops cell-by-cell, because it involves the least human intervention and input application in natural endowment conditions. This however also means that the potential yields under the low input scenario will typically be lower than the actual yields, given that all countries have at least some input application, cultivation practices, and possibly irrigation.

In levels, the production potential yield does not differ systematically across rich and poor countries in the world. It is about 230 GK \$. In the LAC countries the potential yield ranges between 170 GK \$ in Mexico (just above what it is in Canada) and 430 GK \$ in the Dominican Republic. The average potential yield across all LAC countries is 279 GK \$, which is about the value in the United States. In other words, in terms of natural suitability

TABLE 2 Actual and Production-Potential (low inputs) Yields

	Actual Yield	Act Rel to Rich	Potential Yield	Pot Rel to Rich
North America				
Canada	441.2	0.60	166.1	0.70
Mexico	415.8	0.56	170.2	0.72
United States	814.4	1.10	284.6	1.20
Central America				
Belize	639.8	0.87	276.5	1.17
Costa Rica	960.6	1.30	322.9	1.36
El Salvador	435.4	0.59	275.8	1.16
Guatemala	560.8	0.76	326.2	1.38
Honduras	371.4	0.50	301.9	1.27
Nicaragua	343.8	0.46	265.4	1.12
Panama	520.9	0.70	292.7	1.23
Caribbean				
Antigua and Barbuda	165.1	0.22	353.4	1.49
Bahamas	497.2	0.67	224.6	0.95
Cuba	605.3	0.82	406.1	1.71
Dominican Republic	684.9	0.93	430.5	1.81
Jamaica	1152.8	1.56	187.2	0.79
South America				
Argentina	563.8	0.76	314.9	1.33
Bolivia	404.8	0.55	300.6	1.27
Brazil	637.6	0.86	213.3	0.90
Chile	825.0	1.12	285.7	1.20
Colombia	901.7	1.22	312.5	1.32
Ecuador	504.7	0.68	245.9	1.04
French Guiana	547.2	0.74	170.5	0.72
Guyana	858.0	1.16	220.9	0.93
Paraguay	650.6	0.88	204.9	0.86
Peru	759.1	1.03	176.6	0.74
Uruguay	607.7	0.82	366.8	1.55
Venezuela	653.4	0.88	262.6	1.11
Europe				
Portugal	455.8	0.62	345.3	1.46
Spain	654.6	0.89	288.4	1.22
LAC countries	606.6	0.82	279.3	1.18
Rich 10% of all countries	739.5	1.00	237.2	1.00
Poor 10% of all countries	235.5	0.32	225.7	0.95

Notes: Actual and potential yields are measured as total value output per hectare in international prices (GK \$/ha). Low inputs assumes rainfed water supply and low-input cultivation practices.

of the land the LAC are on average above the rest of the world, with some countries like the Dominican Republic and Uruguay considerably above.

The fourth column reports the aggregate potential yield relative to the rich group of countries. If countries produced the crops they are producing in the locations they are actually producing them but according to their potential yields, the aggregate yield deficit between LAC countries and the rich group of countries would be reversed. With no complementary inputs and rainfed water conditions, LAC countries would attain an 18 percent higher aggregate yield. In other words, the agricultural productivity shortfall of LAC countries is not due to poor land quality and unfavorable geography. There is considerable variation across LAC countries, with Portugal, Uruguay having 46 and 55 percent higher potential yields relative to rich countries, and several countries like Peru and Paraguay considerably below. Comparing the second and third column the relative position of Chile and Colombia in actual yields is closest to that in potential yields.

To what extent are the actual yield differences across LAC countries the result of differences in land quality and geography, captured by the low-input aggregate potential yields, across them? In Figure 1, I plot (in logs) the aggregate production-potential yield for the rainfed low-input scenario against the aggregate actual yield. If aggregate potential yields were driving the actual yields then we would expect countries to roughly fall on a 45 degree line. Instead, country-level actual and production potential yields are completely uncorrelated across LAC countries, with a correlation coefficient of -0.05. This implies that current land quality and geographic conditions play a weak role in accounting for the observed agricultural productivity differences.⁵

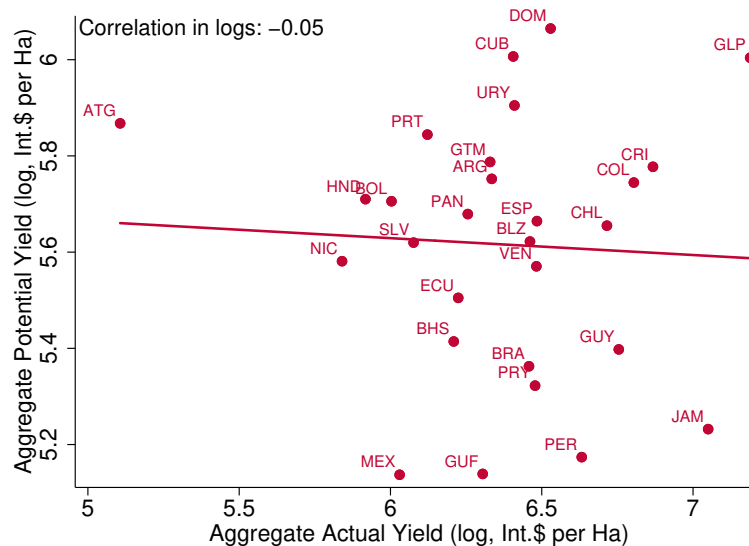


FIGURE 1 Aggregate low-input production-potential versus actual yield across countries.
Notes: Aggregate production-potential yield under rainfed low-input scenario.

In order to picture the geography of the cross-country variation in the natural suitability of the land, in Figure 2 I draw a map of the average country-level production potential yield under the rainfed - low input scenario. The darker shading indicates a higher potential

⁵In Appendix A, I show that this finding is robust to the inclusion of coffee, tea, cocoa in the set of crops considered.

yield. Geographically potential yields appear to be better in the Central America region, with countries like Guatemala and the Dominican Republic standing out, as well in the Southern Cone region with countries like Argentina and Uruguay being distinguishable.

4.2 | Land Quality with Input Application

While the production potential counterfactual yield under the rainfed - low input scenario, captures a country's raw natural land quality endowments, it is typically below countries' actual yields, as all farmers tend to apply some form of inputs, management, and cultivation practices. I now estimate the average production potential counterfactual yield across countries under the mixed input scenario, which includes irrigation (in addition to rainfed water supply) and an intermediate level of input application. The mixed input scenario is a more reasonable approximation of current production conditions across many countries. The crop-cell potential yields capture how the natural land quality and geographic endowments of a location can be combined with reasonable application of appropriate inputs to achieve the highest attainable yield for that crop in that location.

The second column of Table 3 reports the counterfactual production potential yield for individual LAC countries, their average, as well as for Canada, the United States, and the averages of the richest and poorest countries of the world. The production potential yield maintains the observed distribution of harvested land across all crops and all cells within countries, but production for each crop-cell takes places according to the mixed input potential yields rather than the actual. The first column repeats the actual yield. Across LAC countries the level of the mixed input potential yields ranges from a low of 836 GK \$ in the Bahamas to a high of 2136 GK \$ in Chile, with an average of 1477 GK \$, well above the averages of rich and poor countries.⁶

The third column of Table 3 reports the ratio of the mixed input production potential yield for each country relative to the rich group of countries. Similar to the conclusion under the low input scenario, on average LAC would be 21 percent more productive than the richest countries in the world if they exploited their raw land endowments and all countries applied the same reasonable set of inputs. The implication is that LAC countries are not taking advantage of their land and geographic endowments enough. There is however considerable variation in potential yields relative to the rich countries, with Chile, Colombia, Peru and Portugal exhibiting much higher potential productivity, and Bahamas, Mexico, Nicaragua lower.

The aggregate potential yields under the mixed input scenario are typically higher than the aggregate actual yields across all countries, because they assume efficient use of appropriate cultivation practices. The yield gap, that is the ratio of the mixed production potential yield to the actual represents the potential yield gains countries could attain if they combined their land quality endowments with a mix of inputs. Across all countries, while the level of the potential yield with mixed inputs is very similar, the yield gap is substantially higher in poor countries at 4.9, relative to rich at 1.7. This implies that on average poor countries are much further away from their production potential than rich countries. Across LAC countries the yield gap ranges between 1.08 in Jamaica to 4 in Portugal, with an average of 2.4 across all LAC countries (excluding the outlier of Antigua and Barbuda). In other words, LAC countries produce closer to their potential than the typical country, and exploit their natural conditions at a level more similar to that in rich countries, than poor countries.

To put the range of yield gaps across LAC countries into geographic perspective, Figure 3, displays the average yield gap for each LAC country, with the darker shades of orange

⁶Antigua and Barbuda is an outlier, but is very small and has relatively little agricultural land.

