Research Futures

Projecting Agricultural R&D Potentials for Latin America and the Caribbean

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Research Futures: Projecting Agricultural R&D Potentials for Latin America and the Caribbean

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Foreword

This volume offers substantive clarification of the proper roles for public agricultural research and development (R&D) throughout Latin America and the Caribbean (LAC) and introduces an analytical framework for assessing cross-country collective action in funding and carrying out research. To inform research policy decisions, the book provides a wealth of newly digested information about trends in agricultural production, productivity, consumption, and trade for the region, placing those trends in a comparative international context. It also provides new information about the spatial patterns of agricultural production and productivity in LAC—especially critical information for making informed research priority decisions given the inherent agroecological specificity of many agricultural technologies.

A major contribution of this volume is the provision of a new agroecological framework for analyzing local and spillover consequences of agricultural R&D in economic terms. The spatial spillover of technologies has been an important aspect of agricultural advances in the past and is likely to be even more important in the future. This is especially so as the critical size and scale for doing some of the important parts of agricultural R&D continue to increase, and as liberalizing trade regimes and other regulatory, market, and technological changes affect the prospects for cross-country research spillovers. The reconciliation of national, regional, and international interests in funding and conducting agricultural R&D will be greatly enhanced by meaningful information on the incidence of the benefits from the research. The new, ex ante assessment methods applied here provide a structured sense of these local and spillover consequences in ways that illustrate the efficiency gains (or losses) of collectively conceived and funded (or at least harmonized) agricultural R&D among countries and regions within and beyond LAC.

Like all decisions to deploy public funds, politics plays a role in funding agricultural R&D. By improving our understanding of the potential incidence of the benefits of research, and better matching those benefits to the costs involved, we provide a basis for movement toward socially optimal amounts and mixes of research funding and effort. The result will be sizable and sustained long-term economic gains for LAC and other world regions.

Nicolás Mateo
Executive Director, FONTAGRO

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Philip Pardey, Stanley Wood, and Reed Hertford
Editors

Acronyms

AEZs	agroecological zones
AgGDP	agricultural gross domestic product
ASTI	Agricultural Science and Technology Indicators (an IFPRI initiative)
CACM	Central American Common Market
CAFTA	Central American Free Trade Agreement
CARICOM	Caribbean Community
CGIAR or CG	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical
CIF	cost, insurance, and freight
CIP	International Potato Center
Dream	Dynamic Research EvaluAtion for Management (model)
EDC	EROS Data Center
EROS	Earth Resources Observation and Science Center
FAO	Food and Agriculture Organization of the United Nations
FCC	Fertility Capability Classification
FLAR	Fondo Latinoamericano de Arroz de Riego (Latin American Fund for Irrigated Rice]
FOB	free on board
FONTAGRO	Regional Fund for Agricultural Technology
Fte	full-time equivalent
GATT	General Agreement on Tariffs and Trade
GDP	gross domestic product
GIS	geographic information systems
HYVs	high-yielding varieties
IADB	Inter-American Development Bank
IFDC	International Fertilizer Development Center
IIASA	International Institute for Applied Systems Analysis
IICA	Inter-American Institute for Cooperation on Agriculture
IFPRI	International Food Policy Research Institute
ILO	International Labor Organization
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade (IFPRI)
INESPRE	Instituto Nacional de Estabilización de Precios
LGP	length of growing period (variable)
MC	major climate (variable)
Mercosur	Southern Common Market (Latin America)
MFP	multi-factor productivity
MS	marginally suitable (classification)
NAFTA	North American Free Trade Agreement

NARS(s)	national agricultural research system(s)
NES	not otherwise stated
NPK	nitrogen, phosphorus, and potassium
NS	not suitable (classification)
OECD	Organisation for Economic Co-operation and Development
PFP	partial-factor productivity
PSEs	producer subsidy equivalents
R&D	research and development
ROW	rest of the world
S	suitable (classification)
SLCRs	seasonal land-cover regions
TFP	total-factor productivity
USGS	United States Geological Survey
VS	very suitable (classification)
WTO	World Trade Organization

Chapter 1

Introduction

Philip G. Pardey, Julian M. Alston, and Stanley Wood

Economists have long reported the growth-promoting effects of agricultural research and development (R&D) and the sizable social payoffs to sustained public investments in it.[1] But, as this volume makes clear, the economic evidence of the returns to research has failed to generate adequate public commitment to agricultural R&D throughout much of Latin America and the Caribbean (LAC). The widely described underinvestment phenomenon that appears to bedevil agricultural R&D worldwide is attributable to inadequate incentives for individual producers or firms to invest in R&D. For similar reasons, individual countries have inadequate incentives to invest in global public goods (see Alston and Pardey 2006 for a more complete exposition).

