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IFPRI Discussion Paper 01749

August 2018

The Agricultural R&D Investment Gap in Latin America and the Caribbean

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ABSTRACT

Given the importance of agricultural R&D investment to sustain agricultural growth in the future, this study looks at the state of agricultural R&D investment in LAC, with the goal of identifying the level of underinvestment in the region. To do this the study uses a new indicator, the ASTI Intensity Index (AII) to measure agricultural R&D intensity in Latin America and the Caribbean (LAC) and compares research intensity with that of other regions and between countries within the region. The index can be used to identify potential under investors, determine intensity gaps and quantify R&D investment needed to close this gap by comparing countries with similar characteristics. Results obtained using a sample of 100 countries including 29 LAC countries show that despite rapid growth in R&D investment after 2004, the region shows low levels of intensity and the largest R&D intensity gap when compared to other regions. Results also show large differences between countries in the region. The Southern Cone (Brazil, Argentina, Chile, Uruguay and Paraguay) is among the regions showing highest levels of research intensity globally. Low levels of R&D intensity in the region are explained mainly by countries in Central America and by Andean countries. Results also show that the intensity gap represents almost 75 percent of total R&D investment in 2012 and that the region will need to increase investment from $5 to $8.5 billion 2011 PPP to close the intensity gap.

Keywords: agriculture, investment intensity, Latin America and the Caribbean, research and development

ACKNOWLEDGMENTS

This work was undertaken as part of the work of the analytical component of the Agricultural Science and Technology Indicators (ASTI) led by the International Food Policy Research Institute (IFPRI), and in collaboration with the Environment and Natural Disasters Division of the Inter-American Development Bank (IDB), and funded by the IDB. This paper has not gone through IFPRI's standard peer-review procedure. The opinions expressed here belong to the author, and do not necessarily reflect those of IFPRI, CGIAR or IDB.

ABBREVIATIONS AND ACRONYMS

AgGDP	agricultural gross domestic product
AII	ASTI R&D intensity index
EAP	East Asia and Pacific region
DEA	data envelopment analysis
DI	diversification index (DI)
GDP	gross domestic product
HHI	Herfindahl-Hirschman Index
HI	high income countries
IG	intensity gap
IP	intellectual property
IR	intensity ratio (R&D spending/AgGDP)
LAC	Latin America and the Caribbean
LP	linear programming
PIR	potential intensity ratio
OLS	ordinary least squares
R&D	research and development
SA	South Asia
SSA	Africa south of the Sahara
TFP	Total Factor Productivity

1. INTRODUCTION

Compared with many other regions around the world, Latin America and the Caribbean (LAC) is well placed to scale up its agricultural production and trade, in a world where food security will continue to be one of the key global challenges in the coming decades. LAC's share of global agricultural trade rose from just 8 percent in the mid-1990s to 13 percent in 2015 (FAO 2015). Brazil, the region's economic engine, is now the world's second-largest supplier of food and agricultural products based on continued productivity improvements in support of fast-growing exports.

Agricultural research and technical change has been one of the key factors in increasing agricultural productivity in the region over the past decades, especially in Brazil and the Southern Cone (Nin Pratt et al. 2015). However, more will need to be done in the region in terms of R&D investment and new technologies to be able to sustain the high levels of output and trade growth observed in the last ten years. A recent report on the present situation of agricultural R&D systems and institutions in LAC by Stads et al. (2016)[1] concludes that higher levels of investment and improved human resource capacity are prerequisites for the attainment of agricultural productivity growth, food security, and poverty reduction in the coming decades.

According to Stads et al. (2016), after considerable volatility throughout the 1980s and the early 1990s and a declined in the early 2000s, R&D spending in the region increased rapidly after 2004. By 2013, the region was spending close to $5 billion on agricultural R&D in 2011 PPP prices[2], a 75 percent increase compared to spending levels in the early 1980s. Total researcher numbers—measured in full time equivalents or FTEs followed a similar pattern, with rapid increases in the 1980s, a period of stagnation during 1990–2004, and rapid increases once again thereafter. In 2013, LAC employed close to 20,600 agricultural researchers (in FTEs), nearly twice as many as in the early 1980s.

[1] The report assesses trends in investments, human resource capacity, and research outputs in agricultural R&D, targeting close to 700 agencies in 27 LAC countries

[2] Unless otherwise stated, all dollar values in this document are in 2011 PPP $ exchange rates, which reflect the purchasing power of currencies more effectively than do standard exchange rates because they compare the prices of a broader range of non-tradable —as opposed to internationally traded—goods and services.

Despite rapid growth in R&D investment, the regional figures mask considerable differences across countries. Brazil is the largest country in LAC in terms of agricultural R&D spending and outperforms every other country with its highly qualified research staff and world class research infrastructure and outputs. In 2013, Brazil spent $2.7 billion on agricultural R&D, representing more than half the region's total spending in that year. Argentina and Mexico each spent more than $700 while Colombia ($254 million) and Chile ($186 million) complete the top five countries in terms of spending levels. These countries together with Costa Rica and Uruguay are the countries with the most developed agricultural research systems in the region. However, many other countries—especially the Central American countries, Caribbean island nations, and poorer Andean countries—are increasingly falling behind in terms of infrastructure, investment levels, and capacity.

Given the heterogeneity between countries in terms of the size of their economies and of their agricultural sector, how can we quantify differences in investment between diverse countries and assess their effort in terms agricultural research? Which countries are falling behind in R&D spending? Is actual R&D spending high or low? Is there an investment gap in the region? If yes, which countries contribute the most to this gap? Which countries show the lowest levels of investment?

The most used indicator of the research effort made by an economy is the Intensity Ratio (IR), defined as the percentage of agricultural gross domestic product (AgGDP) invested in agricultural R&D (excluding the private for-profit sector). For example, IR values for the period 2001-2011 calculated using ASTI (2016) data, show an average IR of 3.40 for North America (USA and Canada); 1.97 for Europe; 0.83 for East Asia and the Pacific, 0.50 for Africa south of the Sahara (SSA) and Middle East and North Africa, 0.34 for South Asia and 1.10 for LAC. These figures have been used as evidence of R&D underinvestment in developing countries, given that estimated returns to R&D are expected to rise with distance from the technological frontier, reflecting the gains that follower countries can make from catching-up (Griffith et al. 2004) suggesting that returns to R&D investment should be truly large and that developing countries should increase research intensity in agriculture.

Different types of R&D intensity measures are calculated in many countries and areas to monitor progress towards meeting R&D policy objectives, and in some cases, explicit targets. For example, Governments at the Rio+20 conference in 2012 (Legget and Carter 2012) agreed to develop a universally applicable set of sustainable development goals (SDGs) to promote focused and coherent action on development with a strong focus on agriculture, food systems, and nutrition outcomes, areas linked to the goal of eradicating hunger and poverty. Among the targets defined under this general goal, there is a call for a minimum of 5 percent annual growth in agricultural R&D spending in low- and middle-income countries over the next decade to reach an IR value of at least 1 percent.

This widespread agreement on the need to promote agricultural R&D investment could have a significant impact on future allocation of scarce public resources in low income countries, so it justifies a second look at the R&D underinvestment hypothesis, especially because this proposition rests on very weak assumptions, mainly the high rates of return to agricultural R&D found in the literature and the low intensity of investment measured by the IR.

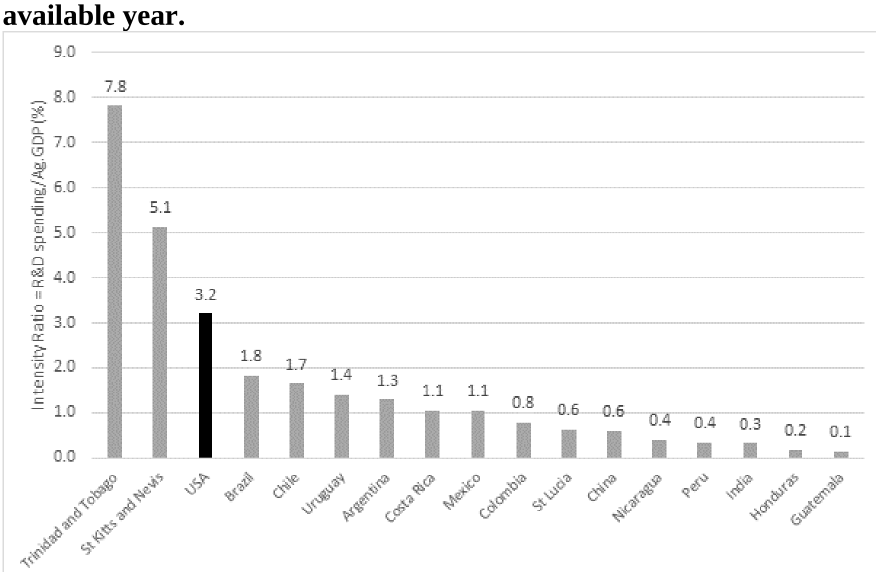
This study builds on the paper by Nin-Pratt (2016) that shows that the IR is an inadequate indicator to measure and compare research effort of a diverse group of countries and uses a new measure of R&D intensity, the ASTI Intensity Index (AII), to compare investment effort in LAC. This new measure allows to: a) unequivocally rank and compare countries according to R&D intensity levels; b) identify underinvesting countries by comparing countries with similar characteristics; and c) use this information to determine intensity gaps and quantify R&D investment needs for different countries and regions.

The rest of the paper is organized as follows. The next section looks at the correlation between the IR and structural characteristics of countries, showing that it is not possible to compare R&D intensity between two countries if they differ in these characteristics. This section is followed by the conceptual framework, the methodological approach and data used in the study to build the new intensity index applied to LAC. Section 4 presents results and country comparisons and quantifies the intensity gap using the proposed index. Section 5 concludes.