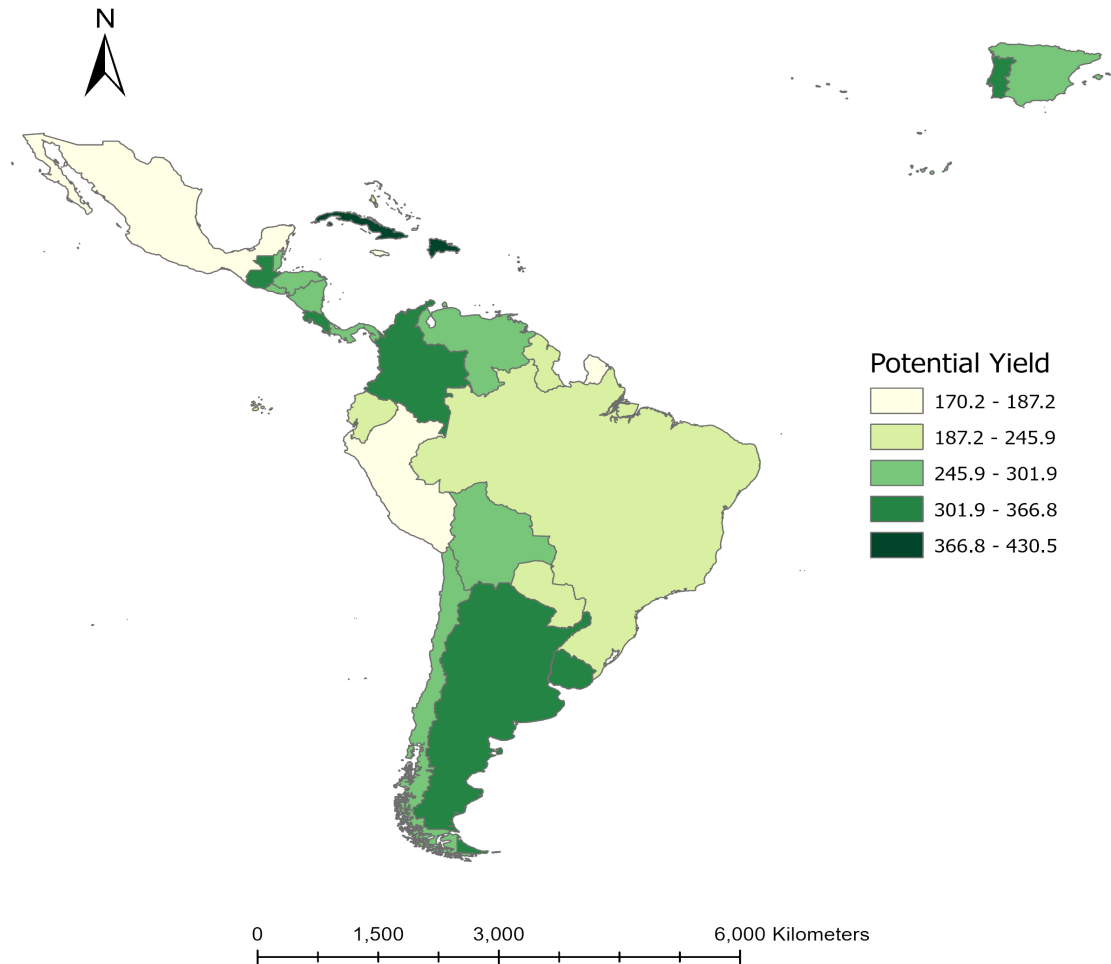


FIGURE 2 Country-Level Potential Yields (low inputs). *Notes:* “Potential Yield (low)” refers to the country-level potential yield from the Production Potential experiment, that replaces actual yields in each cell and for each produced crop with the corresponding potential yield, under rainfed conditions and low level of inputs. The potential yield is expressed in Geary-Khamis international \$. In the map darker shades reflect higher potential yields.

TABLE 3 Actual and Production-Potential (mixed inputs) Yields

	Actual Yield	Potential Yield	Pot Rel to Rich	Potential/Actual
North America				
Canada	441.2	648.3	0.53	1.47
Mexico	415.8	1003.4	0.82	2.41
United States	814.4	1457.3	1.19	1.79
Central America				
Belize	639.8	1275.5	1.05	1.99
Costa Rica	960.6	1610.5	1.32	1.68
El Salvador	435.4	1128.5	0.92	2.59
Guatemala	560.8	1243.2	1.02	2.22
Honduras	371.4	1180.3	0.97	3.18
Nicaragua	343.8	985.0	0.81	2.87
Panama	520.9	1294.8	1.06	2.49
Caribbean				
Antigua and Barbuda	165.1	2878.9	2.36	17.44
Bahamas	497.2	835.6	0.68	1.68
Cuba	605.3	1923.9	1.58	3.18
Dominican Republic	684.9	1918.4	1.57	2.80
Jamaica	1152.8	1241.7	1.02	1.08
South America				
Argentina	563.8	1210.1	0.99	2.15
Bolivia	404.8	1419.9	1.16	3.51
Brazil	637.6	1108.0	0.91	1.74
Chile	825.0	2135.8	1.75	2.59
Colombia	901.7	1693.0	1.39	1.88
Ecuador	504.7	1296.4	1.06	2.57
French Guiana	547.2	1561.9	1.28	2.85
Guyana	858.0	1482.4	1.22	1.73
Paraguay	650.6	1385.7	1.14	2.13
Peru	759.1	1902.5	1.56	2.51
Uruguay	607.7	1545.0	1.27	2.54
Venezuela	653.4	1424.0	1.17	2.18
Europe				
Portugal	455.8	1821.1	1.49	4.00
Spain	654.6	1359.9	1.11	2.08
LAC countries	606.6	1476.5	1.21	3.0
Rich 10% of all countries	739.5	1220.0	1.00	1.65
Poor 10% of all countries	235.5	1160.6	0.95	4.93

Notes: Actual and potential yields are measured as total value output per hectare in international prices (GK \$/ha). The production potential yield is calculated under the mixed input scenario.

reflecting a higher gap. Brazil stands out as a country with a fairly low yield gap, implying smaller potential gains from better input application. Bolivia, Honduras and Cuba are the furthest away from their production potential with a yield gap of over 3. Interestingly, there is no specific geographic pattern to the yield gap variation across countries, which is consistent with the idea that economic factors (policies, constraints, frictions) are the drivers of how much countries exploit their natural endowment conditions in producing agricultural goods.

Despite being lower in levels, to what extent can the variation in actual yields be accounted for by the variation in mixed input potential yields across LAC countries? In Figure 4, I plot the mixed input production potential yield against the actual yield (in logs) for LAC countries, excluding the outlier of Antigua and Barbuda.⁷ The mixed input production potential and the actual yields are positively correlated, with a correlation coefficient of 0.56. This is different than the virtually flat relationship between the low input production potential and the actual yield. The implication is that while all countries are under-utilizing their natural land endowments, LAC countries with the highest actual agricultural productivity are likely the ones that effectively utilize their land's potential by applying sufficient inputs (such as fertilizers, irrigation, and improved agricultural practices). As a result, inputs play a crucial role in unlocking the potential of land to achieve higher yields, by overcoming environmental and natural limitations.

4.3 | Gains from Spatial and Crop Reallocation

In many developing countries large segments of the population live in rural areas, operating in the agricultural sector at subsistence levels, with poor connectivity to markets to sell their crops and buy inputs. Insufficient transport infrastructure and other distortions, can be a major constraint for farmers who may end up producing crops that are not necessarily suitable to the geography of the land they farm, see for instance [Adamopoulos \(2025\)](#). These constraints can affect what is produced and where it is produced in the country. Here, I assess the potential for productivity gains from the spatial reallocation of production within a country and gains from the shift in the mix of crops produced towards higher value yielding varieties. To do this, I estimate in turn, the counterfactual spatial potential and total potential yields by country, under the mixed input scenario.

The spatial potential yield captures gains from reallocation across space by asking: how would the aggregate yield change if we reallocated the production of individual crops across cultivated cells according to where they exhibit the highest relative yield in the country, holding the total land allocated to each crop in the country at its actual level? Table 4 reports the results of the spatial potential counterfactual in column 2 and the yield gains relative to the production potential (repeated here in column 1), in column 3. In the richest and poorest countries in the world the yield benefits from the spatial reallocation of production is similar, at 19 and 17 percent respectively. Across LAC countries the average yield gain under the production potential is similar, at 14 percent but this ranges from a low 1 percent in French Guiana to a high 33-35 percent additional potential gain in Portugal and Spain. Given that the effect is similar between LAC and other countries, spatial reallocation does not help further increase the productivity advantage of LAC relative to rich, beyond what the production potential does.

The total potential counterfactual asks, how would the aggregate yield change if in each cell the highest value yielding crop was produced, holding the amount of cultivated land in each cell to its actual level? This counterfactual captures the maximum potential yield that can be achieved from a shift in the set of produced crops to the highest return ones, above

⁷Including Antigua and Barbuda the correlation is positive but much lower at 0.08.

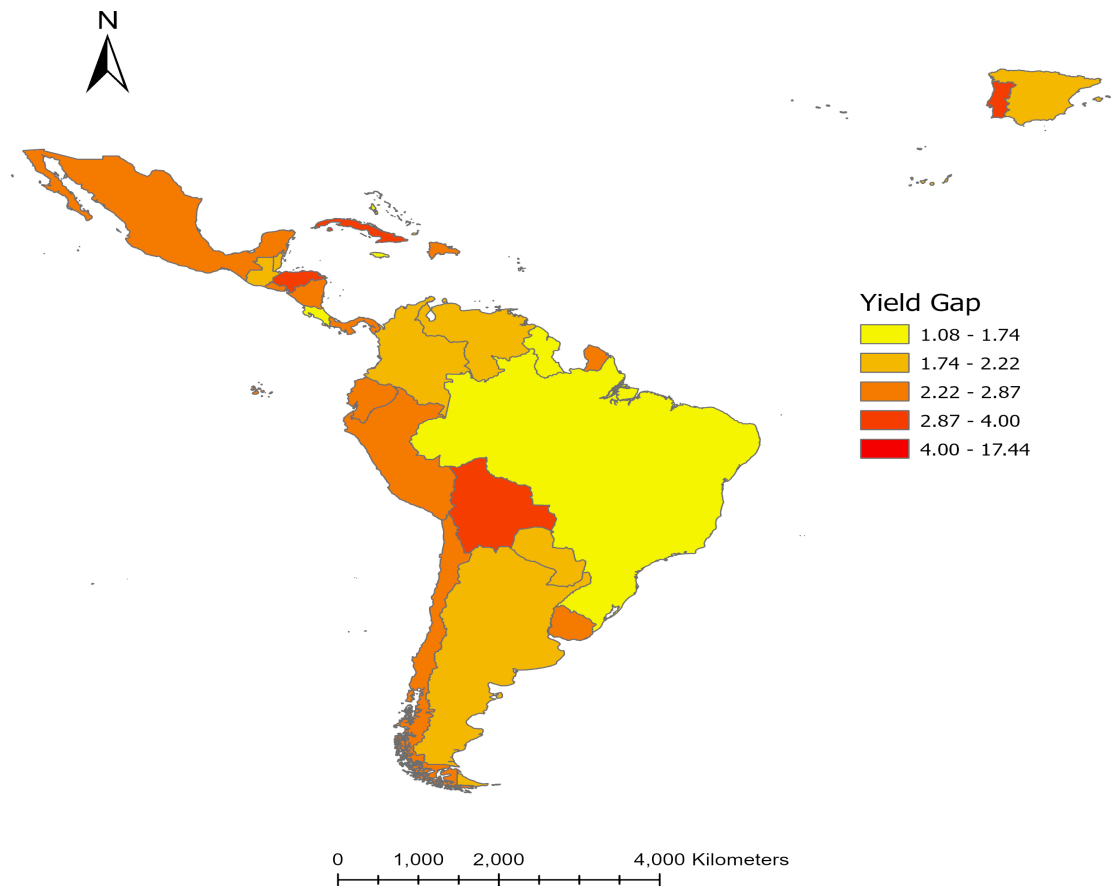


FIGURE 3 Country-Level Potential Yield Gaps (mixed inputs). *Notes:* “Yield Gap (mixed)” refers to the country-level gap in the production potential yield under mixed inputs and the actual yield. Potential and actual yields are expressed in Geary-Khamis international dollars. The map shows yield gaps as ratios. In the map darker shades of orange reflect higher yield gaps, that is opportunities for yield gains.