Innovators often face appropriability problems and hence fail to fully reap the rewards of their research, which gives rise to a mismatch between the costs and benefits of research. The appropriability problem confronts firms, industries, or countries that invest in R&D. Thus countries may invest less than the socially optimal amounts in R&D in the belief that they can "free-ride" on research conducted in other locales (thereby capturing some of the benefits of research without having to pay for them).

Agricultural research throughout LAC is in the midst of substantial but uneven change involving shifts in the public and private funding, conduct, and orientation of agricultural R&D (see Trigo et al. 2002; Chapter 6, this volume). This change also encompasses substantial regulatory and institutional shifts in the development and transfer of technologies used in food and agriculture (Josling, Roberts, and Orden 2004), including changes in the access to and use of know-how and technologies developed in other parts of the world. Some of these changes stem from a broad set of policy and institutional reforms that have spurred re-evaluation of the

1 See Alston et al. (2000) for a detailed review.

proper public role in agricultural R&D, along with the optimal amounts and forms of research funding. Some of the changes also derive from even more fundamental shifts in the pattern of food demand and supply chain linkages (Reardon and Berdegué 2002), as well as sectoral, macroeconomic, and trade policy reforms (Chapter 5, this volume) that directly affect food and agriculture and the research that serves these sectors. Overarching all of these changes—and with major consequences for LAC agriculture—is an increasing interconnectedness among countries in LAC and elsewhere in the world, most visibly manifest in regional trade agreements such as the North American Free Trade Agreement (NAFTA) that came into force in January 1994 and the Central American Free Trade Agreement (CAFTA) that was ratified by the United States in mid-2005. These changes in the context of agricultural R&D may have contributed to the underinvestment in LAC. Changes in domestic policies, especially policies dealing with trade in agricultural inputs and outputs (along with changes in the intellectual property incentives for agricultural R&D as reviewed by Wright et al. 2006), may add to uncertainty about appropriate roles for public agricultural R&D in the long run.

Perspectives on Research Priorities in Latin America and the Caribbean

Whether viewed from an agroecological, geopolitical, or economic perspective, any geographic region both constitutes a part of larger regions and comprises various subregions. The determination of responsibilities of different institutions—each owing allegiance to different geopolitical entities—is complicated by the mismatch between agroecological and geopolitical boundaries. Within a country, for instance, the distinction between provincial and national government responsibilities over water resources is complicated if catchments extend beyond provincial boundaries.

Such complications are especially pronounced in relation to agricultural R&D, the results of which may be widely applicable beyond the place where it is carried out, and which therefore may be of interest to, supported by, or carried out by, a range of multinational, national, and provincial governments and private organizations. A particular institution may conduct certain research activities that are strictly of local interest, some that are of global interest, and some that represent the range of possibilities in-between. Since the different organizations have different responsibilities and objectives, they also have different perspectives and hence may use different criteria for evaluating a given R&D project or investment. One implication of this is that relevant research impacts and priorities are assessed differently across organizations.

Implications may also exist regarding who should finance or carry out particular lines of research. Sometimes this issue is addressed based on economic efficiency: which geopolitical entity, for example, has the appropriate incentives to make the "right" research investment and is capable of minimizing the costs? Converse-

ly, what is the appropriate "division of labor" for funding and executing research among (a) national agricultural research systems (NARSs), (b) international research systems, including the international centers of the Consultative Group on International Agricultural Research (CGIAR or CG), and others, (c) private foundations and other private entities, and, (d) multinational regional groups of various sizes and configurations? In other words, what should be done by national governments or the CG system, what remains, and what types of regional organizations are required for the remaining elements to be done effectively and efficiently?

Research Spillovers

One way to structure thinking about these issues is in terms of spillovers. Clearly, research investments with entirely domestic (that is, national) consequences are a country's own business. Similarly, research investments with global ramifications should, in principle, be treated as global public goods conducted on a correspondingly global basis. But in the absence of a global government, such investments have more often been left to a small subset of the richer nations (for example, the U.S. and U.K. governments, in particular, have financed and conducted a disproportionately large share of the world's investments in so-called basic scientific, medical, and industrial research). Whether these investments have been based on a perception of national interest or some form of altruism, it seems likely that the absence of a global government has meant that some nations have acted as free-riders, and in such a setting under-investment from the global standpoint is to be expected.