2. THE INTENSITY RATIO AND COUNTRY COMPARISONS

A simple comparison of average IR values of selected countries for the most recent available years (Figure 2.1) is sufficient to show some of the difficulties that arise when using the IR to measure R&D investment intensity. Assuming that the IR is a good measure to compare research intensity between countries, Figure 2.1 suggests that a high-income country like the US makes a higher effort in agriculture R&D investment than most LAC countries, which is normally expected. What is not expected is that two Caribbean islands like Trinidad and Tobago and St. Kitts and Neves can show levels of research intensity that are 2 to 3 times bigger than those of the USA. Or take for example the cases of China and India. These countries show IR values that are only a small fraction of those of Brazil. Why these differences between Brazil, China and India and why are their IR values smaller than Trinidad and Tobago's when it is well established that these three countries are leading agricultural research developing countries with comparably large, relatively developed and successful R&D systems (Fan 2000, Fan et al. 2006, Pal 2008, Pal and Byerlee 2008, Beintema et al. 2009)?

Figure 2.1— Intensity ratio (agricultural R&D spending/AgGDP) for selected countries, latest available year.



Source: Elaborated by authors.
Note: Exclude agricultural R&D spending by the private for-profit sector. Figures for Central America and Caribbean countries are from 2012, South American countries from 2013; USA, China and India are averages 2001-2011.

The reason is that the IR is an inadequate indicator to measure and compare research effort of a diverse group of countries, which makes the comparison in Figure 2.1 a misleading exercise. The more general literature on R&D investment at the firm level shows that poor countries invest far less in R&D as a share of their GDP than rich countries. One explanation for this fact, relevant for our analysis, is that the necessary complementarities to R&D expenditure are likely to diminish at lower levels of income and hence reduce the efficacy of a given unit of R&D. In other words, the efficacy of R&D investment in developing countries is much lower than in high income countries due to any number of institutional, and educational factors which can offset the Schumpeter catch-up effect and significantly reduce the returns to R&D (Goñi and Maloney 2014).

Lederman and Maloney (2003) looked at the links between development and R&D investment and found that R&D rises exponentially with the level of development measured by GDP per capita, mainly because high income countries tend to have higher government capacity to mobilize public R&D expenditures and a better quality of research institutions. Private R&D is also higher in rich countries because they have better intellectual protection (IP) and deeper credit markets. Other authors have emphasized the importance of market size as a determinant of innovative activity. For example, Eaton et al. (1998) found that Europe's research intensity was lower than that of the USA because Europe has smaller and more fragmented markets for innovations. Notice that in this case, market size is related to the absolute value of R&D investment, not to the IR. As will be discussed below, the actual size of the economy could be negatively related to the IR.

A first conclusion derived from the literature on R&D investment is that richer economies are expected to show higher IR values. If this also applies to R&D in agriculture, it could be at least a partial explanation of observed heterogeneity in IR between countries. At the sectoral level, there are other factors that could potentially affect IR. In the case of agriculture, one of these factors is the size of the agricultural sector relative to the economy. A country with a smaller share of agriculture in GDP could potentially allocate relatively large amounts of resources to agricultural R&D investment given that the investment needed is small relative to GDP. This could contribute to explain why in general, IR is higher in high income countries than in developing countries, as the share of agriculture decreases with income growth. This explanation could also apply to developing countries with small agricultural sectors relative to GDP as in the case of Trinidad and Tobago shown in Figure 2.1.

As in the more general literature on R&D, the size of the economy should be another factor affecting agricultural R&D investment and the IR. A large economy could facilitate the development of innovation activities in agriculture due to a larger market for innovations, not only for agriculture but for other sectors. However, the effect of a large economy doesn't result necessarily in higher IR levels. Economies with large markets for innovation might depend less on investment from the public sector and non-for-profit organizations which might result in less R&D investment relative to agricultural GDP. However, this could also be affected by other variables like income per capita, spill ins and the relative size of agriculture which makes it difficult to determine a priori the sign of its effect on IR.

The potential of a country to benefit from spillovers from other countries (spill ins) is another factor that could affect the IR. For example, countries with similar output composition (reflecting similar agroecologies and natural resources) and similar use of capital and land per worker in agriculture are "closer" to each other than to countries in different agroecologies and with different relative factor prices (for example, land and capital abundant countries compared to land scarce and labor abundant countries). Countries with high potential of receiving spillovers from other countries could show lower IR (negative correlation) because they can rely on technologies developed elsewhere that can be adapted to their own conditions with a lower research effort than countries with low potential for spillovers. The negative correlation between spill ins and IR could be expected if there is a simple linear relationship between these variables. However, this relationship could be more complex because countries might need to invest in R&D to take advantage of spill ins and the level of investment needed could vary along the distribution of IR.

Finally, diversification or specialization within agriculture is another factor with potential impact on the intensity of R&D investment as measured by the IR. In terms of absolute levels of R&D investment, we could assume that the more diversified agricultural production is, the more R&D investment is needed assuming other factors being equal. This is because countries need a much-diversified portfolio with sufficient investment in each of its components to have the same impact at the sectoral level than more specialized countries. An example of this situation could be the rice-economies of East and Southeast Asia compared to the diversity of agroecologies and production systems in West Africa. African countries will need to invest more to have a similar impact on productivity than the Asian countries, ceteris paribus. However, when thinking of correlation between diversification and IR, it is more difficult to have clear hypotheses about the sign of the correlation between these variables. Countries have limited resources to invest in R&D, which means that they will not invest proportionally in all activities, setting investment priorities independently of the degree of diversification of their agricultural sectors. If this is the case, we could observe a negative correlation between IR and diversification, with countries still investing in a limited number of activities independently of the level of diversification of their agricultural sector.

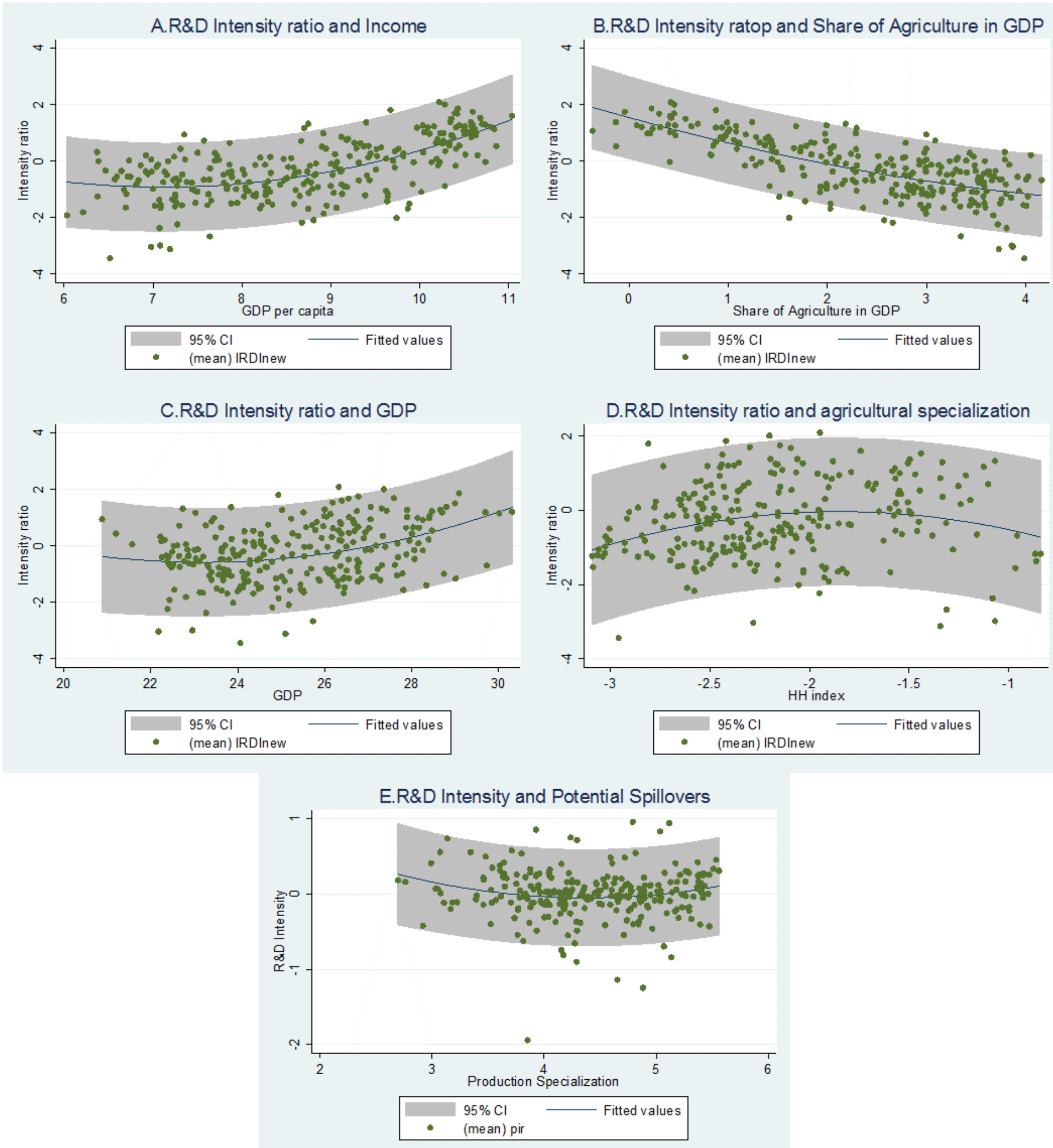
The purpose of the discussion so far was to show the different variables that could affect IR values at the country level and the difficulties of trying to determine the sign of the correlation between IR and other variables assuming that there is no simple linear relationship between them. The last part of this section shows the result of different measures that try to capture the correlation between the IR and the five factors assumed to affect its value: income, size of the economy, relative size of the agricultural sector, potential to receive spillovers and specialization in agriculture. GDP per capita is used as a proxy for the country's income, GDP is a proxy for the size of the economy, and the share of agriculture in GDP looks at the effect of the relative size of the agricultural sector. In the case of potential spillovers, this study uses a similar approach than that in Jaffe (1986, 1989), Alston et al. (2011) and Eberhardt and Teal (2013) to calculate similarity between agriculture in different countries. As in Alston et al. (2011), the measure of spillover potential in this study is based on the similarity of the commodity composition of output between pairs of countries. Finally, the Herfindahl-Hirschman Index (HHI), which is frequently used to measure industrial concentration and corporate diversification (Jacquemin and Berry. 1979) is adapted to create a diversification index (DI). The DI takes values between 0 and 1, with 1 being the highest level of diversification (see Appendix A for details on the calculation of the potential spillover and diversification indicators). Data used are for 100 countries from 1981 to 2011. R&D data are from ASTI (2016), AgGDP and GDP are from World Bank (2016), and the diversification and specialization indices are built using data from FAO (2015).