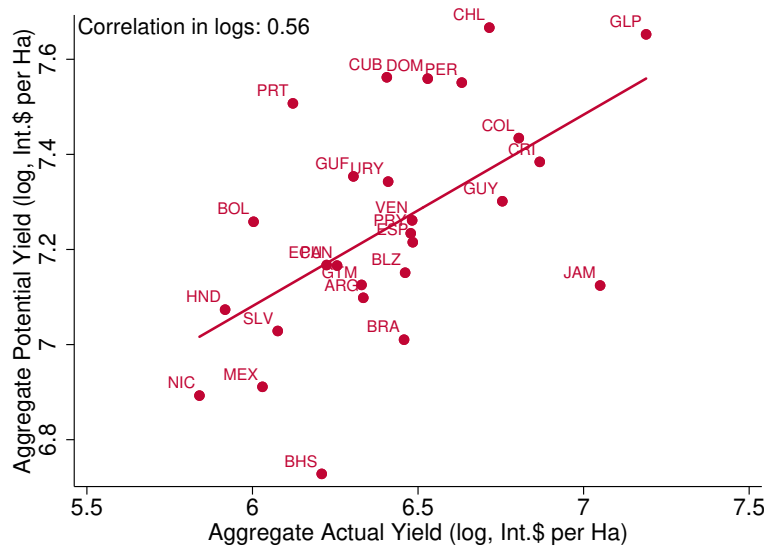


FIGURE 4 Aggregate mixed input production-potential versus actual yield across countries.
Notes: Aggregate production-potential yield is under the mixed input scenario.

the spatial and production potential. The results of the total potential counterfactual are reported in column 4 of Table 4, with the last column reporting the additional yield gains from the total potential relative to the spatial potential. Across the world the additional total potential gains are 1.7 for rich countries and 2.4 for poor countries. Across the LAC countries the average additional yields gains from the total potential are in between at 2.1, but range from 1.1 (Bahamas) to 3.6 (Argentina). The higher the additional potential gains from the total potential counterfactual experiment, the stronger the misalignment between the highest yielding value crops and the actual crops produced.⁸

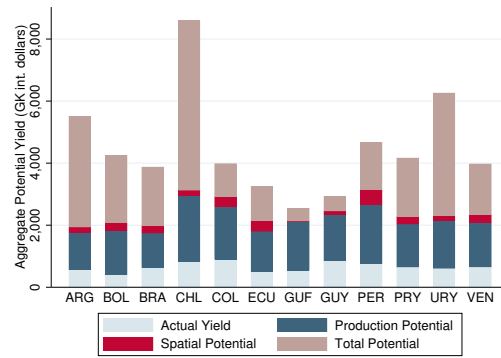
To visualize the effects of all the counterfactuals relative to the actual yields by country, Figure 5 displays in stacked bar format the additional yield gain from each counterfactual relative to the previous one from the bottom up, production potential relative to actual, spatial potential relative to production potential, and total potential relative to spatial potential. To facilitate exposition I display the results in three separate panels: South America in Panel (a); Central America in Panel (b); Caribbean and Europe in Panel (c). In all cases, the actual yield is lower than the production potential, which in turn is lower than the spatial potential and the total potential. As can be seen, while there is variation in the magnitude of the different components across countries, the largest yield gains are observed when moving from the actual to the production potential and from the spatial potential to the total potential. The additional yield gains from the spatial potential are fairly small in comparison. The countries with the highest total potential yields are Chile, Uruguay and Argentina.

⁸I note here that because this is an accounting exercise, the total potential counterfactual does not take into account changes in the cost structure, the demand side, and relative prices.

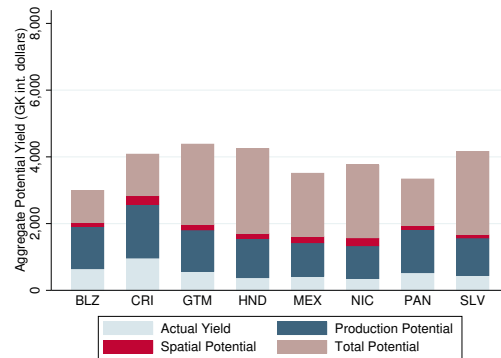
TABLE 4 Counterfactual Spatial and Total Potential Yields (mixed inputs)

	Aggregate potential yield with mixed inputs				
	Production	Spatial	Spatial/ Production	Total	Total/ Spatial
North America					
Canada	648.3	763.4	1.18	1596.9	2.09
Mexico	1003.4	1197.1	1.19	3100.2	2.59
United States	1457.3	1725.7	1.18	2610.9	1.51
Central America					
Belize	1275.5	1383.8	1.08	2363.2	1.71
Costa Rica	1610.5	1869.6	1.16	3128.6	1.67
El Salvador	1128.5	1232.6	1.09	3736.4	3.03
Guatemala	1243.2	1417.4	1.14	3828.2	2.70
Honduras	1180.3	1334.4	1.13	3884.7	2.91
Nicaragua	985.0	1223.2	1.24	3414.2	2.79
Panama	1294.8	1415.4	1.09	2823.3	1.99
Caribbean					
Antigua and Barbuda	2878.9	2909.1	1.01	3844.4	1.32
Bahamas	835.6	876.8	1.05	952.2	1.09
Cuba	1923.9	2120.6	1.10	3415.5	1.61
Dominican Republic	1918.4	2096.6	1.09	3048.6	1.45
Jamaica	1241.7	1368.2	1.10	1901.8	1.39
South America					
Argentina	1210.1	1374.9	1.14	4943.8	3.60
Bolivia	1419.9	1669.9	1.18	3842.6	2.30
Brazil	1108.0	1346.1	1.21	3238.8	2.41
Chile	2135.8	2300.7	1.08	7777.9	3.38
Colombia	1693.0	2024.0	1.20	3086.0	1.52
Ecuador	1296.4	1643.1	1.27	2745.5	1.67
French Guiana	1561.9	1585.3	1.01	1994.1	1.26
Guyana	1482.4	1599.7	1.08	2074.9	1.30
Paraguay	1385.7	1631.9	1.18	3518.1	2.16
Peru	1902.5	2381.6	1.25	3908.8	1.64
Uruguay	1545.0	1702.9	1.10	5655.1	3.32
Venezuela	1424.0	1684.1	1.18	3323.9	1.97
Europe					
Portugal	1821.1	2414.2	1.33	4203.8	1.74
Spain	1359.9	1834.6	1.35	3814.0	2.08
LAC countries	1476.5	1690.3	1.14	3465.5	2.05
Rich 10% of all countries	1220.0	1446.0	1.19	2498.3	1.73
Poor 10% of all countries	1160.6	1361.1	1.17	3254.7	2.39

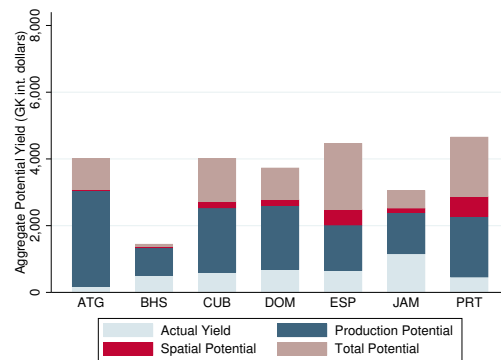
Notes: "Production," "spatial," "total" refer to the production-potential, spatial-potential, and total-potential counterfactual yields (GK \$/ha) under mixed inputs.



(a) South America



(b) Central America



(c) Caribbean and Europe

FIGURE 5 Yield Gains by Production, Spatial, Total Potentials. *Notes:* Different colors show the change in GK \$/ha relative to the yield below it in the stacked bar.

4.4 | Implications for Structural Change

In order to put into perspective the yield gains implied by the production potential counterfactual, I study their implications for structural change and aggregate GDP per capita gains through the lens of a simple two sector model of agriculture and non-agriculture. The model features non-homothetic preferences with a subsistence constraint for agricultural consumption. The structure of the model follows [Adamopoulos and Restuccia \(2022\)](#), and I provide a brief description of the model in Appendix 2. A key implication of the model is that when agricultural productivity is low, a country devotes a disproportionate amount of labor to producing agricultural goods, taking away resources from the rest of the economy. As agricultural productivity improves, subsistence needs are met with fewer resources allocated to agriculture, which releases labor to the rest of the economy.

I calibrate the model to the United States, with a share of labor in agriculture of 1.7 percent, as per Table 1. I choose TFP in agriculture for every economy in Table 1 (i.e., all LAC countries and Canada) to exactly match the share of labor in agriculture, keeping all other parameters the same as in the benchmark US economy. Then I examine what the effect would be on structural change (the share of labor in agriculture) and real GDP per capita if all countries produced in agriculture according to their production-potential yield under mixed inputs rather than their actual one. Specifically, I increase the calibrated TFP in agriculture in each country by a factor equal to the ratio of the actual to the production potential yield (including the United States). The results of this experiment are presented in Table 5. In calculating real GDP per capita I keep the relative price of agriculture constant to the benchmark economy, thus evaluating GDP at a common set of prices across all countries as is done by statistical agencies.