Between these two somewhat stylized and extreme cases is the more relevant and typical case of research being conducted in one place, but yielding applicable results in a number of other, often closely neighboring, places. Soybean research is a good example. Within the United States, the results of soybean research conducted in any of the mid-western states (for example, Iowa) would likely be highly applicable in neighboring states (for example, Minnesota, Illinois, and Indiana, among others). As a consequence, every such state is likely to free ride to some extent on investments in soybean research by the other states and this leads to a collective under-investment in soybean research compared with what would be done if the investment were made on behalf of the U.S. mid-west as a whole. In other words, the individual U.S. state is not the economically efficient jurisdiction for soybean research.[2] In precisely the same manner, given cross-country spillovers among LAC countries, it is unlikely that a particular LAC country constitutes the efficient jurisdiction for funding and conducting commodity research.

The practical and policy implications of efficient jurisdictions for funding agricultural R&D extend well beyond the consequences of spillovers among U.S. states or LAC countries. For example, in addition to being concerned about these spillovers of benefits to neighboring states, mid-western farmers have also expressed concern about international spillovers. In particular, they were concerned that

2 See Alston (2002) for an elaboration of the notion of "efficient jurisdictions" in funding agricultural R&D.

improved soybean varieties and cultural practices developed in the United States would be adopted by their competitors, especially in Brazil and Argentina. To have such concern is appropriate since, in fact, U.S.–developed technology was adopted overseas. As a result, the U.S. competitive position was undermined such that U.S. producers received lower prices for their products and the U.S. benefits from the investment in R&D were reduced. While it is not in the U.S. producers' interest to have U.S.–developed soybean technology adopted in Brazil, it is in the interest of Brazil and the world as a whole (including U.S. consumers) to have the technology developed, and to have it adopted in Brazil as well as the United States. Some collective action by the governments of the affected nations is likely to be required if investment in soybean R&D, and adoption of the results, is to be optimized globally.

Should the U.S. government have introduced policies aimed at preventing the international spillovers of soybean technology? U.S. soybean producers might say so, but it is not even clear that U.S. soybean producers would have been better off under a U.S. soybean technology export embargo. First, such policies are almost impossible to enforce fully, and unenforceable policies are not usually a good idea. Second, technology spillovers run in both directions, and if other countries were to retaliate with corresponding policies, then a country that initiates a policy of barriers to trade in ideas might end up being worse off: the world as a whole would surely lose from a knowledge trade war. Third, it is difficult to predict the precise pattern of spillovers in advance, so optimizing a technology trade-restriction policy would be challenging. Fourth, it is hard to apportion "ownership" of ideas, even ex post. It ought to be remembered, for example, that soybeans originated in China and many varieties found their way to Brazil (and presumably elsewhere in Latin America) by way of improved material developed in the United States.

The states or nations that have a common interest in particular lines of research need not be close together, or even in the same hemisphere. What is important is agroecological similarity, not physical proximity. A good example is revealed by improvements in wheat varieties, in which the CGIAR played a major role. The semidwarf wheat varieties, which played an important role in the Green Revolution, may have been developed with a view to Mexico and (later) the Indian subcontinent, but they proved to be particularly well adapted to California and Australia.

The CG system's contribution to wheat variety improvements ought to be (and is) looked at differently by the Australian government (as a partial supporter of the CG system) compared with other donor governments (that may not have been beneficiaries or users of the new technology) and governments of other beneficiary countries (some of which were not financial supporters). An entirely different perspective might be taken by the CG system managers (or the donor community) whose objectives increasingly emphasize poverty alleviation. Similarly, institutions taking a regionally focused, multinational perspective would have a different mea-

sure of benefits and possibly different evaluation criteria and priorities.[3] In short, agricultural R&D undertaken in one place typically will have implications for other places, either through effects on prices and trade or because the technology itself can be adopted in other places. These technological and price spillover effects influence the appropriate institutional structure for getting the research funded and conducted efficiently from a global perspective. Since the technological research spillover potential is determined by agroecological similarity, it would seem to be natural to organize research on an agroecological basis, but this basis might be different for every project or program of research. As it happens, however, funding and conducting research is done on a geopolitical basis.

Geopolitical and agroecological boundaries don't match, and different geopolitical institutions have different constituencies and therefore different objectives. In principle, a solution might be to coordinate among geopolitical interests such that they could share in the costs and benefits of activities spilling across geopolitical boundaries. In practice, the costs of coordination can be very high, and in many instances these costs will exceed the benefits. A practical solution may be to ignore spillovers when they are incidental and spend resources on coordination and collaboration where the stakes are large, such as in the cases of soybeans and wheat, mentioned above. Even still, there may be multiple elements of the solution, with some types of the work still being done nationally and others being done by different multinational enterprises, each perhaps pursuing a different objective and a different agenda.