Figure 2.2 plots predicted and observed levels of IR as a function of GDP per capita (Figure 2.2A), of the share of AgGDP in GDP (Figure 2.2B), of GDP levels (Figure 2.2C), of output specialization (Figure 2.2D) and of potential spillovers (Figure 2.2E). Predicted values are generated from a regression of the log of RDI against the log of the independent variables, including square terms in the regression with GDP per capita and GDP; using data for 103 countries during the period 1981-2012.

It is clear from Figure 2.2 that IR increases with the relative size of the agricultural sector. The correlation between income and IR, and between GDP and IR is also positive but the effect of the square terms results in a flat or negative response at low levels of GDP and income, and exponential growth of IR at higher levels. Figure 2.2D shows that IR increases with production specialization at low levels of specialization but decreases with further increases of specialization if countries already show high specialization. Finally, the measure of potential spillovers is negatively correlated with IR.

The links between IR and these five variables could explain the variation in IR between countries, and the growth path of a country will also depend on its particular structural characteristics. For example, we expect IR in a large but poor country, like China in the early 1980s, to increase slowly at the beginning because of a relatively small GDP and low income. Growth will increase income and GDP with small increase in IR until the country reaches the region of exponential growth in Figure 2.2C. At this point, we expect accelerated growth in IR. Small poor countries might never reach the GDP level at which research intensity is boosted by the size of the market for innovations, depending only on growth in income per capita and structurally constrained by its market size to increase research intensity.

Figure 2.2 Correlation between the Intensity Ratio and country characteristics



Source: Elaborated by authors based on data from ASTI (2016) and World Bank (2016).
Note: Each point represents the average value of the variables in the horizontal and vertical axes while the line is the prediction for the IR from a regression of IR on the variable in the horizontal axis and its square, while the gray area represents the confidence interval of the predicted values.

A more formal test of the correlation between IR and different variables is shown in Table 2.1. As in Lederman and Maloney (2003), OLS and quantile regressions (including median regressions) are used to model conditional quantiles of the joint distribution of IR and the independent variables. This approach allows the estimation of multiple coefficients and provides a more complete picture of the relationship between IR and other variables. Median regression is more robust to outliers than least squares and it avoids assumptions about the parametric distribution of the error process, while quantile regressions allow us to describe the relationship between IR and the independent variables at different points in the conditional distribution of IR (see for example Koenker and Hallock 2001). In contrast with correlations shown in Figure 2.2, Table 2.1 shows the simultaneous regression between IR and the five independent variables. Variables that capture country and year fixed effects are used in all regressions.[3]

Table 2.1—Estimated coefficients of median and quantile regressions of the Intensity Ratio (IR) against GDP per capita, GDP levels, share of agriculture in GDP, production diversification and potential spillovers, 1981-2011.

	OLS	Q(0.10)	Q(0.25)	Q(0.50)	Q(0.75)	Q(0.90)
GDP per capita	0.643***	0.895***	0.812***	0.895***	0.599***	0.307**
	(6.52)	(5.77)	(7.88)	(8.34)	(4.36)	(2.69)
Share of agriculture in GDP	-0.906***	-1.054***	-1.073***	-0.984***	-0.955***	-0.984***
	(-25.58)	(-18.15)	(-26.24)	(-23.13)	(-28.71)	(-28.57)
GDP	-0.549***	-1.066***	-0.940***	-0.914***	-0.688***	-0.464***
	(-5.79)	(-7.47)	(-9.68)	(-8.17)	(-5.07)	(-4.22)
Diversification Index	-0.201***	-0.151**	-0.131*	-0.0682	-0.054	-0.0532
	(-3.79)	(-2.61)	(-2.38)	(-1.26)	(-1.29)	(-1.38)
Potential spillovers	0.238	-2.637*	-1.459	-0.694	-0.898	-1.062
	(0.31)	(-2.29)	(-1.33)	(-0.82)	(-1.12)	(-1.32)
Number of observations	2728	2728	2728	2728	2728	2728
R2/pseudo R2	0.907	0.866	0.887	0.895	0.88	0.869

Source: Elaborated by author.
Note: t statistics in parentheses, * p<0.05, ** p<0.01, *** p<0.001; all models include dummy variables for countries and years, coefficients are not shown; pseudo R-square= square of the correlation between the fitted values and the dependent variable in the quantile regression; standard errors of quantile regressions are asymptotically valid under heteroskedasticity and misspecification (Machado et al. 2011).

[3] Notice that regressions reported in Figure 2.2 and in the first column of Table 2.1 are not the same. Figure 2.2 plots the values of IR against the different variables individually and predicted values from the regression are included only to show graphically the correlation between IR and the different variables. The first column of Table 2.1 shows results of an OLS regression between IR and all five variables assumed to be correlated with IR simultaneously.

The first thing to notice in Table 2.1 is that coefficients obtained for income and the share of agriculture are robust in all specifications: the effect of income on IR is consistently positive while that of the share of agriculture in GDP is negative. When controlling for the effect of other variables as is the case in the results in Table 2.1, the effect of GDP on IR becomes consistently negative and the diversification index shows negative and significant coefficients with the OLS and the Q(0.10) regressions only. Coefficients of the potential spillover index become not significantly different from zero.

To conclude, results in Figure 2.2 and Table 2.1 show that the IR depends on structural variables (not controlled by policy makers): income, the size of the economy, the size of the agricultural sector, agricultural diversification and potential for technology spillovers. The effect of these variables on IR is not linear but changes with the particular level and combination of the five variables. This explains why IR is a misleading measure of research intensity and cannot be used to determine intensity gaps of individual countries When using IR as a measure of R&D intensity, the implicit assumption is that R&D investment depends only on the size of the agricultural sector and also that optimal investment is proportional to the size of the sector. Put it differently, the IR can be thought of as a misleading measure of research intensity in the same way that labor or land productivity are not necessarily good proxies for Total Factor Productivity (TFP).

Due to the limitations of the traditional IR as an indicator of R&D intensity and as a tool to compare and rank countries according to their effort in R&D investment, this study uses a multi ratio indicator of R&D intensity that combines R&D investment with AgGDP, GDP, income, agricultural specialization and potential spillovers. Countries with similar relative values of the individual ratios included in the index are expected to show similar intensity levels of R&D investment. On the other hand, differences in R&D expenditure between countries with a similar mix of individual ratios will indicate higher intensity by the country with higher expenditure, where higher intensity means that the country is investing more than expected given its particular structural characteristics. This leads to a conceptually meaningful definition of the R&D intensity gap: the difference between R&D investment of a particular country and the highest investment among all countries with the same mix of AgGDP, GDP, income, agricultural specialization and spill-in potential.

A major difficulty to build this index is to define the weights to aggregate the individual indicators into a single measure of R&D intensity. These weights should reflect the importance that the five determinants of R&D have as constraints of R&D investment in each country. For example, R&D investment in a small, high income economy could be constrained by the relative size of GDP and/or by a very small agricultural sector, so these two variables should enter the intensity index with a higher weight than income to reflect the importance of these constraints on R&D intensity. Technical details of the approach followed to build the index are discussed in the next section.

3. APPROACH AND DATA

The data envelopment analysis (DEA) approach is used to obtain a multifactor R&D intensity measure, the ASTI intensity index (AII). This index calculates R&D investment of a particular country relative to the main structural factors affecting intensity: GDP, AgGDP, income per capita, agricultural specialization and potential spillovers. In generic form, this measure can be represented as:

$$AII_i = f\left(\frac{R\&D_i}{GDP_i}, \frac{R\&D_i}{AgGDP_i}, \frac{R\&D_i}{y_i}, \frac{R\&D_i}{DI_i}, \frac{R\&D_i}{SP_i}\right) \tag{3.1}$$

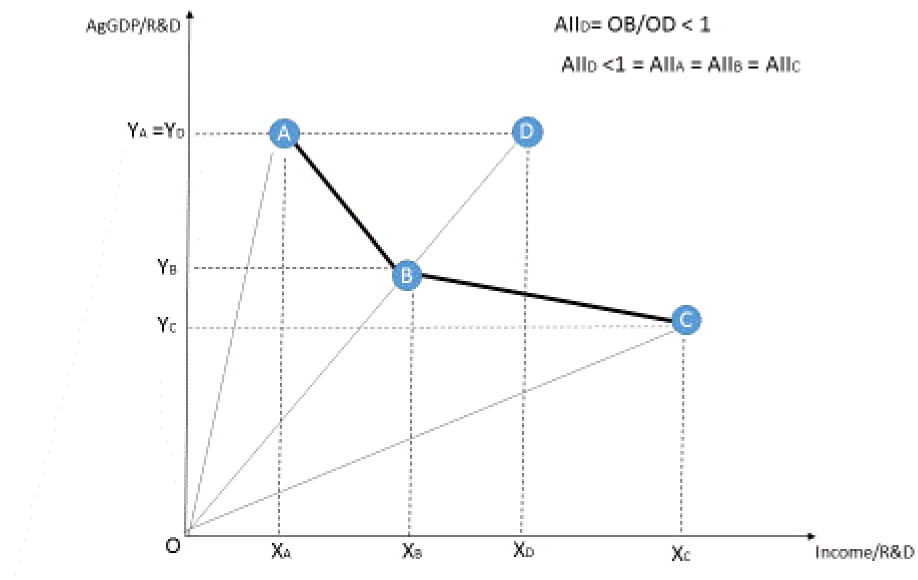
where AII_i is the ASTI intensity index of country i, R&D is expenditure in agricultural research and development, y is income per capita, DI is a measure of output diversification, SP measures potential spillovers, and f[•] is a function aggregating the five intensity ratios into a single number that measures R&D investment intensity of country i. This problem is equivalent to that of estimating an index of input quantities when no prices are available, where the main difficulty is to determine the weights to be used to aggregate the five partial intensity measures.

A well-known feature of DEA is that it looks for endogenous weights that maximize the overall score for each decision-making unit given a set of other observations, yielding most favorable, country-specific weights. The DEA approach has been extensively used to solve this problem in production analysis when prices of inputs or outputs are not available, and it has been extended more recently to build indices that comply with required characteristics from index theory. The approach used by Whittaker et al. (2015) is adapted here to build a multifactor measure of R&D intensity.