The first column of Table 5 repeats the share of labor in agriculture for each country from the data, to which I calibrate the baseline economies. The second column shows the percentage point change in the share of labor in agriculture, capturing the implied structural transformation, and the third column the percentage change in real GDP per capita relative to each baseline economy, capturing economic development. Because potential yields with mixed inputs are higher than the actual yields, the model implies substantial structural change and income gains particularly for economies heavily engaged in agriculture and with low income like Bolivia, Guatemala, Honduras and Nicaragua. In other words, if the observed distribution of land quality was complemented with appropriate inputs to fully exploit its potential, LAC countries could see substantial structural change benefits, especially the lower income ones.

5 | SUB-NATIONAL RESULTS

The actual and counterfactual yields constructed so far have been at the country level. As a result, they are (weighted) averages across all cells with harvested land in the country. Country averages could mask considerable heterogeneity across space within countries. Here, I consider the role of land quality and geography for agricultural productivity at the sub-national level across LAC countries. Below, I report the results of the production potential counterfactual at the cell-level, as well as the first sub-national administrative boundaries level, i.e., states or provinces. I also report summary statistics at the sub-national level.

TABLE 5 Aggregate Implication of Potential Yield Gains

	Agr. Empl. Share (%)	p.p. Ch. in Agr. Empl. Share (%)	Perc. Ch. in Real GDP pc
North America			
Canada	1.8	-0.8	+0.8
Mexico	14.6	-10.7	+12.2
United States	1.7	-1.0	+1.0
Central America			
Belize	18.5	-11.9	+14.1
Costa Rica	12.4	-6.7	+7.4
El Salvador	20.8	-15.8	+19.3
Guatemala	33.5	-23.4	+33.8
Honduras	36.5	-30.0	+45.4
Nicaragua	29.6	-23.5	+32.2
Panama	17.4	-13.0	+15.3
Caribbean			
Antigua and Barbuda	21.0	-20.7	+25.4
Bahamas	3.3	-1.8	+1.8
Cuba	18.6	-15.3	+18.2
Dominican Republic	12.4	-9.8	+10.8
Jamaica	17.7	-1.9	+2.3
South America			
Argentina	6.0	-4.1	+4.3
Bolivia	31.7	-26.9	+38.0
Brazil	11.5	-6.5	+7.1
Chile	10.1	-7.7	+8.3
Colombia	18.5	-11.3	+13.5
Ecuador	27.9	-21.1	+28.3
Guyana	21.4	-12.0	+14.8
Paraguay	25.6	-17.4	+22.6
Peru	28.0	-21.0	+28.2
Uruguay	11.6	-8.7	+9.6
Venezuela	8.5	-5.9	+6.3
Europe			
Portugal	11.2	-9.8	+10.7
Spain	4.2	-2.8	+2.8
LAC countries	18.2	-13.1	+16.6

Notes: First column displays data from the World Bank's *World Development Indicators*. The second and third column show model-based aggregate implications of potential yield gains, for structural change and development.

5.1 | Cell-level estimates

Figure 6 displays the results of the production potential counterfactual under the rainfed low input scenario, at the 5-arc minute resolution. In each cell, of roughly 10×10 kilometers, the same crops actually produced and in the amounts they are produced, takes place according to their potential rather than their actual yields. These cell-level potential yields aggregate across all crops in a cell, and capture the natural suitability of the land for agricultural production at a high spatial resolution. The map coloring is continuous, with bluish shades reflecting low potential yields, yellowish shades intermediate potential yields, and darker orange shades high potential yields. No coloring means zero yields or missing data.

It is clear that the coloring within countries is not homogeneous and that the continuity of land quality characteristics transcends country borders. For example, the Rio de la Plata part of Argentina is highly productive compared to the southern part of the country where productivity is spotty. In contrast Uruguay and southern Brazil are more similar in land quality to northern Argentina even though they are different countries. Peru, Ecuador and Colombia also have patches of very productive land.

5.2 | Province-Level Results

The results in Section 4 are all at the country-level. However, there is considerable variation within countries, as to where production takes place, the actual yield observed, and the attainable potential yield achieved. In order, to examine within country variation in geography and land quality, in this section, I expand the analysis of Adamopoulos and Restuccia (2022) to the first administrative sub-national level, typically provinces or states. The sub-national administrative boundaries for each LAC country are obtained from GADM. I provide four figures with two sets of maps for each of the largest four LAC countries, Argentina in Figure 7, Brazil in Figure 8, Colombia in Figure 9 and Mexico in Figure 10. The first map in each figure, Panel (a), shows the intensity of crop production by sub-national unit, as measured by the total sum of harvested hectares of land allocated to all crops in that unit. The coloring in this map is from yellow to red with darker shades indicating more hectares allocated to crop production. The second map in each figure, Panel (b), shows the average potential yield at the sub-national unit level, under the production potential counterfactual with the low input level scenario. Panel (b) captures the natural suitability of the land for agricultural production. The map coloring is from light yellow to green, with darker shades of green reflecting higher average potential yields.

There is considerable heterogeneity within countries in terms of both location of crop production and potential yields. In Argentina most agricultural production takes place in the Buenos Aires and Cordoba regions which are indeed among the most productive in the country. However, the provinces of Santiago del Estero and Chaco which have similarly high potential yields see less agricultural production.

In Brazil the provinces in the western part of the country have the highest potential yields, whereas a lot of agricultural production takes place in the central southwestern part of the country. For example, in the provinces of Goias and Minas Gerais one finds the most hectares of harvested land in the country, which do not have the highest potential yields.

In Colombia most agricultural production takes place in the northeast of the country, especially Cordoba, Antioquia, Tolima and Santiago de Cali. However, the western part of the country has the highest potential yields.

In Mexico production is concentrated in the south part of the country, which is the most productive as well. Large concentration of harvested hectares are observed in the provinces of Chiapas and Veracruz, whereas Guerrero and Oaxaca have the highest potential yields.

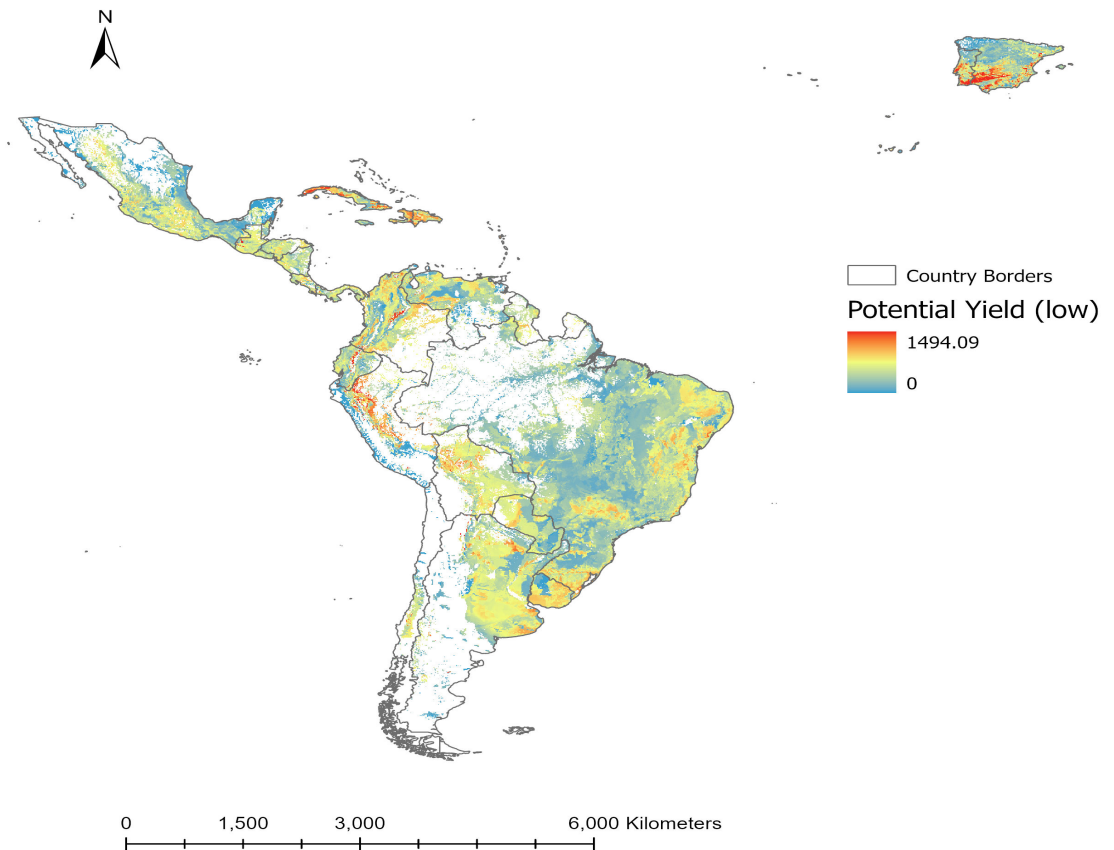


FIGURE 6 Cell-Level Potential Yields (low inputs). *Notes:* “Potential Yield (low)” refers to the country-level potential yield from the Production Potential experiment, that replaces actual yields in each cell and for each produced crop with the corresponding potential yield, under rainfed conditions and low level of inputs. The potential yield is expressed in Geary-Khamis international dollars. Map shading is continuous.