Volume Outline

Our primary objective in writing this volume is to inform national and cross-country collective action regarding agricultural R&D throughout Latin America and the Caribbean. To this end, we identify a set of fundamental forces shaping LAC agriculture and thus, its future. Some of these aspects lie beyond the reach of sectoral policies but can nonetheless influence those policy outcomes. Others are more amenable to the influence of investment and policy choices directly targeted to agriculture. As part of this assessment, we provide a quantitative retrospective of changes in LAC agriculture, emphasizing production, productivity and policy aspects, and agricultural R&D patterns. The location-specific nature of much agricultural R&D and

3 The Inter-Amercian Development Bank (IADB) and Regional Fund for Agricultural Technology (FONTAGRO) as funders of research, or the Inter-American Institute for Cooperation on Agriculture (IICA)–convened Procis, as a set of subregional organizations more directly involved in the conduct of agricultural R&D, are examples in this case. FONTAGRO is a consortium to promote strategic agricultural research of relevance for the LAC region with direct participation of the countries of the region in priority setting and funding of research projects (http://www.fontagro.org/). IICA is a specialized agency of the inter-American system, whose objective is to encourage and support the efforts of its member states to foster agricultural development and rural well-being in their territories. IICA pursues this objective in part through the Procis, subregional research and technology development systems governed through local stakeholder-lead processes (http://www.iica.int/Procis/).

the sector's heavy reliance on natural resource inputs makes a spatial assessment of agriculture especially revealing, and so we also highlight some of the important spatial dimensions. Drawing on new spatial data, we also summarize the results of some economic simulations designed to illustrate the spatial spillovers of research targeted to different crops and agroecologies. Understanding the pattern of these spillovers is crucial to developing a consensus about collective efforts to fund, conduct, or at least coordinate research in LAC. The book also provides a multi-country perspective on the potential trade in technologies and scientific know-how that should ideally underpin national R&D investment strategies and inform decisions about the optimal division of labor and fiscal responsibilities among those national, regional, and international agencies funding, conducting, or using the results of agricultural R&D.

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Chapter 2

Setting the Economic Scene

Philip G. Pardey, Stanley Wood, Ulrike Wood-Sichra, Connie Chan-Kang, and Liang You

This volume is concerned with the prospects for agriculture and agricultural R&D in LAC. Looking back to look forward is instructive. The future of agriculture builds on past developments, and so anchoring our views of the future on these past changes injects realism into current public policy and research investment choices. In this chapter we present a quantitative retrospective on the agricultural economies in LAC, the region's population and food consumption patterns, and its agricultural trade trends.

LAC contains a large, fast-growing, and increasingly urbanized population—about one-half billion people in total—with slightly more than half that total living in just Brazil and Mexico. As a group, the economies of LAC grew faster than those of the rest of the world after the mid-l960s.[1] As a region, only South Asia (Bangladesh, Bhutan, India, the Maldives, Nepal, Pakistan, and Sri Lanka) did better. Yet, overall, LAC's agricultural gross domestic product (AgGDP), a value-added measure of agricultural output, grew more slowly than reported for all other developing regions, except Africa. Per capita food consumption grew little in LAC over the past several decades—at 2,852 calories per day per person in 2001, about the world average—despite significant growth in agricultural imports that outpaced agricultural export growth. Lackluster production growth and stagnant per capita caloric intake are indicative of the unremarkable performance of the region's agriculture.

Most of LAC agriculture is to be found in just three countries, Argentina, Brazil, and Mexico (about 73 percent of the value of the region's output in 2002). Averaging across all LAC countries, the sector generated about 7.0 percent of total gross domestic product (GDP) in 2002, but over 15 percent in eight smaller and poorer

1 They grew at 3.38 percent per year for the period 1965–2002 versus 3.22 percent annually for the rest of the world.

LAC countries. The Caribbean relies least on agriculture. Highest production growth occurred in the livestock sector, with chicken meat showing the best results. Oil crops (chiefly soybeans) were the high growth commodities in the crops sector. In crop production, area expansion outpaced yield growth for fruits, oil crops, sugar, and pulses, which actually lagged the rates of yield growth achieved by the world's other developing regions. On the other hand, yield growth outpaced area growth for cereals, vegetables, and fiber crops.

Soybean oil is now the fifth most important source of calories in LAC. Maize consumption by humans has slipped from first place (with sugar now ranking first); and bananas, beans, cassava, and potatoes have become less significant in LAC diets. Furthermore, half of the cassava crop, almost 60 percent of corn, and nearly all sorghum are now used for animal feed. Livestock commodities, notably poultry meat, have dramatically increased their shares of per capita daily calorie intake since 1961.

The labor input in LAC agriculture grew less rapidly than in other developing countries, but the land input increased more rapidly. Consequently, the region's land–labor ratios are significantly higher than in the rest of the world, consistent with a commodity and land-use mix that is more heavily weighted toward livestock and pastures.