The intuition behind the proposed multifactor measure of intensity is shown in the example in Figure 3.1. The axes in the figure represent values of R&D investment relative to two variables, GDP per capita and AgGDP. The use of two inputs in the figure is only for illustrative purposes. A formal discussion of the methodology and the calculation of the index extended to n variables can be found in Appendix A but the analysis will be presented more formally later in this section and extended to n variables.

Each point in Figure 3.1 represents a country and the coordinates that define the position of each country in the figure are: AgGDP/R&D and income/R&D in the vertical and horizontal axes, respectively. Notice that these coordinates represent the inverse of partial intensity ratios, with the measure in the vertical axis being the inverse of the IR normally used to measure intensity of agricultural R&D investment. Notice that point *B* and point D have the same proportion of AgGDP and income (they are in the same ray from the origin), but the level of AgGDP and income per unit of R&D invested is lower in B than in D. This means that R&D intensity of point B is higher than that of *D*. Also notice that countries *A*, *B* and *C* are the countries with highest R&D intensity because there is no other country with the same proportion of AgGDP and income closer to the origin than these countries. Investments by countries *A*, *B* and *C* are equally intensive and outline the "intensity frontier." This frontier defines the space of investment intensity for the sample of countries, with the highest intensity defined by points *A*, *B* and *C* and by all linear combinations of these three points (the lines connecting *A*, *B*, and *C*). Countries with less intensive investment are located in the space above and to the right of the frontier.

Figure 3.1—Example of the multifactor R&D intensity index using two partial measures of intensity: R&D spending/AgGDP and R&D spending/income.



Source: Elaborated by authors
Note: The intensity ratios are expressed as the inverse of R&D spending/AgGDP and R&D/income., A, B and C determine the intensity frontier, showing the value of AgGDP and income per unit of R&D invested.

The DEA approach uses the piecewise linear frontier as the benchmark curve and distances of country vectors are measured relative to this frontier. The distance of each country to the frontier is calculated as the proportional reduction of AgGDP and income needed to bring each point in the "intensity space" to the frontier. For example, the intensity measure for country *D* can be calculated as $AII_D = OB/OD$, which is the distance of country *D* to the frontier. The result of multiplying the values of AgGDP and income of country *D* by *OB/OD*, is the coordinates of country B, that is, the value of AgGDP and income of vector B, the point on the frontier with the same proportion of AgGDP and income than country D. In this way, the multifactor intensity measure for country D (AII_D) is calculated as the distance between *D* and a similar point at the frontier. Notice that this distance is a measure of the difference on investment intensity between *D* and the maximum potential investment (investment at the frontier), which is defined by B. Also notice that countries at the frontier have, by definition, values of the intensity index equal to 1 because the distance of each of these countries to the frontier is: AII_A= OA/OA = AII_B= OB/OB = AII_C

=OC/OC = 1. Countries in the intensity space above the frontier will show values of AII between 0 and 1. Comparing frontier countries to country *D* in Figure 3.1 we get intensity indices: $AII_A = AII_B = AII_C = 1 \geq AII_D \geq 0$. The closer to 1 AII is, the higher the investment intensity of that country, which is to say, the higher R&D investment relative to the value of AgGDP and income.

Notice that countries are compared to countries with the same proportion of AgGDP relative to income. In Figure 3.1, country A could represent a low-income country (small value in horizontal axis) with a large agricultural sector. On the other extreme, the particular mix of income and AgGDP of country *C* could represent that of a high-income country with a small agricultural sector. Country *D* is compared to *B*, the country with the same ratio AgGDP/Income. This is important because it means that the DEA approach allows us to determine the maximum potential intensity that a country can reach (given observed intensities of all countries) and as a corollary of this, we can obtain the actual intensity gap for that country, which can be measured as the difference between maximum potential intensity and actual intensity, defined at the frontier by a country with the same characteristics (same income/AgGDP ratio).

Since AII_D measures the proportional reduction of AgGDP and income needed to reach maximum potential intensity, the product of each of the two intensity measures ($AgGDP_D/R\&D_D$ and income/$R\&D_D$) with AII_D gives the maximum potential value of the two partial intensity measures for country D. This allows to express the potential intensity and the intensity gap in terms of the conventional IR. For example, potential intensity of country D can be seen as the maximum reduction of AgGDP that allows to "obtain" 1 unit of R&D. In the example in Figure 3.1, this is the AgGDP coordinate of point B, the point at the frontier, which is the potential intensity ratio (PIR) of country D: $PIR_D = AgGDP_D * AII_D$. In Figure 3.1, $PIR_D = Y_B$, which is the actual value of the inverse of the IR of the reference point B at the frontier. The intensity gap for country D in Figure 3.1 can then be measured in percentage points of AgGDP: $IG_D = (1/Y_B) - (1/Y_D)$.

As the interest here is in the actual intensity measures and not in their inverse, potential intensity can then be calculated as the maximum increase in R&D investment given AgGDP to reach the frontier, and express the potential intensity ratio as $PIR_D=(R\&D_D/AgGDP_D)/AII_D$ or $PIR_D = 1/Y_B$ in the example in Figure 3.1 and as before, measure the intensity gap in percentage points.

The same data and sources used in section 2 are used in the next section to construct the AII. Data on agricultural expenditure of 100 developing and high-income countries, including 29 LAC countries[4] were obtained from Agricultural Science & Technology Indicators (ASTI 2016), data on GDP, AgGDP and GDP per capita are from World Bank (2016) and detailed agricultural production data at the crop and livestock activity level to calculate diversification and distance between countries are from FAO 2015. The dataset covers the period 1981-2012. All figures were converted to 2011 PPP $. The next section looks at the results of the calculation of the intensity index and the intensity gaps for LAC countries.

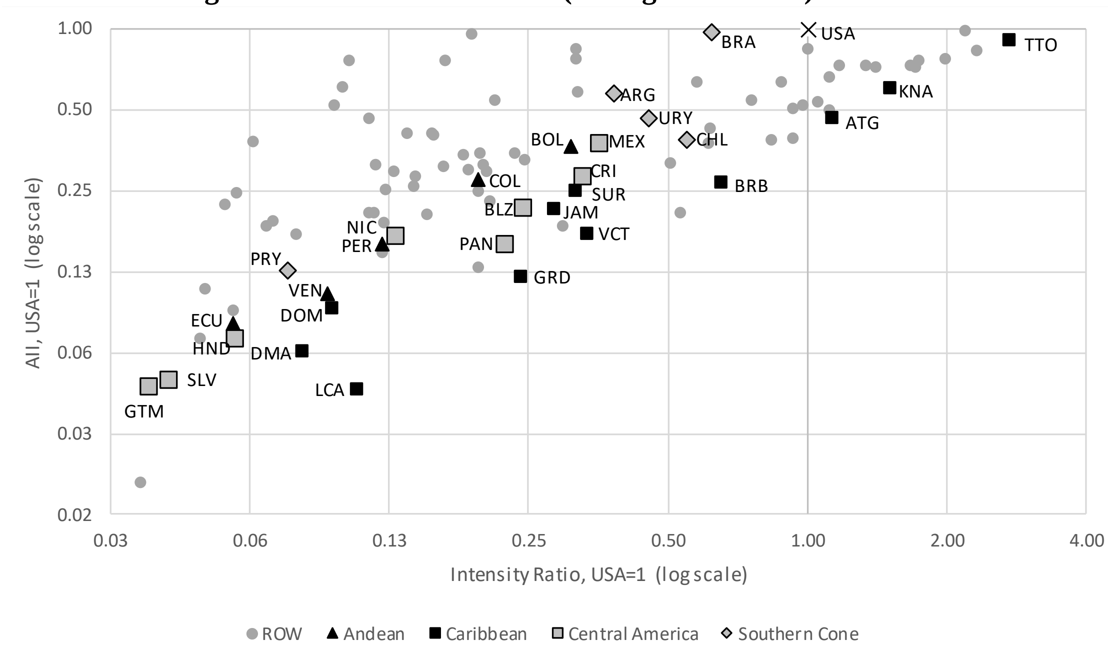
[4] The list of countries together with average values of the variables used in the analysis can be found in Appendix C.

4. RESULTS

Figure 4.1 compares the new intensity measure (AII) with the conventional IR, showing where LAC regions stand compared with other countries. The AII and IR are shown as the coordinates of the country points in the vertical and horizontal axes, respectively. Values of the IR and AII are relative to those of the USA to facilitate comparisons (USA coordinates in the figure are *1,1*).

The correlation between the two indicators in Figure 4.1 is 0.7 but the two measures result in very different country rankings of R&D intensity. Focusing in Latin America, Brazil is the country with the highest AII, equivalent to the research intensity of the USA. Some of the Caribbean islands like Trinidad and Tobago, St. Kitts and Nevis and Antigua and Barbuda, with very high IR levels (more than 4 times bigger than that of Brazil in the case of Trinidad and Tobago) still rank high using the AII but now show intensity values smaller than those of Brazil. A second group of countries, with AII values between 0.5 and 0.25 of those of Brazil includes Argentina, Uruguay, Chile, Mexico, Bolivia, Costa Rica and Colombia. Caribbean countries, Suriname and Barbados, are at the lower bound of this group. Countries with low AII (below 0.25) are Belize, Jamaica, Nicaragua, Peru, St. Vincent and the Granadines and Panama. Finally, with very low levels of R&D intensity as measured by the AII (less than 0.15) we find Paraguay, Venezuela, Dominican Republic, Ecuador, Honduras, El Salvador and Guatemala.

Figure 4.1—The ASTI Intensity index (AII) and the R&D Intensity ratio (IR) for different countries and regions relative to USA values (average 2001-2011).