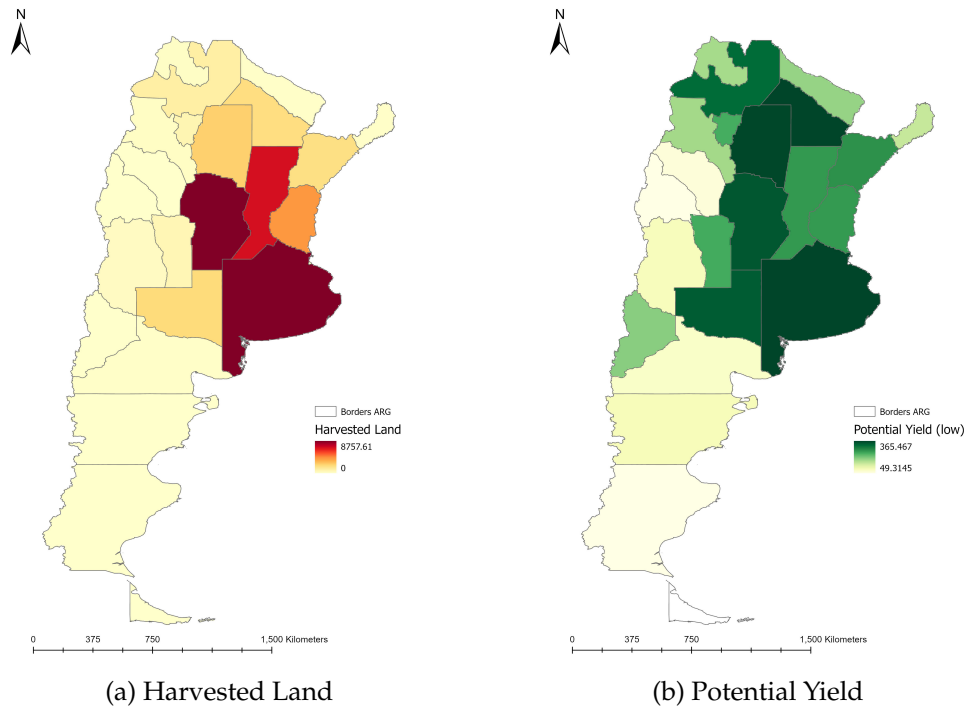


FIGURE 7 Argentina. *Notes:* “Harvested Land” is the total amount of harvested land over all crops in hectares. “Potential Yield” from the Production Potential experiment, replaces actual yields in each cell and for each produced crop with the corresponding potential yield, under rainfed conditions and low level of inputs. The potential yield is expressed in Geary-Khamis international dollars. Map shading is continuous.

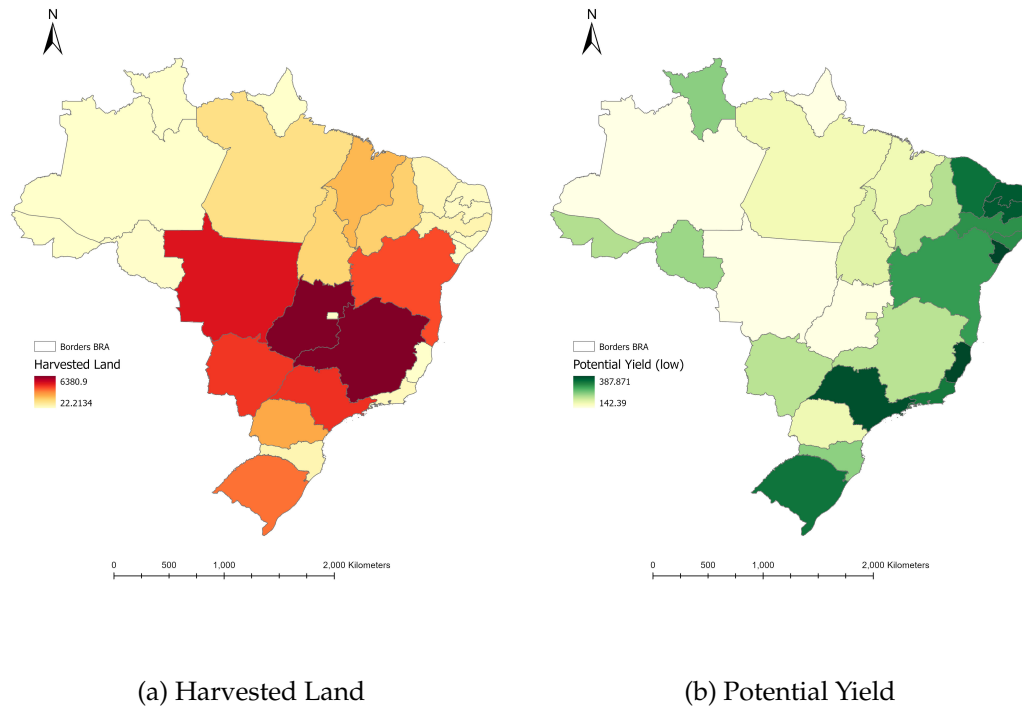


FIGURE 8 Brazil. *Notes:* "Harvested Land" is the total amount of harvested land over all crops in hectares. "Potential Yield" from the Production Potential experiment, replaces actual yields in each cell and for each produced crop with the corresponding potential yield, under rainfed conditions and low level of inputs. The potential yield is expressed in Geary-Khamis international dollars. Map shading is continuous.

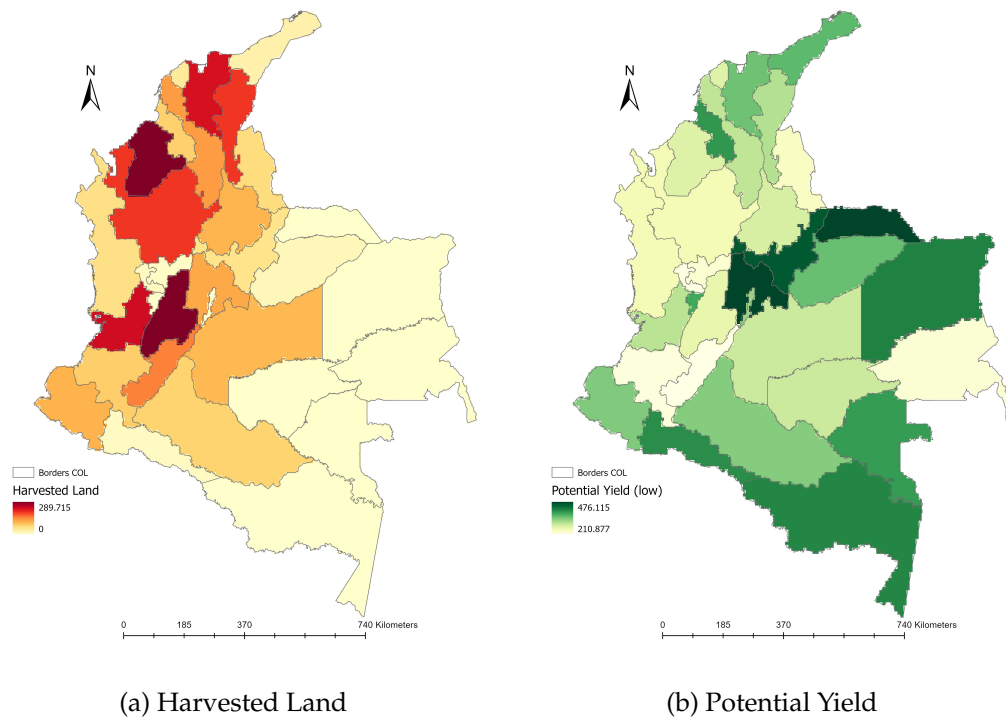


FIGURE 9 Colombia. *Notes:* “Harvested Land” is the total amount of harvested land over all crops in hectares. “Potential Yield” from the Production Potential experiment, replaces actual yields in each cell and for each produced crop with the corresponding potential yield, under rainfed conditions and low level of inputs. The potential yield is expressed in Geary-Khamis international dollars. Map shading is continuous.

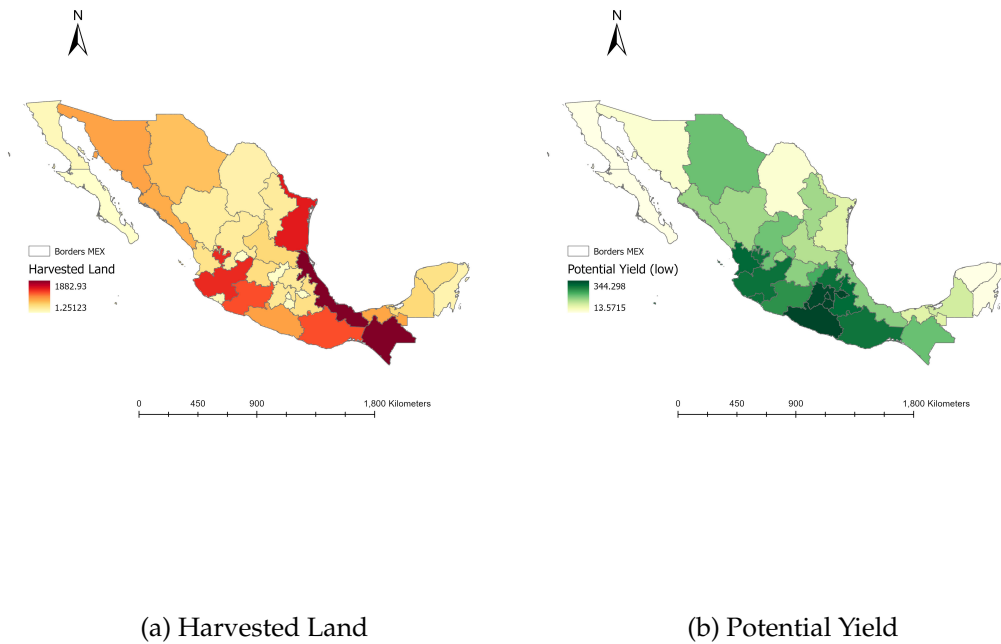


FIGURE 10 Mexico. *Notes:* “Harvested Land” is the total amount of harvested land over all crops in hectares. “Potential Yield” from the Production Potential experiment, replaces actual yields in each cell and for each produced crop with the corresponding potential yield, under rainfed conditions and low level of inputs. The potential yield is expressed in Geary-Khamis international dollars. Map shading is continuous.

5.2.1 | Sub-National Summary Results

Here I examine more systematically the relationship between agricultural production, potential yield, and actual yield across provinces/states within LAC countries.

In Figure 11, I plot the average potential yield at the province level against the actual yield, for all provinces within LAC countries. In the scatter plot countries vary by color shading, with the observations corresponding to provinces of the same country all having the same color. Interestingly, across all provinces of all LAC countries taken together there is no correlation between actual and potential yields, just as at the cross-country level under the low input scenario.