The Agricultural Economy of Latin America and the Caribbean in Retrospect

The economic fortunes of agriculture are inextricably intertwined with more general developments in domestic economies and, increasingly, developments elsewhere in the world. Here we provide some indications of these international economic relativities and interdependencies.

Economic Output

In 2002, LAC GDP was US$1.93 trillion (1995 dollars)—almost 5.5 percent of the world's GDP (World Bank 2004).[2] Since 1965, the economies of LAC grew faster than the global average, eclipsing the yearly rate of growth in Africa and western Europe, but not that of either South Asia or the East Asia and Pacific region, which grew at an outstanding 5.4 and 7.9 percent per year respectively in the 1980–2002 period, compared with 2.5 percent for LAC. However, the economies in the region have had their ups and downs. Reca and Diaz Bonilla (1997) point to favorable world economic trends during the 1960s and 1970s, which lifted regional growth (see also Chapter 5, this volume). But it did not last; from 1980 to 1983 economic activity in the region contracted (real GDP shrank by 1.45 percent per year) so that 20 countries were producing less in real terms in 1983 than they were three years before.

2 GDP measures are value-added measures (that is, gross value of output minus the value of purchased inputs) taken from national accounts data and reported by the World Bank (2004).

The shift toward more market-friendly macroeconomic policies, trade liberalization, and the scaling back of government interventions in many Latin American economies during the 1990s was associated with a general resurgence in growth. Real output grew by 2.9 percent per year in the 1990–2002 period. Of course, regional averages hide substantial country differences. Per capita GDP in 2002 was highest in the Bahamas and lowest in Haiti (US$13,462 and US$359, respectively, in 1995 dollars). It grew fastest in the smaller economies of Grenada, St. Vincent and the Grenadines, and St Kitts and Nevis and slowest in a diverse group of countries that include Haiti, Nicaragua, and Venezuela.

Aggregate Agricultural Output

Aggregate gross agricultural output in LAC grew to US$173 billion international dollars (1989–91 prices) by 2002.[3] This represented a 2.8-fold increase in the index over the 42 years prior to 2002, or an average rate of growth of 2.8 percent per year. Yet, as Figure 2.1a illustrates and Table 2.1 shows in more detail, Latin America's agricultural output performance has been unremarkable by developing-country standards, lagging well behind the 3.7 percent per year rate of growth in the 1961–2002 period for the entire developing world, but especially Asia's growth rate of 3.8 percent per year. Neither has Latin American agriculture performed especially well on a per capita basis, with output per person growing by only 0.5 percent per year—that is, faster than Africa (which shrank by 0.6 percent per year) but slower than all other regions of the world (Figure 2.1b). Agricultural output grew slowest in the Caribbean countries, followed by Mesoamerica then the Southern Cone (excluding Brazil and Chile).[4]

Like the region's economies more generally, agriculture also suffered during the early 1980s, but not severely. AgGDP grew by 2.1 percent per year during 1980–85 (total GDP grew by just 0.1) compared with 3.4 percent in the preceding decade (total GDP grew by 5.6 percent) and 2.7 percent per year in the decade that followed (while total GDP rose by 3.8 percent yearly).

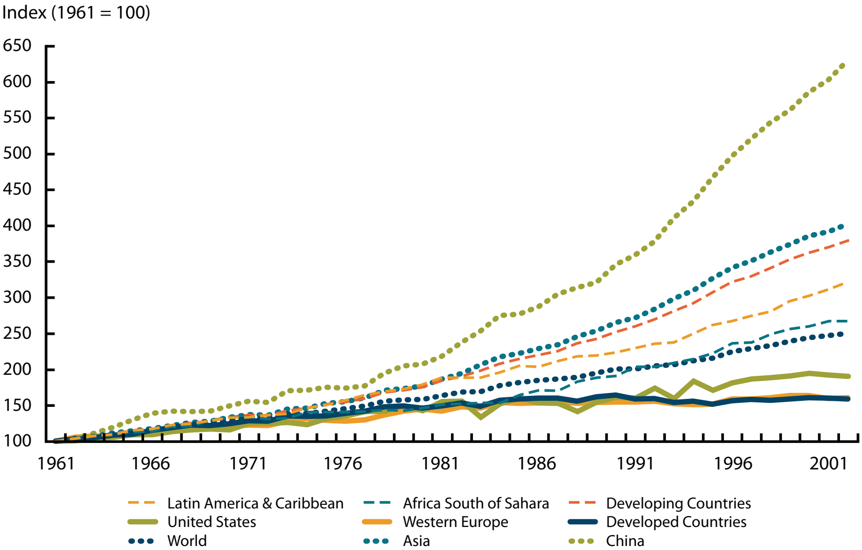
Figure 2.2 gives some different perspectives on the relationship between AgGDP and GDP. Figure 2.2a shows the link between the rate of growth in agriculture (measured by AgGDP) and the growth in the size of the overall economy for 25 Latin American countries during the 1965–2002 period. Omitting several small countries (Trinidad and Tobago, St. Kitts and Nevis, Puerto Rico, and Grenada), we observe a positive relationship between growth in AgGDP and growth in GDP. Apparently, countries with robust overall economies also have robust agricultural sectors (and