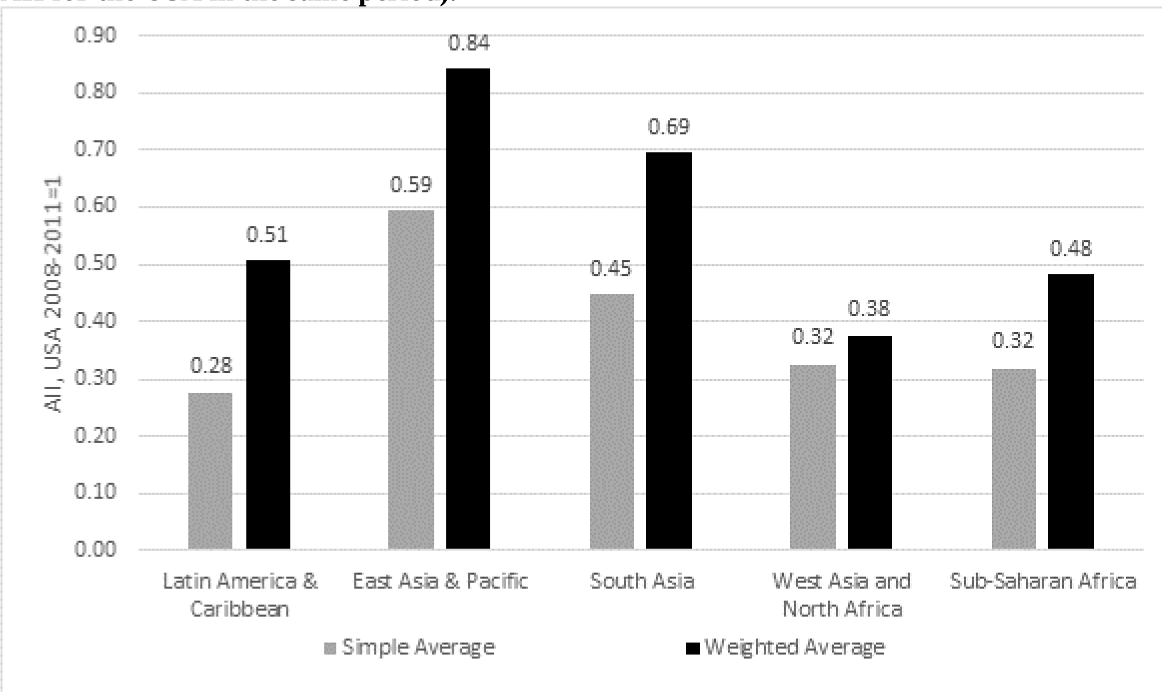


Source: Elaborated by authors.
Note: ROW=Rest of the World includes high income and developing countries. Coordinates for the USA are (1,1).Country codes are as follows: ARG= Argentina, ATG= Antigua and Barbuda, BLZ= Belize, BOL= Bolivia, BRA= Brazil, BRB=Barbados, CHL= Chile, COL= Colombia, CRI= Costa Rica, DMA= Dominica, DOM= Dominican Rep., ECU= Ecuador, GRD= Grenada, GTM= Guatemala, HND= Honduras, JAM= Jamaica, KNA= St. Kitts and Nevis, LCA= St. Lucia, MEX= Mexico, NIC= Nicaragua, PAN= Panama, PER= Peru, PRY= Paraguay, SLV= El Salvador, SUR= Suriname, TTO= Trinidad and Tobago, URY= Uruguay, VCT= St. Vincent and the Granadines, VEN=Venezuela.

Figure 4.2 compares AII average values of LAC for the period 2008-2012 with those of other developing regions. Simple averages in Figure 4.2 are calculated using the same weight for every country, so AII values reflect the average country performance in each region. The weighted average in the same figure uses AgGDP as the weight to calculate the averages, so it is a better measure of the AII of each region, showing the average AII of those countries producing most of agricultural output.

A first and surprising conclusion is that R&D intensity in LAC is way below of that in Asia and at a similar level of AII in SSA, given income, the size of the economy and of the agricultural sector, output diversification and potential of spillovers. Looking at the weighted average, intensity in LAC is only half of that of the USA compared to 84 and 70 percent in EAP and SA respectively, and it is almost at the same level of AII in SSA (48 percent). Given that Brazil, the largest economy in the region shows AII levels equivalent to those of USA, the explanation for the lower value obtained by LAC lies on the other major agricultural producers in the region (Argentina, Mexico and Colombia). On the other hand, values of the simple average of AII in Figure 4.2 show that LAC, with an AII value of 0.28, is the region with the lowest R&D intensity among all regions. This value is close to that of SSA and WANA (0.32) but below AII in SA (0.45) and half the value of AII in EAP (0.59). In other words, according to the AII, the average LAC country invests less in R&D than the average country in other regions.

Figure 4.2—Average AII values for developing regions, 2008-2012 (relative to the average value of AII for the USA in the same period).

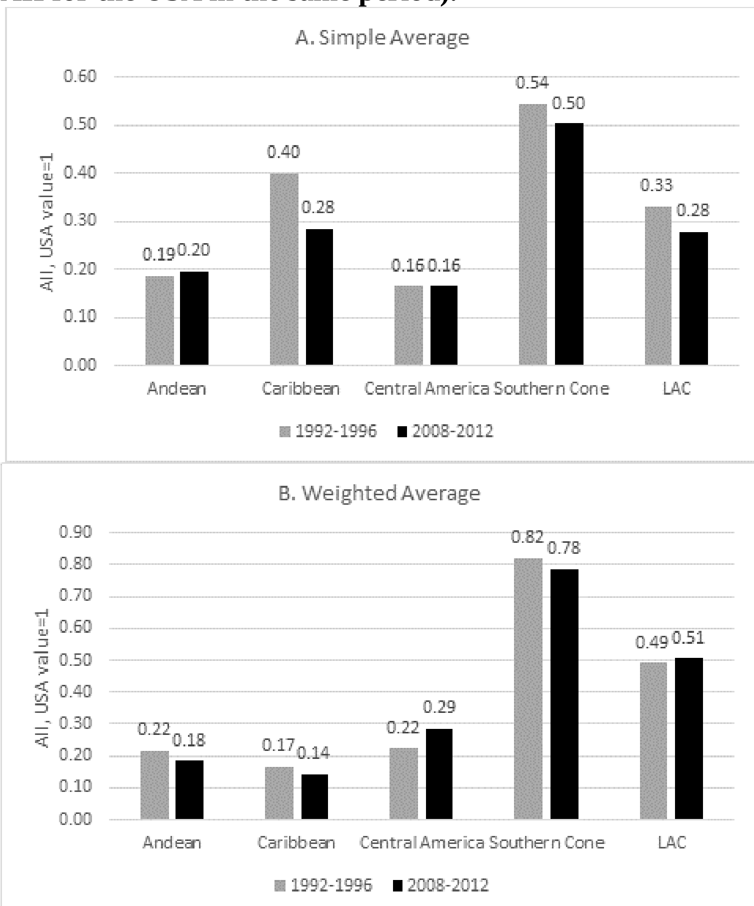


Source: Elaborated by authors.
Notes: Weighted averages use AgGDP as weight, mostly reflecting AII largest producers in each region.

Figure 4.3 presents average values of the AII by subregion in LAC. By comparing the two averages we obtain a good picture of R&D levels and changes in the region. Notice first that countries in the Southern Cone show AII levels very similar to those of EAP and SA, that is, high intensity levels compared to other regions. Notice also that this is true when we compare both the simple and the weighted averages with their equivalents in other regions. We conclude from this comparison that the low intensity in LAC is the result of low AII values in other regions than the Southern Cone. For example, Central America including Mexico shows weighted AII averages of only 0.29 in 2008-2012 compared to 0.78 in the Southern Cone. Levels of other regions are even lower: 0.18 and 0.14 for Andean and Caribbean countries in 2008-2012. The contrast between the simple and weighted averages in the case of the Caribbean (for example 0.40 compared to 0.17 in 1992-1996) results from the effect of a few countries with relatively high AII values in the simple average in Figure 4.3B.

Figure 4.3 also shows that intensity in the average LAC country decreased from 0.33 to 0.28 between 1992-1996 and 2008-2012 (Figure 4.3A). Average intensity in the different subregions also decreased, with the only exception of the Andean subregion. Looking at weighted averages we observe a small increase in intensity, which is mostly explained by a significant increase in Mexico’s AII, as reflected in Central America’s change in AII and the fact that AII in the Southern Cone decreased during the period. The observed decreased in intensity must be interpreted with caution. As discussed in the first section, R&D investment increased in recent years, but this happened during a period of high economic growth. This means that the observed decline in intensity is the result of the rate of growth in R&D investment falling slightly behind growth in GDP, AgGDP and income, the references against which R&D intensity is measured here.

Figure 4.3— Average AII values for subregions in LAC, 2008-2012 (relative to the average value of AII for the USA in the same period).



Source: Elaborated by author.

Notes: Weighted averages use AgGDP as weight, mostly reflecting AII largest producers in each region.