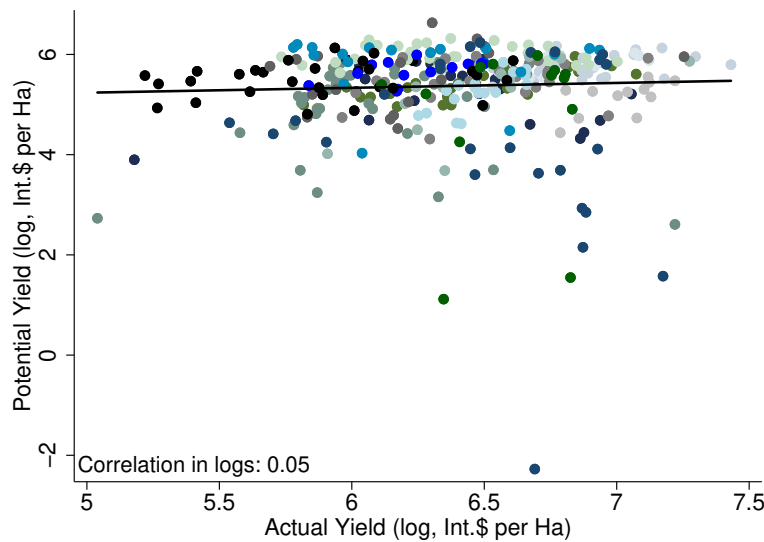


FIGURE 11 Aggregate production-potential versus actual yield across provinces. *Notes:* Figure displays all sub-national units (states/provinces) for all LAC countries, with the units of the same country having the same color shading. Production-potential yield is under rainfed low-input scenario.

However, this masks considerable heterogeneity across countries. In Table 6, I report for each country the correlation across provinces/states of harvested land and potential yield in logs, as well as the correlation between the potential yield and the actual yield in logs. The first correlation is a metric of whether agricultural production takes place primarily where the highest quality land is. The second correlation captures whether actual yields are closely related to the productive potential yields across provinces. There is a lot of variation across countries. The correlation of production and potential yield ranges from -0.20 across provinces in Jamaica to 0.83 across provinces in Argentina. The median correlation across these countries is 0.06. The correlation of actual and potential yields ranges from a low of -0.20 across provinces in Peru, to a high of 0.80 in Bolivia, and a median of 0.30 across all countries. These results indicate an imperfect alignment of production and natural land suitability at the sub-national level, a source of potential productivity gains.

TABLE 6 Within Country Cross-Province Correlations

	Correlation in logs Pot. Yield & Land	Correlation in logs Pot. Yield & Act. Yield
Argentina	0.83	0.06
Bolivia	0.45	0.80
Brazil	-0.03	0.73
Chile	0.43	0.09
Colombia	-0.19	0.30
Cost Rica	-0.11	0.71
Dominican Republic	0.13	0.01
Ecuador	-0.10	0.25
Spain	0.45	0.66
Jamaica	-0.20	0.60
Mexico	-0.04	-0.01
Panama	0.15	0.49
Peru	0.06	-0.20
Portugal	0.51	0.32
Paraguay	-0.05	0.77
Uruguay	-0.12	-0.03
Venezuela	0.12	0.30

Notes: Actual and potential yields (low inputs) are measured as total value output per hectare in international prices (GK \$/ha). Harvested land is measured in hectares.

6 | CLIMATE CHANGE RESULTS

The projected rise in global temperatures and other climatic phenomena are expected to affect future economic outcomes across several sectors. Agriculture, which uses location-specific natural inputs such as rainfall, humidity and temperature will be affected directly the most. Here, I examine the effects of expected climate change on future agricultural productivity, using my spatial accounting framework and the potential yields by crop and cell that GAEZ v4.0 estimates, with its agronomic models factoring in climate change from the most updated climate models. Importantly, given that climate change is expected to have heterogeneous effects across locations, even within countries, these potential yields account for climate change at the high spatial resolution level of roughly 10×10 kilometers. I use the crop-cell future projected yields to estimate for each LAC country (along with Canada and the United States) expected aggregate potential yields from the production-potential, spatial-potential, total-potential counterfactuals.

I consider two moderate, intermediate climate change scenarios, that in turn use climate models GFLD-ESM2M (climate model “M1” below) and IPSL-CM5A-LR (climate model “M2” below). I focus on climate change projections for the period 2041-2070. In both cases I use the cell-crop potential yields under rainfed water conditions, and high level of inputs, with CO₂ fertilization, and RCP 4.5 which corresponds to a middle path warming scenario.⁹ For aggregation across crops I use the same set of FAO international prices

In Table 7, I report by country the aggregate potential yields from the production-potential counterfactual under climate model M1 (second column) and model M2 (third column). For comparability, in column 1, I repeat the production-potential yield under the mixed input scenario, which captures a realistic potential attainable yield today under current climate conditions and a reasonable input application. Columns 4 and 5 display the ratio of the potential yield under climate model M1 and M2 respectively to the current potential yield. The picture painted by the two climate change models is similar, even though there are variations for individual countries. In most countries the level of potential agricultural productivity is expected to fall relative to current potential productivity, but not everywhere and not by the same amount, capturing the heterogeneity projected effects across countries. For example, Canada with its cold climate today is expected to benefit in terms of crop productivity. Among LAC countries Nicaragua, Bahamas, Jamaica, are expected to see a rise in their productivity. The countries expected to see the largest drops in their potential yield from climate change are Antigua and Barbuda, Chile, and Peru, Portugal and Spain. The average, across LAC countries, of the climate based potential yield relative to the current potential yield is 0.78 under model M1 and 0.77 under model M2.

Next, I ask whether in the face of climate change, there is scope to achieve yield gains from the spatial reallocation of crop production across locations in a country, and changes in the composition of produced crops? To answer this question, I conduct the spatial-potential and total-potential counterfactuals under each of the two climate models. The results of these counterfactuals are provided in Tables 8 for climate model M1 and 9 for climate model M2. The first column in each table repeats the production-potential under the respective climate model. The tables also report the ratios of the spatial to production potentials, and total to spatial potential, capturing in turn the additional yield gains coming from spatial reallocation and crop mix changes. One key takeaway under both climate models is that the scope for yield gains from the spatial reallocation of crop production on average doubles across LAC relative to current conditions, from 14 percent to 29 percent. This

⁹The projected cell-crop level potential yields are available from GAEZ v.4 only under the high level of inputs. The implicit assumption in this estimation is that all countries would be using a level of inputs by this point that corresponds to the high level of inputs today.

TABLE 7 Production Potential Yields under Climate Change

	Current Pot Yield	Clima Pot Yield (M1)	Clima Pot Yield (M2)	Ratio M1/Current	Ratio M2/Current
North America					
Canada	648.3	887.6	829.0	1.37	1.28
Mexico	1003.4	719.0	735.9	0.72	0.73
United States	1457.3	1308.8	1183.2	0.90	0.81
Central America					
Belize	1275.5	1241.2	1065.1	0.97	0.83
Costa Rica	1610.5	1502.7	1472.9	0.93	0.91
El Salvador	1128.5	1105.7	1167.4	0.98	1.03
Guatemala	1243.2	1060.6	1087.3	0.85	0.87
Honduras	1180.3	1012.1	1207.1	0.86	1.02
Nicaragua	985.0	1096.7	1033.5	1.11	1.05
Panama	1294.8	1354.9	1377.2	1.05	1.06
Caribbean					
Antigua and Barbuda	2878.9	994.5	1284.6	0.35	0.45
Bahamas	835.6	956.2	804.4	1.14	0.96
Cuba	1923.9	1636.2	1371.6	0.85	0.71
Dominican Republic	1918.4	1543.5	1170.2	0.80	0.61
Jamaica	1241.7	1782.7	1762.5	1.44	1.42
South America					
Argentina	1210.1	1116.6	1137.6	0.92	0.94
Bolivia	1419.9	1321.0	1241.3	0.93	0.87
Brazil	1108.0	942.1	953.3	0.85	0.86
Chile	2135.8	993.6	1171.1	0.47	0.55
Colombia	1693.0	1356.2	1390.0	0.80	0.82
Ecuador	1296.4	1061.3	1116.2	0.82	0.86
French Guiana	1561.9	1445.5	1420.7	0.93	0.91
Guyana	1482.4	1395.6	1383.8	0.94	0.93
Paraguay	1385.7	1258.7	1170.5	0.91	0.84
Peru	1902.5	755.7	731.4	0.40	0.38
Uruguay	1545.0	933.6	1172.6	0.60	0.76
Venezuela	1424.0	1086.3	1035.3	0.76	0.73
Europe					
Portugal	1821.1	640.9	625.0	0.35	0.34
Spain	1359.9	644.8	702.1	0.47	0.52
LAC countries	1476.5	1146.6	1140.4	0.78	0.77

Notes: "Current Pot Yield" refers to the production-potential counterfactual under the mixed input scenario. "Clima Pot Yield" refers to the production-potential counterfactual under the climate change yield projections of climate models M1 and M2.

implies that in the face of heterogeneous climate change across locations, countries can exploit the spatial misalignment of challenges and opportunities. In turn, the potential for further gains from changing the crop mix is lower under climate change than under current conditions, from 108 percent to 68 percent under M1 and to 70 percent under M2. There is however considerable variation of these gains across countries. Peru, Portugal, Spain especially but also Mexico, Chile and Nicaragua are expected to benefit the most from the spatial reshuffling of production. Argentina and Uruguay as well as the countries in Central America are expected to benefit the most from changing the set of crops they produce in each location.

To visualize the variation in yield gains from climate change under the production, spatial and total potential, in Figure 12 I show the contribution of each counterfactual in stacked bar format for climate model M1. Panel (a) displays South American countries, Panel (b) Central America, and Panel (c) Caribbean and European countries. The larger contribution of the spatial reallocation to overall yield gains under climate change is seen from the longer stacked bar for the spatial-potential yield in several of the countries.