3 Our gross measure of agricultural output was formed by aggregating yearly national-output measures for 141 crop and 22 livestock categories taken from FAO (2004), where each commodity quantity in the index was weighted by the respective 1989–91 average of its unpublished international price (denominated in international dollars based on an unpublished agricultural purchasing power parity index obtained from FAO).

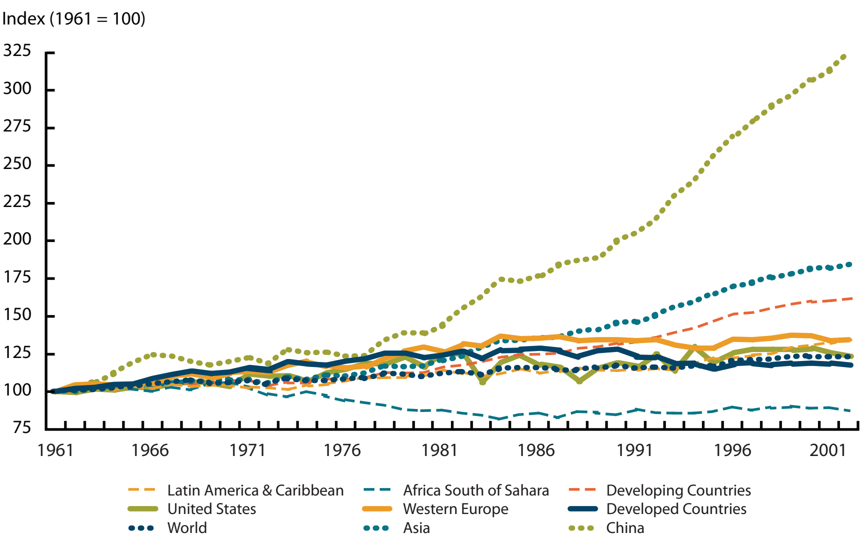
4 Mesoamerica comprises Costa Rica, El Salvador, Honduras, Guatemala, Mexico, Nicaragua and Panama. The Southern Cone countries comprise Argentina, Brazil, Chile, Paraguay and Uruguay.

Figure 2.1 Agricultural production trends: Latin America and the world, 1961–2002

a. Total agricultural output



b. Agricultural output per capita



Sources: Compiled by authors from FAO 2004.

Notes: Total and per capita output measures were indexed to 1961=100.

Table 2.1 Growth in crop, livestock, and total agricultural production, 1961–2002

Country/region	1961–2002 Crop	1961–2002 Livestock	1961–2002 Total	1993–2002 Crop	1993–2002 Livestock	1993–2002 Total
		(percent per year)			*(percent per year)*	
Mexico	1.97	3.32	2.61	2.09	3.62	2.84
Mesoamerica excluding Mexico	2.33	3.25	2.66	2.03	2.81	2.31
Mesoamerica	2.06	3.30	2.62	2.08	3.47	2.72
Caribbean	–0.87	–0.19	–0.62	2.82	1.45	2.30
Andean countries	2.55	3.09	2.82	2.43	3.28	2.85
Brazil	2.32	4.89	3.44	3.24	4.78	3.94
Southern Cone excluding Brazil	4.00	1.64	2.89	4.68	0.80	2.87
Southern Cone	2.89	3.69	3.25	3.74	3.38	3.57
Latin America and the Caribbean (47)	2.51	3.39	2.91	3.21	3.32	3.26
Asia (40)	3.06	5.54	3.81	2.79	4.57	3.36
Sub-Saharan Africa (53)	3.35	2.27	3.06	3.06	2.73	2.97
Developing countries (183)	3.06	4.94	3.66	2.93	4.31	3.39
United States	1.98	1.92	1.95	1.41	1.92	1.65
Western Europe (29)	0.67	0.21	0.41	1.34	0.42	0.83
Developed Countries (67)	0.39	–0.41	–0.03	0.78	0.20	0.48
World (246)	2.12	1.95	2.05	2.22	2.20	2.21

Sources: Compiled by the authors from FAO 2004.

Notes: See footnote 2 for data compilation details. Sub-Saharan Africa excludes South Africa. Figures in parentheses indicate the maximum number of countries included in the aggregation. Throughout this report the following regional aggregates are considered:

Mesoamerica. Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, and Panama.