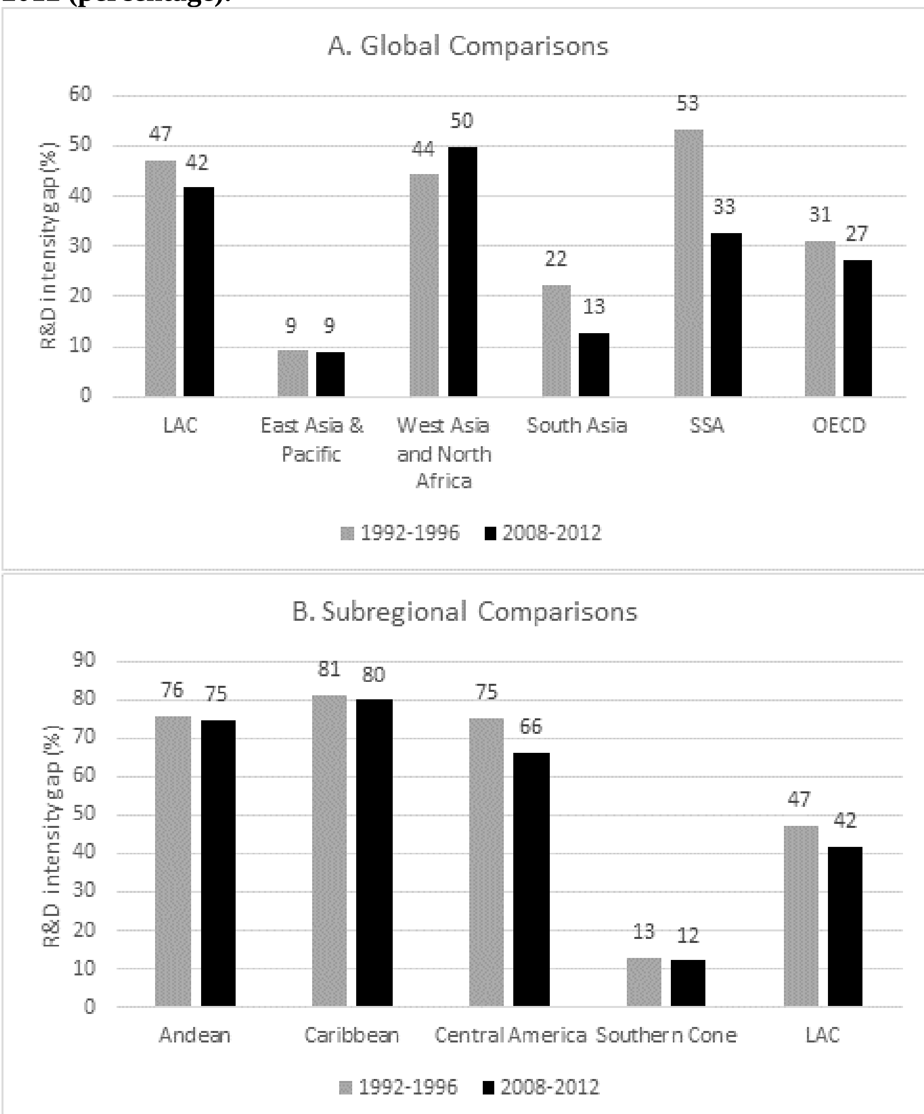
Results so far show a low R&D intensity in most LAC countries. What are the implications of this low R&D intensity in terms of increased R&D investment for the different subregions and countries in LAC? The rest of this section focuses on answering this question.

The R&D intensity gap is determined by comparing the multifactor intensity of each country against that of countries with the highest intensity and with the same mix of the five intensity ratios included in the multifactor index (Section 3 and Appendix A). These are the countries that define the "intensity frontier" for different mixes of the intensity ratios. Potential R&D intensity of a particular country refers here to the intensity of the reference countries (countries at the intensity "frontier") against which the particular country is compared.

Figure 4.4A compares R&D intensity gaps in developing regions, while Figure 4.4B shows the gap for subregions in LAC. According to results in Figure 4.4A, SSA was the developing region with the highest intensity gap in the early 1990s, followed closely by WANA and LAC. Twenty years later, SSA has substantially reduced its gap from 53 to 33 percent, while the gap in LAC decreased only from 47 to 42 percent. The intensity gap in EAP is very low (9 percent) and has remained at the same level during the period while SA reduced its gap almost by half in percentage points from 22 to 13 percent. OECD countries show intermediate values between those in LAC and Asia.

Figure 4.4B reinforces the conclusions derived from the analysis of AII values in the region. There is a very large subregional gap in LAC, with Southern Cone countries showing intensity gaps similar to those of EAP and SA, and other subregions reaching gaps of 75 percent or more. The only exception is Central America, where the intensity gap decreased from 75 to 66 percent between 1992-1996 and 2008-2012 as the result of R&D intensity growth in Mexico, but it is still very high compared to other regions. If we don't include the countries with the most advanced R&D systems in the Southern Cone, LAC countries show the highest R&D intensity gap among all regions globally.

Figure 4.4—R&D intensity gap measured as the difference between potential R&D investment and actual R&D investment relative to potential investment, weighted averages 1992-1996 and 2008-2012 (percentage).



Source: Elaborated by author.
Note: Averages are calculated using AgGDP as weights.

Results using the AII index show that LAC is the region with the highest R&D intensity gap. How much R&D investment is needed to close this gap? We answer this question in Table 4.1, showing the value of the IR and R&D expenditure in 2012, the target values of the IR that each country needs to reach to close the gap and the investment needed to reach this target. Target IR values are derived from the calculation of the AII as discussed in Section 3. Notice how target IR vary by country and region. The small economies of the Caribbean show the highest IRs at present and the highest targets. On average, Caribbean countries need to increase average IR from 1.98 to 4.5 percent to close the intensity gap. However, the subregion represents only 6 percent of the regional intensity gap, and most of the investment should be allocated to Dominican Republic and Jamaica. Andean and Central American countries show similar present and target IR averages. These regions will need to increase the IR roughly from 0.5 to 2.0 percent to close the intensity gap. The two subregions together represent more than 80 percent of the total regional gap. Almost 30 percentage points of this gap correspond to Mexico, a similar value than the total for Colombia, Venezuela and Peru.

How much does this gap represent in value? In 2012 the region was investing almost $5 billion in 2011 PPP. The gap represents $3.6 billion, for the whole region. Of these total, $1 billion corresponds to Mexico, $0.6 billion to the rest of Central America, $1,4 billion to the Andean countries, $0.5 billion to the Southern Cone, and $0.2 billion to the Caribbean. It is important to keep in mind that these are not recommendations or economically optimal levels of investment. These are simple measures of investment intensity and the target values result from the comparison of investment levels of other countries with similar characteristics. More information is needed to determine optimal levels of investment and to understand why intensity is relatively low in LAC compared to other developing regions.

Table 4.1—The investment gap and R&D investment needed to close the gap in millions of dollars, 2012.

Subregion	Country	Intensity Ratio (%) Actual	Intensity Ratio (%) Potential	R&D (mill. 2005 PPP$) Actual	R&D (mill. 2005 PPP$) Potential	R&D (mill. 2005 PPP$) Gap	Share of the gap (%)
Andean	Bolivia	0.93	1.57	51	102	52	1.4
	Colombia	0.79	2.19	240	613	373	10.2
	Ecuador	0.18	1.46	26	212	186	5.1
	Peru	0.35	1.62	69	396	327	9.0
	Venezuela	0.45	3.28	119	565	446	12.2
	Sub-total	**0.54**	**2.02**	**505**	**1,889**	**1,384**	**38.0**
Caribbean	Antigua and Barbuda	2.98	4.64	1	2	1	0.0
	Barbados	2.42	7.39	1	4	3	0.1
	Belize	0.66	1.93	2	8	6	0.2
	Dominica	0.18	1.54	0	2	2	0.1
	Dominican Rep.	0.30	2.17	20	157	137	3.8
	Grenada	0.71	3.46	0	2	2	0.1
	Jamaica	0.89	3.46	12	54	42	1.1
	St Kitts and Nevis	5.13	6.80	1	1	0	0.0
	St Lucia	0.63	8.16	0	2	2	0.1
	St Vincent and the Gren.	1.07	3.42	1	3	2	0.1
	Suriname	1.02	2.91	7	25	18	0.5
	Trinidad and Tobago	7.82	8.11	18	18	0	0.0
	Sub-total	**1.98**	**4.50**	**64**	**279**	**215**	**5.9**
Central America	Costa Rica	1.06	2.75	37	114	77	2.1
	El Salvador	0.13	1.70	7	95	88	2.4
	Guatemala	0.14	1.76	16	176	160	4.4
	Honduras	0.17	1.47	8	77	69	1.9
	Mexico	1.05	2.45	686	1,755	1,069	29.3
	Nicaragua	0.41	1.43	17	66	49	1.3
	Panama	0.74	3.67	15	94	79	2.2
	Sub-total	**0.53**	**2.18**	**786**	**2,377**	**1,591**	**43.6**
Southern Cone	Argentina	1.29	1.66	670	833	163	4.5
	Brazil	1.82	1.82	2,646	2,646	0	0.0
	Chile	1.65	2.97	192	375	183	5.0
	Paraguay	0.26	1.27	28	103	75	2.1
	Uruguay	1.40	1.86	69	103	35	1.0
	Sub-total	**1.28**	**1.92**	**3,605**	**4,061**	**456**	**12.5**
	LAC	**1.08**	**2.95**	**4,960**	**8,606**	**3,646**	**100.0**

Source: Elaborated by authors

Note: Sub-totals and LAC value of the IR are simple averages of country values

5. CONCLUSIONS

This paper uses a new measure to determine agricultural research intensity in LAC, compares country efforts in R&D and identifies the intensity gap at the regional and country level. Results show that despite rapid growth in R&D investment after 2004, the region shows low levels of intensity and the largest R&D intensity gap when compared to other regions in a sample of 100 countries. Results also show large differences between regions. With high R&D intensity and a small intensity gap, the Southern Cone (Brazil, Argentina, Chile, Uruguay and Paraguay) is among the regions showing the highest levels of research intensity globally. Low levels of R&D intensity in the region are explained by very low intensities in Central American and Andean countries. Mexico's R&D intensity is relatively low and because of the size of its agricultural sector, explains a significant share of the regional intensity gap. Results also show that the intensity gap represents almost 75 percent of total R&D investment in 2012 and that the region will need to increase investment from $5 to $8.5 billion 2011 PPP to close this gap. The countries that contribute the most to the gap are Mexico (29 percent), Venezuela (12 percent), Colombia (10 percent), Peru (9 percent), Ecuador, Chile and Argentina (5 percent), and Guatemala and Dominican Republic (4 percent). These results should be interpreted with caution. The AII provides a measure of R&D intensity suitable for country comparisons allowing also to derive investment potential or targets from the comparison of investment levels of other countries with similar characteristics. However, these are not recommendations or economically optimal levels of investment. More information and analysis will be needed to understand why intensity is relatively low in LAC compared to other developing regions.