7 | CONCLUSIONS

I combine high-resolution spatially explicit grid-level data on potential yields by crop and an accounting framework to study the role of land quality and geography for agricultural productivity across and within Latin American and Caribbean countries. I find that overall, LAC countries are naturally endowed with rich land quality and geography compared to other countries, that they do not fully exploit. While actual agricultural productivity is still high, it is at 82 percent of that in the richest countries. However, producing the same crops in the same locations with potential yields would give LAC countries an 18 percent advantage relative to the richest countries. Nevertheless, the variation in potential yields across LAC countries cannot account for the variation in actual yields.

I find considerable potential gains from the raw suitability of the land if complemented with inputs application and adoption of more modern cultivation practices, doubling productivity in many LAC countries. I also find additional, but smaller gains from the spatial reallocation of crop production across locations within countries, and the switch to higher return crops cell-by-cell on the grid.

There is considerable variation in land quality and geography within LAC countries, with some locations much better suited for agricultural production. However, production does not always take place in the most productive parts of the country, as is the case for Brazil and Colombia. In contrast, in Argentina production takes place in locations with a comparative advantage in their land quality. Overall, actual yield variation across sub-national administrative units across LAC countries is not driven by variation in potential yields, implying a mis-alignment between suitability and production practices.

If land quality and geography are not the drivers of actual agricultural productivity, then it is important to understand the role of policies, constraints, institutions shaping the economic decisions of farmers about where to produce and how to produce, i.e., production and management practices, input application, mechanization and technologies used. The literature has made considerable headway in understanding the role of these factors at the micro and macro level, but understanding how these economic choices interact with land quality and geography could yield benefits.

I have also examined the role that expected climate change will play for the future of agricultural productivity across LAC countries, through their projected effects on crop-cell yields as predicted by natural scientists. I find that the effects are highly heterogeneous

TABLE 8 Spatial and Total Potential under Climate Change (M1)

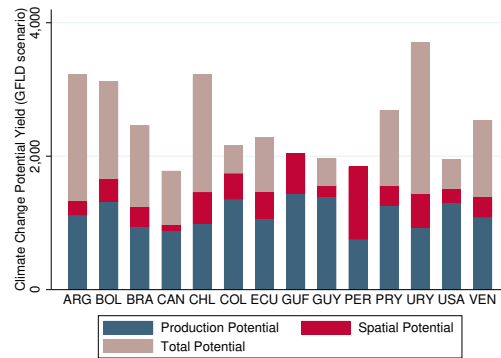
	Aggregate potential yield with climate change				
	Production	Spatial	Spatial/ Production	Total	Total/ Spatial
North America					
Canada	887.6	971.7	1.09	1778.8	1.83
Mexico	719.0	987.6	1.37	1715.3	1.74
United States	1308.8	1512.4	1.16	1956.4	1.29
Central America					
Belize	1241.2	1375.2	1.11	2062.5	1.50
Costa Rica	1502.7	1864.2	1.24	2567.5	1.38
El Salvador	1105.7	1193.3	1.08	2859.1	2.40
Guatemala	1060.6	1374.7	1.30	2808.1	2.04
Honduras	1012.1	1174.8	1.16	3056.2	2.60
Nicaragua	1096.7	1376.7	1.26	3150.3	2.29
Panama	1354.9	1623.9	1.20	2906.1	1.79
Caribbean					
Antigua and Barbuda	994.5	1016.8	1.02	2973.3	2.92
Bahamas	956.2	1143.8	1.20	1321.9	1.16
Cuba	1636.2	1851.2	1.13	2570.8	1.39
Dominican Republic	1543.5	1821.5	1.18	2455.0	1.35
Jamaica	1782.7	1930.9	1.08	2405.0	1.25
South America					
Argentina	1116.6	1335.0	1.20	3229.5	2.42
Bolivia	1321.0	1666.2	1.26	3123.6	1.87
Brazil	942.1	1240.8	1.32	2458.7	1.98
Chile	993.6	1463.8	1.47	3221.1	2.20
Colombia	1356.2	1741.7	1.28	2160.0	1.24
Ecuador	1061.3	1469.7	1.38	2280.3	1.55
French Guiana	1445.5	2045.1	1.41	1603.2	0.78
Guyana	1395.6	1563.0	1.12	1967.6	1.26
Paraguay	1258.7	1557.2	1.24	2689.1	1.73
Peru	755.7	1843.6	2.44	1333.6	0.72
Uruguay	933.6	1437.3	1.54	3705.9	2.58
Venezuela	1086.3	1392.8	1.28	2532.1	1.82
Europe					
Portugal	640.9	1220.3	1.90	2111.0	1.73
Spain	644.8	1169.5	1.81	1832.1	1.57
LAC countries					
	1146.6	1477.1	1.29	2485.1	1.68

Notes: "Production," "spatial," "total" refer to the production-potential, spatial-potential, and total-potential counterfactual yields with climate change. "M1" uses climate model GFLD-ESM2M.

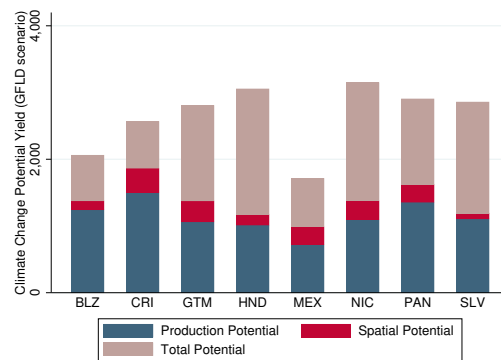
TABLE 9 Spatial and Total Potential under Climate Change (M2)

	Aggregate potential yield with climate change				
	Production	Spatial	Spatial/ Production	Total	Total/ Spatial
North America					
Canada	829.0	948.1	1.14	1618.2	1.71
Mexico	735.9	1031.5	1.40	1603.6	1.55
United States	1183.2	1410.0	1.19	1728.2	1.23
Central America					
Belize	1065.1	1191.7	1.12	2155.7	1.81
Costa Rica	1472.9	1826.1	1.24	2681.9	1.47
El Salvador	1167.4	1251.4	1.07	3250.0	2.60
Guatemala	1087.3	1372.4	1.26	2815.1	2.05
Honduras	1207.1	1395.0	1.16	3142.3	2.25
Nicaragua	1033.5	1442.8	1.40	2994.8	2.08
Panama	1377.2	1691.0	1.23	2987.3	1.77
Caribbean					
Antigua and Barbuda	1284.6	1309.9	1.02	3454.2	2.64
Bahamas	804.4	957.1	1.19	1278.9	1.34
Cuba	1371.6	1588.3	1.16	2345.7	1.48
Dominican Republic	1170.2	1578.2	1.35	2150.3	1.36
Jamaica	1762.5	1924.2	1.09	2364.3	1.23
South America					
Argentina	1137.6	1340.8	1.18	3136.0	2.34
Bolivia	1241.3	1581.3	1.27	2850.1	1.80
Brazil	953.3	1232.2	1.29	2357.7	1.91
Chile	1171.1	1671.8	1.43	3819.0	2.28
Colombia	1390.0	1775.5	1.28	2277.0	1.28
Ecuador	1116.2	1496.8	1.34	2322.0	1.55
French Guiana	1420.7	2008.7	1.41	1579.6	0.79
Guyana	1383.8	1542.6	1.11	1937.0	1.26
Paraguay	1170.5	1478.3	1.26	2500.0	1.69
Peru	731.4	1755.1	2.40	1261.5	0.72
Uruguay	1172.6	1340.9	1.14	3755.4	2.80
Venezuela	1035.3	1369.2	1.32	2358.6	1.72
Europe					
Portugal	625.0	1254.5	2.01	1832.3	1.46
Spain	702.1	1247.8	1.78	2103.1	1.69
LAC countries					
	1140.4	1468.7	1.29	2493.1	1.70

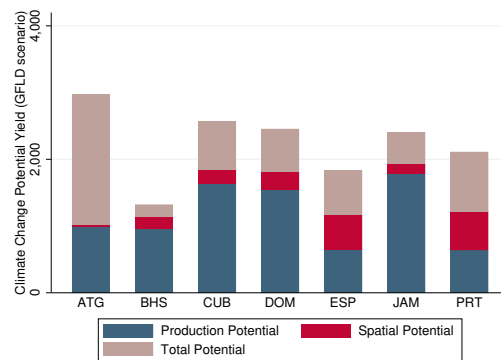
Notes: "Production," "spatial," "total" refer to the production-potential, spatial-potential, and total-potential counterfactual yields with climate change. "M2" uses climate model IPSL-CM5A-LR.



(a) South America



(b) Central America



(c) Caribbean and Europe

FIGURE 12 Yield Gains under Climate Change. *Notes:* Different coloring captures the yield change relative to the previous counterfactual yield in the stacked bars. Assumes climate change scenario M1.

not only across countries, but also across locations within countries. Overall, average potential agricultural productivity is expected to fall in most countries, although not for all. However, because of the heterogeneous impact of climate change I find much larger gains from spatial reallocation of production across locations within countries, which can partially mitigate the pitfalls of global warming. More research on the role of climate change and its implications for future agricultural productivity is sure to yield important insights, in the face of sustainability challenges, as well as environmental and other risks.

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A | ROBUSTNESS: INCLUDING COFFEE, COCOA, TEA

The main analysis has focused on 18 major crops produced across the world. I have abstracted from high value cash crops such as coffee, tea and cocoa as these crops have high relative prices compared to other crops and can have a disproportionate effect on aggregate values. However, LAC countries are known to be large producers and exporters of coffee, tea and cocoa. Here, I examine the robustness of the baseline results of the production potential counterfactual, under the low input scenario, when coffee, tea, and cocoa are included in the analysis.

Table A.1 displays the aggregate actual yield (column 1) and the production potential yield with low inputs (column 3) for each LAC country. Columns 2 and 4 show the actual yield and the potential yield relative to the richest group of countries for comparison. This table reproduces Table 2 but with coffee, cocoa and tea. Interestingly, when focusing on actual yields there is no significant change between the baseline set of crops and the set that includes the additional cash crops, in relative terms, except for individual countries like Costa Rica. When taken together, all LAC countries are still at 82 percent of the richest countries. However, there are larger differences in the potential yield when coffee, cocoa, tea are included. The potential yield for all LAC countries is now 42 percent higher than the richest countries (as opposed to 18 percent above without coffee, cocoa, tea). This is driven by the fact that relative potential yield with coffee, cocoa, tea of some LAC countries is considerably higher, such as Colombia, Dominican Republic and the Central America countries of Costa Rica, Honduras and Guatemala.