Caribbean. Antigua, Barbuda, Bahamas, Barbados, Belize, British Virgin Islands, Cayman Island, Cuba, Dominica, Dominican Republic, Falkland Island, French Guiana, Grenada, Guadeloupe, Guyana, Haiti, Jamaica, Martinique, Montserrat, Nethantilles, Puerto Rico, St Kitts Nevis, St Lucia, Suriname, St Vincent, Trinidad and Tobago, and U.S. Virgin Islands.

Andean countries. Bolivia, Colombia, Ecuador, Peru, and Venezuela.

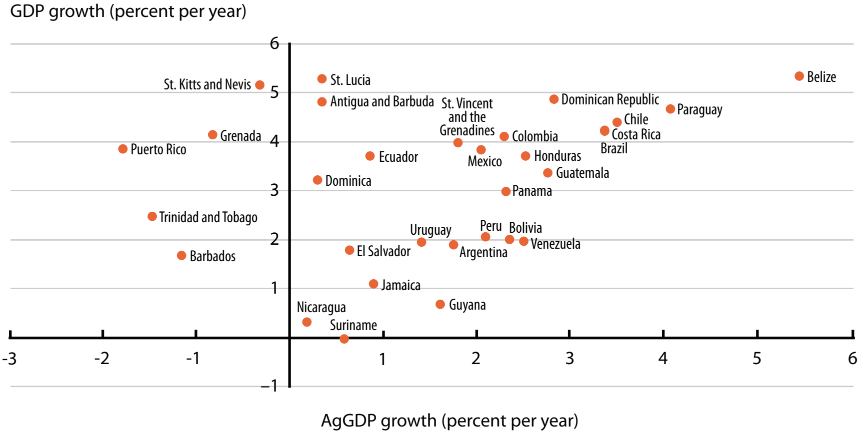
Southern Cone. Argentina, Brazil, Chile, Paraguay, and Uruguay.

vice versa). However, there is no obvious correlation between the relative size of the agricultural sector, taken as the ratio of AgGDP to GDP, and overall GDP growth (Figure 2.2b), although there does appear to be a positive relationship (but by no means a perfect fit) between AgGDP and total GDP (Figure 2.2c).

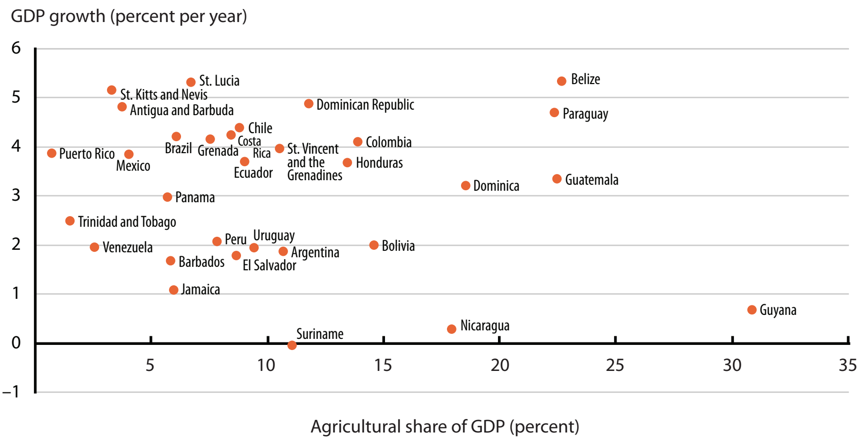
LAC agricultural production is spatially concentrated, with Argentina, Brazil, and Mexico alone producing more than two-thirds of the region's agricultural output since 1961 (measured in gross value terms). The top 10 countries have typically accounted for about 90 percent of the region's output. Notably, Brazil is the only country to have significantly increased its share of the region's total value of agricultural production (growing from a 31.6 percent share in 1961 to 43.9 percent in the early 2000s). Value shares for most of the other countries have been comparatively stable. Cuba is one exception. It was in the top 5 producing countries in 1961, held fifth position from the late 1970s through to the late 1980s, dropped from the top 10 list in 1993, and reentered in 2000. In contrast,