APPENDIX A: THE INTENSITY INDEX

Consider a set of countries that define the space of R&D investment values for different levels of GDP, AgGDP, income per capita (y), DI and SP. This set can be defined as in the case of a technology for a given production process, as follows:

$$T = \{z: (z, Y)\ z \text{ can produce } Y\} \tag{A.1}$$

where z is a vector of variables associated to R&D investment levels (*GDP, AgGDP, y, DI, SP*) and Y is R&D investment. The production technology is assumed to satisfy the usual axioms, such as convexity and strong disposability. If Y is fixed, then the levels of the different variables to obtain input requirement set is:

$$L(Y) = \{z: (z, Y) \in T\} \tag{A.2}$$

This input set shows all possible combinations of inputs belonging to T (z,Y) that can produce Y. Rather than working with absolute values of Y and z, the problem is defined in terms of the inverse of individual intensity indices, with the input set representing in this case all feasible combinations of GDP, AgGDP, *y,* DI *and* SP per unit of R&D invested, where $x_n = X_n/Y$.

$$L(1) = \{x: (x, 1) \in T_1\} \tag{A.3}$$

L(1) is the set of all observed input combinations required to produce one unit of output (R&D). The lower bound of this set is what we call the benchmark isoquant (the *ABC* line in Figure 3.1). These are the minimum observed input combinations required to achieve one unit of output. We can calculate the distance of each input vector x to the benchmark isoquant using Shephard's distance function (Shephard 1970) as in Whittaker et al. (2015).

$$D(1, x_k) = sup\left\{\theta: \frac{x_k}{\theta} \in L(1)\right\} \tag{A.4}$$

where θ is a positive scalar defining the proportional reduction that is needed to reduce the input vector to the benchmark curve, and x is the vector of inputs of country k $(k= 1,....,K)$. For example, in the case of country D in Figure 3.1, $\theta= OD/OB$. The distance function, D(1,x), is non-decreasing, positively linearly homogeneous and concave in x. The value of the distance will be equal to one or bigger than one if the input vector, x, is an element of the feasible input set L*(1)*: $D(1,x)\geq 1$ *if* $x \in L(1)$.
The distance function is used (assuming homotheticity) to build a multifactor R&D intensity measure that compares two input vectors. As in Whittaker et al. (2015) and following Caves et al. (1982), the following expression is obtained:

$$AII(x_i, x_j) = \frac{D(1,x_i)}{D(1,x_j)} \tag{A.5}$$

where x_i and x_j are two input vectors representing countries i and j to be compared. The distances in equation (A.5) are calculated using linear programming and the approach used here defines the "technology" space using observations of all available countries and years. This means that all countries are compared to a unique isoquant, or equivalently, the benchmark isoquant is the same for all countries and years and represents the highest observed R&D intensity for the set of analyzed countries in all periods. The intensity index for a particular country i in period t_o is calculated using the following linear program (LP):

$$D^{-1}_{(1,x_{i,to})} = \min_{\theta,\lambda} \theta$$

$$\text{s.t. } \sum_{k=1}^{K}\sum_{t=1}^{T}\lambda_{k,t}x_{n,k,t} \leq \theta x_{n,i,to} \text{ with n= 1,2,…,N} \quad \text{(A.6)}$$

$$\sum_{k=1}^{K}\sum_{t=1}^{T}\lambda_{k,t} = 1$$

$$\lambda_{k,t} \geq 0 \text{ t=1,…,T and k= 1,..,K}$$

The $D^{-1}_{(1,x_{i,to})}$ is the inverse of Shephard's distance, has an upper limit of one, representing the highest R&D intensity while values close to zero represent low intensity. The index calculated in this way compares the intensity of country *i* with the intensity of a country with the same proportion of GDP, AgGDP, *y, DI* and *SP* in the benchmark isoquant. The final AII measure is represented as an index that compares the inverse of the Shephard distance obtained from LP problem (3.7) relative to the distance of a reference country and year (k*,t*): $AII(x_{i,to}\ x_{k*,t*}) = D^{-1}(x_i,t_o)/D^{-1}(x_{k*,t*})$ where $D^{-1}(x_i,t_o)$ is obtained from linear problem (A.6) and $D^{-1}(x_{k*},t_*)$ is calculated using the same problem (3.7) but replacing $x_{n,I,to}$ with $x_{n,k*,t*}$, that is, the input vector of the reference country (k*) in the reference year (t*).

The AII allows the comparison of intensity values of different countries in different periods as it satisfies a number of desirable properties that an index formulation should possess according to the axiomatic approach to index numbers (for example, Diewert 1987). The properties used to evaluate alternate indexes with the axiomatic approach are: proportionality, time reversibility, transitivity and dimensionality (Diewert and Lawrence 1999). The proportionality condition implies that if the index value that results from comparing $x_{i,to}$ and $x_{k*,t*}$ is $AII(x_{i,to}\ x_{k*,t*})$, then the index comparing ($\alpha\ x_{ito}$) to x_{k*t*} is $AII(\alpha x_{i,to}\ x_{k*,t*}) = \alpha AII(x_i,t_o\ x_{k*,t*})$, that is, the index obtained is a proportional increase to the overall index when an increase occurs to one of the input vectors.

Reversibility guarantees that $AII(x_{i,to}\ x_{k*,t*}) = AII(x_{i,to})/\ AII(x_{k*,t*})$, then $AII(x_{i,to}\ x_{k*,t*}) = AII(x_{k*,t*}\ x_{i,to}) = AII(x_{k*,t*})/AII(x_{i,to}) = 1/AII(x_{i,to}\ x_{k*,t*})$. This means that if the quantity for one country and time period is exchanged with another, the resulting index is the reciprocal of the original index. The transitivity property means that whether a fixed base or a chain of observations is used to calculate the index, the result will be the same. For example, the difference in intensity for the same country between two periods will be equivalent to: $AII(x_{i,t1}\ x_{k*,t*}) \times AII(x_{i,t2}\ x_{k*,t*}) = AII(x_{i,t1}\ x_{i,t2})$. Finally, dimensionality means that when changing the units of measurement of each input by the same positive number α, the index remains unchanged: $AII(\alpha x_{i,to}\ \alpha x_{k*,t*}) = AII(x_i,t_o\ x_{k*,t*})$.

The same framework is used to determine the intensity gap for an individual country, but rather than comparing all observations to a unique benchmark isoquant, we calculate distances for a particular period defining benchmark isoquants by year. The intensity gap (IG) expresses the increase in R&D investment (in percentage of present annual investment) that is needed to close the gap between actual and potential intensity, with potential intensity measured annually.

$$IG(x_{i,to}) = 100 * (1 - D^{-1}_{(1,x_{i,to})}) \quad \text{(A.7)}$$

For this particular analysis, $D^{-1}_{(1,x_{i,to})}$ is calculated as:

$$D^{-1}_{(1,x_{i,to})} = \min_{\gamma,\delta} \gamma$$

$$\text{s.t. } \sum_{k=1}^{K}\delta_{k,to}x_{n,k,to} \leq \gamma x_{n,i,to} \quad \text{with n= 1,2,…,N} \quad \text{(A.8)}$$

$$\sum_{k=1}^{K}\delta_{k,to} = 1$$

$$\delta_{k,to} \geq 0 \text{ k= 1,..,K}$$

Note that in the LP problem (3.9) the comparison is between $x_{i,to}$ and other countries vectors but only for year t_o instead of including observations of all years as in problem (A.6). The decision variables (γ and δ) in problem (3.9), are different from those in 3.7 (θ and λ) to highlight the fact that A.6) and (A.8) are different problems leading to different solutions. Results from (A.6) determine the distance to the maximum potential intensity, the intensity gap, for each country in every year and trace the evolution of this gap. The solution of problem (A.8) also provides the potential intensity for each country, so changes in the intensity gap for a particular country can be decomposed into intensity changes in that particular country and changes in the potential intensity which means that countries with the highest intensities (defining the benchmark isoquant in each year) are reducing R&D investment relative to changes in *GDP*, *AgGDP*, y, DI and *SP*.

As mentioned before, problem (A.6) gives a measure of the distance of vector $x_{i,n,to}$ to the frontier, that is, a measure of country *i*'s total input per unit of R&D investment relative to that of the country with the lowest aggregated input per unit of R&D investment among those countries with the same input mix than country *i*. However, it is not clear from problem (A.6), how the different intensity components are aggregated to obtain the measure of total input that allows this comparison. To better understand this, it is convenient to present the dual to problem (A.6). The dual LP problem (A.9) generates the same result than problem (A.6) but better shows the intuition of the method employed to build the AII. The dual problem is as follows[5]:

$$\begin{aligned} &\min_{u,v} \Theta_i = \textstyle\sum_{n=1}^{N} v_{i,n} x_{i,n} \\ &\text{s.t.}\ \ \textstyle\sum_{n=1}^{N} v_{j,n} x_{j,n} \geq 1 \ \ j = 1,\dots,K \\ &v \geq 0 \end{aligned} \qquad \text{(A.9)}$$

The objective function in problem (A.9) is the weighted sum of the inverse of the different intensity ratios, where N=5 in the particular case of AII as defined here. Problem (A.9) solves to find the weights or shadow prices $v_{i,n}$ for all inputs in country *i* that minimize expression Θ. We define the shadow price of input *n* ($\nu_{i,n}$) as the achievable rate of increase in the objective function per unit increase in input *n*. Formally stated, the shadow price of input *n* is defined as:

$$v_{i,n} = \frac{\partial \Theta^*}{\partial v_{i,n}} \qquad \text{(A.10)}$$

where Θ^* denotes the optimal value of the objective function, provided only increases in $\nu_{i,n}$ are allowed. Translating this to the particular problem in this study, the shadow price gives a measure of how much country *i* can increase output (R&D) by increasing one unit of input *n* (GDP, AgGDP, income, HI or SP). Equivalently, the shadow price of decision unit i is a measure of how much *i* is willing to pay for an extra unit of an input *n*. The higher the shadow price, the more constraining the input is, the bigger the increase in intensity with a change of this input and the more *i* is willing to pay for this input.

[5] This particular form of the dual problem has infinite number of solutions so to solve this problem we need to impose the constraint that $v'x_i=1$ and modified the problem accordingly.