Figure A.1 shows that the earlier conclusion with the 18 crops is robust to the inclusion of coffee, cocoa, tea. The variation in actual yields across LAC is completely uncorrelated with the variation in the production potential yields across these countries. The map in Figure A.2 shows the production potential yield (low inputs) including coffee, cocoa, tea, at the pixel level. This allows to see the continuity of variation across LAC countries, transcending country borders. Relative to the baseline case (without coffee, tea, cocoa), the potential yield now shows patches of higher intensity (darker orange) in Brazil, Colombia and Central America. The takeaway is that the baseline findings are robust to the inclusion of coffee, tea, cocoa and that LAC countries have a natural comparative advantage in the production of these crops.

B | SIMPLE MODEL OF STRUCTURAL CHANGE

The economy produces an agricultural and a non-agricultural good, in separate sectors. Agricultural production Y_a takes place according to a Cobb-Douglas technology,

$$Y_a = A_a L^\theta N_a^{1-\theta}$$

where L is land (in fixed supply), N_a is labor input, and A_a is TFP in agriculture. For simplicity, I abstract from capital and intermediate inputs. Output in non-agriculture takes place according to a constant returns to scale technology that is linear in labor input N_n ,

$$Y_n = A_n N_n$$

TABLE A.1 Actual and Production-Potential (low inputs) Yields with coffee, cocoa, tea

	Actual Yield	Act Rel to Rich	Potential Yield	Pot Rel to Rich
North America				
Canada	441.2	0.60	166.1	0.70
Mexico	416.3	0.56	186.4	0.79
United States	814.4	1.10	284.6	1.20
Central America				
Belize	641.0	0.87	277.5	1.17
Costa Rica	1094.4	1.48	563.7	2.38
El Salvador	516.4	0.70	365.5	1.54
Guatemala	667.5	0.90	464.2	1.96
Honduras	497.0	0.67	446.3	1.88
Nicaragua	396.8	0.54	334.8	1.41
Panama	507.9	0.69	412.9	1.74
Caribbean				
Antigua and Barbuda	165.1	0.22	353.4	1.49
Bahamas	497.2	0.67	224.6	0.95
Cuba	587.7	0.79	410.5	1.73
Dominican Republic	517.3	0.70	618.4	2.61
Jamaica	1073.5	1.45	197.7	0.83
South America				
Argentina	566.6	0.77	315.5	1.33
Bolivia	415.1	0.56	312.7	1.32
Brazil	641.6	0.87	258.7	1.09
Chile	825.0	1.12	285.7	1.20
Colombia	846.2	1.14	490.2	2.07
Ecuador	432.9	0.59	371.8	1.57
French Guiana	547.2	0.74	170.5	0.72
Guyana	853.6	1.15	226.6	0.96
Paraguay	650.8	0.88	207.7	0.88
Peru	749.3	1.01	251.5	1.06
Uruguay	607.8	0.82	366.8	1.55
Venezuela	593.7	0.80	370.7	1.56
Europe				
Portugal	455.8	0.62	345.3	1.46
Spain	654.6	0.89	288.4	1.22
LAC countries	608.1	0.82	337.7	1.42
Rich 10% of all countries	739.5	1.00	237.2	1.00
Poor 10% of all countries	244.0	0.33	239.5	1.01

Notes: Actual and potential yields are measured as total value output per hectare in international prices (GK \$/ha). Low inputs assumes rainfed water supply and low-input cultivation practices.

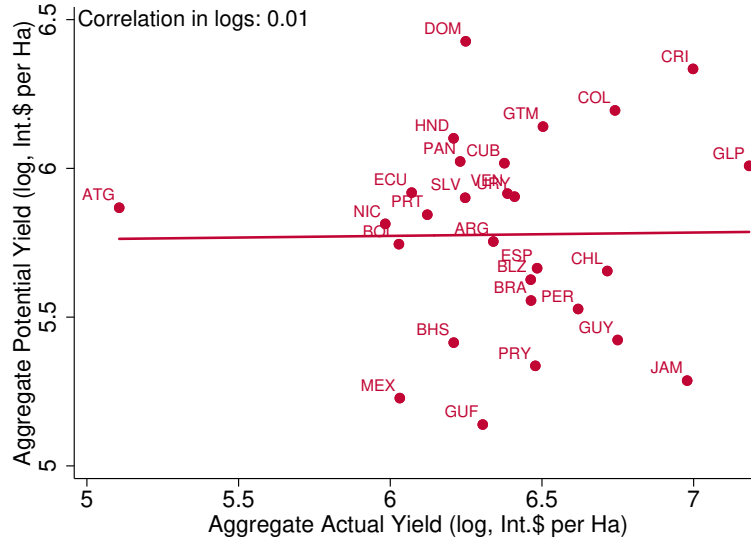


FIGURE A.1 Aggregate low-input production-potential versus actual yield across countries. *Notes:* Aggregate production-potential yield is under rainfed low-input scenario, and includes coffee, cocoa, tea.

where A_n is non-agricultural TFP. There is a fixed amount of labor N which can be allocated to these two sectors. Thus the market clearing condition for labor is,

$$N = N_a + N_n$$

There are non-homothetic preferences with a subsistence constraint for food consumption. These preferences take a simple form, whereby individuals consume a minimum amount of agricultural consumption goods per person $\bar{a}$. Once this minimum is met individuals allocate the rest of their income to the consumption of non-agricultural goods. The market clearing condition for agricultural goods is thus,

$$Y_a = N\bar{a}$$

Denoting per-capita labor in agriculture and land as n_a and l respectively, and combining the agricultural market clearing condition with the agricultural production function, the share of employment in agriculture is,

$$n_a = \left(\frac{\bar{a}}{A_a l^\theta} \right)^{1/(1-\theta)}. \quad (\text{A.1})$$

Labor productivity in agriculture is given by $y_a = A_a l^\theta n_a^{-\theta}$ and average farm size by $\text{AFS} = l/n_a$. Labor productivity in non-agriculture is simply $y_n = A_n$ and income per capita is computed as $y = p y_a n_a + y_n (1 - n_a)$, where p is the relative price of agricultural goods. Without loss of generality we set $l = 1$.

I calibrate the benchmark economy to the United States. Productivity parameters are normalized, $A_a = A_n = 1$. $\bar{a}$ is calibrated to match the share of employment in agriculture in the United States of 1.7 percent (see Table 1). This procedure implies $\bar{a} = 0.07$, and a

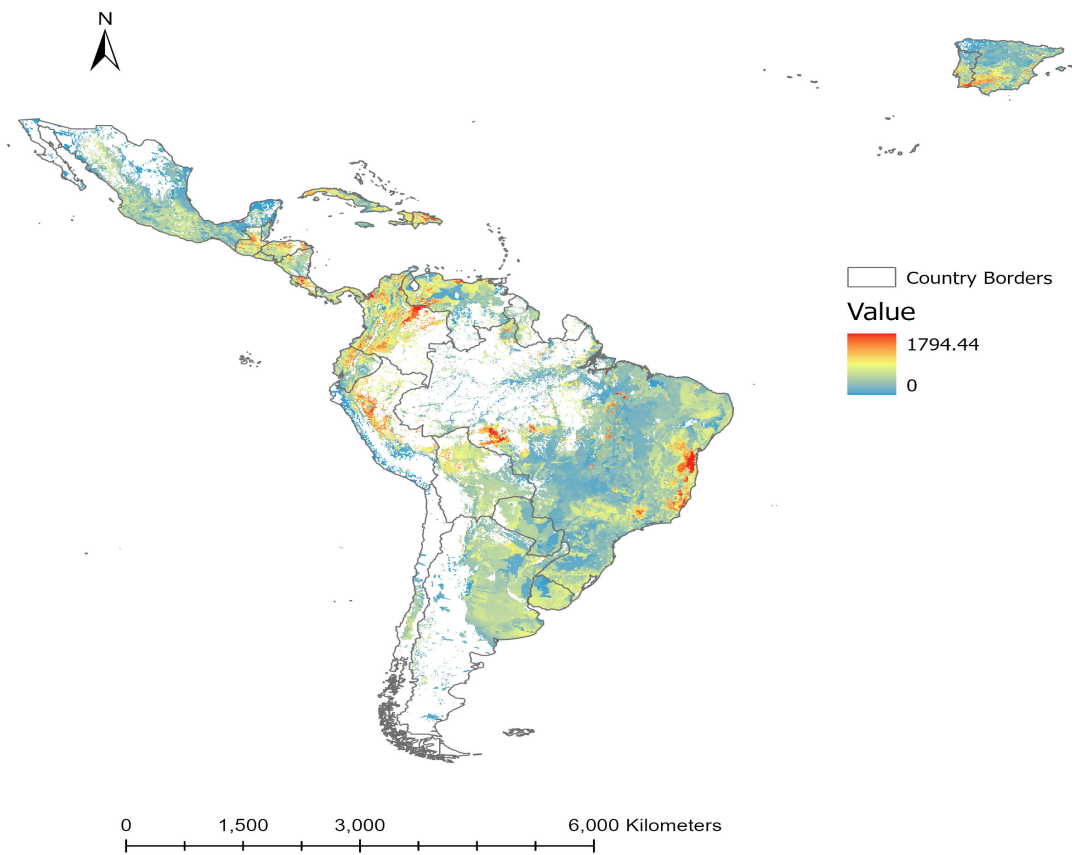


FIGURE A.2 Cell-Level Potential Yields including Coffee, Cocoa, Tea (low inputs). *Notes:* “Potential Yield (low)” refers to the country-level potential yield from the Production Potential experiment, that replaces actual yields in each cell and for each produced crop with the corresponding potential yield, under rainfed conditions and low level of inputs. Coffee, cocoa, and tea are included. The potential yield is expressed in Geary-Khamis international dollars. Map shading is continuous.

benchmark economy relative price of $p = 0.39$.