APPENDIX B: SIMILARITY AND DIVERSIFICATION

To measure "similarity" between countries a linear country-to-country spillover relationship is assumed, and define a spillover coefficient ω_{ij} as the geometric mean of an output spillover coefficient ω^{o}_{ij} and an input spillover coefficient ω^{f}_{ij}. This coefficient is a weight that measures the potential contribution of a unit of the knowledge stock created in country *j* to the knowledge stock used in country *i*.

$$\omega_{ij} = \left(\omega_{ij}^{q} \times \omega_{ij}^{f}\right)^{1/2} = \left(\frac{\sum_{m=1}^{M} q_{mi} q_{mj}}{\left(\sum_{m}^{M} q_{mi}^{2}\right)^{1/2}\left(\sum_{m}^{M} q_{mj}^{2}\right)^{1/2}} \times \frac{\sum_{n=1}^{N} f_{ni} f_{nj}}{\left(\sum_{n}^{N} f_{ni}^{2}\right)^{1/2}\left(\sum_{n}^{N} f_{nj}^{2}\right)^{1/2}}\right)^{\frac{1}{2}} \quad \text{(B.1)}$$

where q_{mi} represents output share of output *m* in country's *i* agriculture, and f_{ni} is the amount of input *n* used per worker in country *i*. Calculated in this way, ω_{ij} can be interpreted as a multivariate correlation coefficient which varies between zero and unity: a high value indicates high similarity in output and in the intensity of the use of different inputs in the two countries (Eberhardt and Teal 2013). Potential spillovers for country *i* result from the product of ω_{ij} and the knowledge stock in country *j*, approximated using the perpetual inventory method (PIM) assuming a ten-year lag between the investment period and the period in which this investment has an effect on productivity, and a decay rate of the knowledge stock of 15 percent.[6]

As a proxy for diversification in agriculture, the Herfindahl-Hirschman Index (HII), which is frequently used to measure industrial concentration and corporate diversification (Jacquemin and Berry. 1979), is adapted to define a diversification index taking values between 0 and 1 (with 0 being the highest specialization):

$$DI_i = 1 - \sum_{m=1}^{M} q_{im}^{2} \quad \text{(B.2)}$$

where q_{im} is again the share of output m in country *i*'s agricultural production.

[6] See discussion in Esposti and Pierani (2003) pg. 45.

APPENDIX C: COUNTRIES AND REGIONS

The sample of countries used in this study includes a total of 88 countries in four groups. The complete list of countries is shown in Table C.1.

Table C.1—Average values of variables used in the analysis by country and region relative to USA values, 2001-2012 (USA=100).

Country	R&D	AgGDP	GDP	Income	DI	SP
LAC						
Antigua and Barbuda	0.0	0.0	0.0	43.8	52.4	73.2
Argentina	8.8	28.2	4.6	34.1	66.0	103.0
Barbados	0.0	0.0	0.0	30.9	35.3	89.5
Belize	0.0	0.2	0.0	15.8	64.0	57.9
Bolivia	0.9	3.2	0.3	10.1	116.3	125.1
Brazil	37.0	70.7	16.9	26.4	96.4	102.8
Chile	3.1	6.7	2.0	36.5	120.7	104.7
Colombia	3.7	19.0	3.0	20.2	111.6	121.0
Costa Rica	0.6	2.1	0.3	23.5	79.4	68.4
Dominica	0.0	0.0	0.0	19.1	108.2	45.2
Dominican Rep.	0.4	3.5	0.6	19.9	129.3	106.2
Ecuador	0.4	7.4	0.9	18.0	59.3	91.4
El Salvador	0.1	2.7	0.3	14.7	101.0	101.8
Grenada	0.0	0.0	0.0	22.5	148.7	53.6
Guatemala	0.2	6.4	0.6	13.2	125.5	81.9
Honduras	0.1	2.2	0.2	8.3	112.0	103.0
Jamaica	0.2	0.7	0.2	17.6	91.3	93.3
Mexico	11.1	34.3	11.7	31.1	148.6	134.8
Nicaragua	0.3	2.1	0.1	7.9	85.3	114.4
Panama	0.2	1.4	0.3	27.3	77.8	109.8
Paraguay	0.3	4.2	0.3	13.3	57.7	83.5
Peru	1.2	10.2	1.6	17.2	171.2	129.6
St Kitts and Nevis	0.0	0.0	0.0	42.3	43.3	42.6
St Lucia	0.0	0.0	0.0	21.3	43.5	30.8
St Vinc. & Gren.	0.0	0.0	0.0	19.3	33.3	37.1
Suriname	0.1	0.3	0.0	26.3	32.8	73.6
Trinidad and Tobago.	0.3	0.1	0.2	55.2	28.1	84.6
Uruguay	1.1	2.5	0.3	29.4	44.1	106.0
Venezuela	1.0	11.6	2.9	32.0	95.4	129.5

Table C.1 (continued)—Average values of variables used in the analysis by country and region relative to USA values, 2001-2012 (USA=100)

Country	R&D	AgGDP	GDP	Income	DI	SP
High Income	0.0	0.0	0.0	0.0	0.0	0.0
Australia	14.9	13.4	5.6	80.6	81.9	106.2
Austria	2.7	2.9	2.4	85.4	83.1	126.6
Belgium	4.1	2.2	2.9	80.9	78.8	124.7
Canada	13.2	11.9	9.0	82.2	97.6	112.6
Denmark	3.0	2.0	1.6	88.5	39.0	95.0
Finland	2.8	2.9	1.4	79.2	55.4	113.2
France	26.8	23.7	15.8	74.5	105.9	122.4
Germany	20.4	15.1	22.0	80.6	72.5	114.2
Greece	1.0	7.2	2.2	59.6	122.5	83.5
Ireland	1.9	1.4	1.3	93.3	35.1	109.1
Italy	11.0	26.5	14.5	74.6	148.7	113.5
Japan	62.6	32.4	29.4	69.0	103.7	113.8
Korea, Rep.	14.0	21.2	8.9	55.1	115.0	121.1
Netherlands	9.8	7.8	5.0	91.3	60.6	118.5
Norway	3.9	2.4	2.0	128.2	52.9	114.5
Portugal	2.9	3.8	1.9	54.8	120.3	127.4
Russian Federation	8.0	74.0	20.1	41.9	92.0	119.9
Spain	12.5	23.6	10.0	67.3	128.5	112.1
Sweden	2.7	3.2	2.6	84.4	63.3	114.4
Switzerland	1.0	2.0	2.7	106.6	39.3	107.8
United Kingdom	8.0	8.9	15.1	74.0	78.1	121.7
United States	100.0	100.0	100.0	100.0	100.0	100.0
WANA	0.0	0.0	0.0	0.0	0.0	0.0
Egypt, Arab Rep.	7.9	56.7	4.7	18.1	188.7	110.5
Jordan	0.6	0.9	0.4	19.6	92.4	98.3
Morocco	1.6	14.0	1.2	12.0	202.1	118.4
Tunisia	1.2	5.0	0.7	19.1	123.8	99.2
Turkey	6.4	55.1	7.3	31.3	195.9	110.3
SA	0.0	0.0	0.0	0.0	0.0	0.0
Bangladesh	3.4	34.0	2.1	4.3	22.2	58.9
India	45.1	447.6	28.9	7.3	137.1	91.9
Nepal	0.7	9.4	0.3	3.7	89.7	88.7
Pakistan	9.0	87.4	4.4	8.3	95.9	72.4
Sri Lanka	2.0	10.1	1.0	14.9	56.3	78.5

Table C.1 (continued)—Average values of variables used in the analysis by country and region relative to USA values, 2001-2012 (USA=100)

Country	R&D	AgGDP	GDP	Income	DI	SP
SSA	0.0	0.0	0.0	0.0	0.0	0.0
Benin	0.4	2.1	0.1	3.5	69.2	37.4
Botswana	0.4	0.3	0.2	24.9	41.1	89.3
Burkina Faso	0.5	3.7	0.1	2.6	119.5	71.1
Burundi	0.2	1.4	0.0	1.4	44.8	43.7
Congo, Rep.	0.1	0.5	0.1	10.5	64.9	41.0
Cote d'Ivoire	1.0	7.5	0.3	5.6	73.7	44.8
Ethiopia	1.6	18.0	0.5	1.8	156.4	103.4
Gabon	0.0	0.7	0.2	34.4	72.4	36.7
Gambia, The	0.1	0.4	0.0	3.2	46.1	39.5
Ghana	2.1	11.4	0.4	5.7	79.3	32.4
Guinea	0.1	1.6	0.1	2.4	118.8	86.8
Kenya	4.3	12.9	0.6	4.8	117.8	112.2
Madagascar	0.3	4.2	0.2	2.9	70.4	95.8
Malawi	0.4	2.4	0.1	1.9	101.1	71.6
Mali	0.8	4.1	0.1	3.0	142.2	83.7
Mauritania	0.3	1.5	0.1	6.4	89.5	52.8
Mozambique	0.3	2.7	0.1	1.6	83.2	57.0
Namibia	0.8	0.9	0.1	15.5	45.0	83.7
Niger	0.1	2.6	0.1	1.6	90.5	65.8
Nigeria	11.8	117.5	4.3	8.7	102.4	39.9
Rwanda	0.4	2.3	0.1	2.3	63.7	48.1
Senegal	0.5	2.1	0.2	4.3	107.3	71.7
Sierra Leone	0.1	2.0	0.0	2.5	62.7	70.0
South Africa	5.5	8.9	3.8	23.3	114.3	128.9
Sudan	1.4	20.9	0.8	7.3	121.9	87.8
Tanzania	1.5	13.8	0.5	3.8	175.0	100.3
Togo	0.2	1.6	0.0	2.5	96.1	51.6
Uganda	1.8	5.9	0.3	2.8	66.2	56.9
Zambia	0.3	2.6	0.2	5.6	104.7	106.6
Zimbabwe	0.3	2.1	0.2	3.4	117.5	99.9

Table C.1 (continued)—Average values of variables used in the analysis by country and region relative to USA values, 2001-2012 (USA=100)

Country	R&D	AgGDP	GDP	Income	DI	SP
EAP	0.0	0.0	0.0	0.0	0.0	0.0
Cambodia	0.4	5.7	0.2	4.4	24.3	65.6
China	95.7	601.7	63.3	14.4	191.2	109.8
Indonesia	25.9	147.0	11.7	15.1	71.3	71.6
Lao PDR	0.4	4.0	0.1	6.8	34.0	73.5
Malaysia	10.7	29.5	3.5	39.3	30.3	44.7
New Zealand	2.7	4.7	0.9	64.9	32.0	91.0
Philippines	5.5	34.4	3.0	10.3	92.6	76.8
Thailand	7.4	47.4	5.4	24.5	73.1	83.3
Vietnam	2.1	37.9	2.2	7.8	46.2	80.1

Source: Elaborated by authors using ASTI(2016), FAO (2015) and World Bank(2015) data.

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