Figure 2.2 Relationships between gross domestic product and agricultural gross domestic product

a. Growth in GDP and AgGDP, 2002



b. GDP growth and ratio of AgGDP to GDP



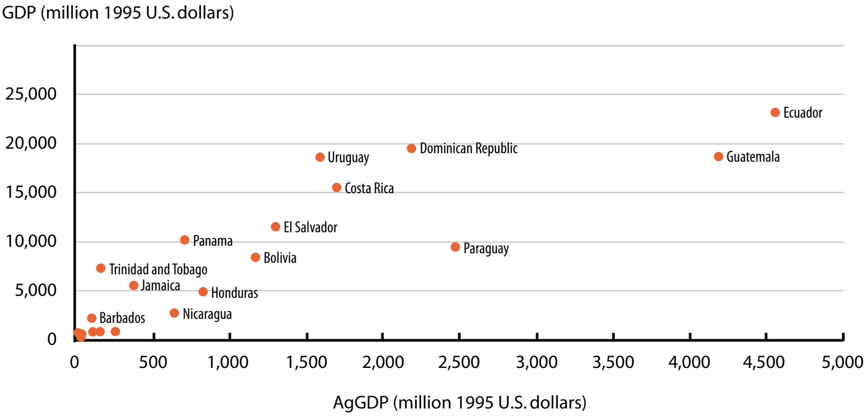
(continued)

Agriculture now accounts for a generally smaller share of total output than in earlier years.[5] In 2002, AgGDP averaged about 7 percent of GDP in Latin America; in 1965 it accounted for 17 percent. Figure 2.3 plots agricultural output shares since 1971. In 2002, AgGDP accounted for no more than 15 percent of GDP for 25 of the

5 The exceptions are Argentina, where agriculture's share has changed little, and Chile, Guyana, and Suriname, where agriculture's output share has actually grown since the early 1960s.

Figure 2.2 (continued)

c. GDP and AgGDP levels

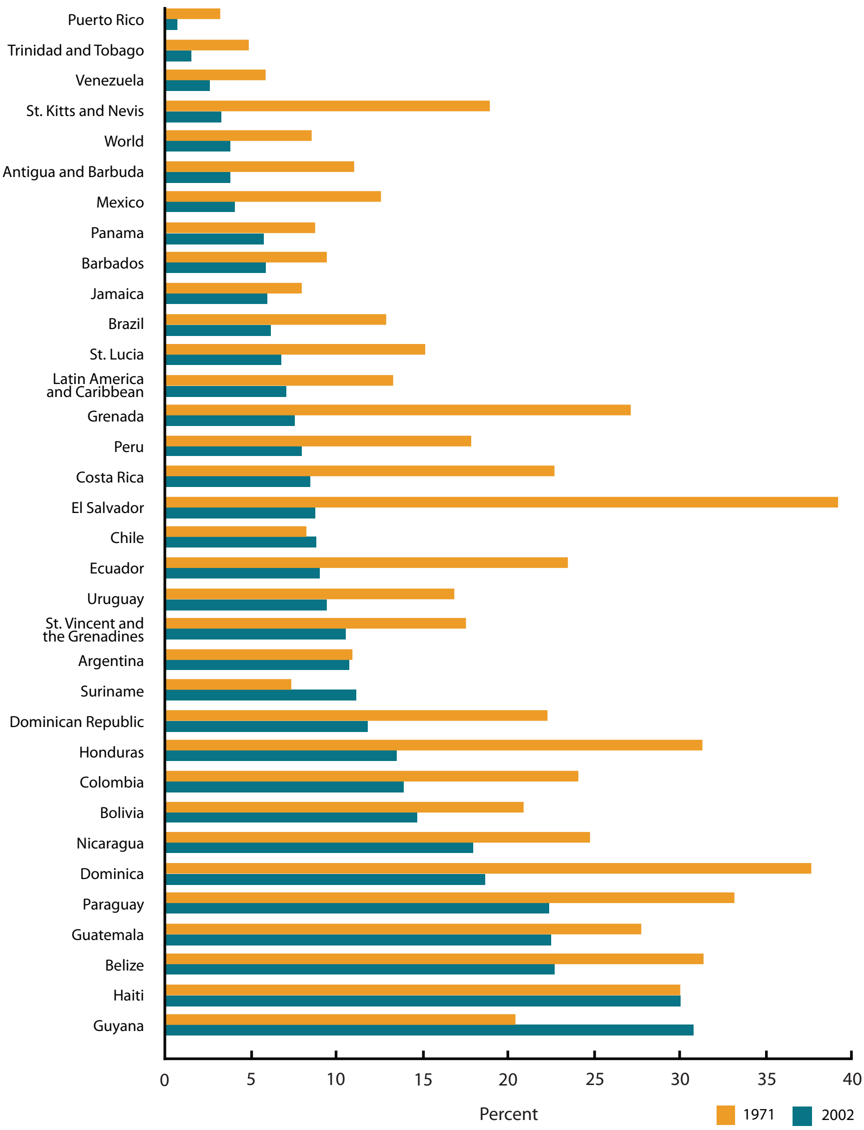


Sources: Compiled from World Bank 2004.
Notes: In Figure 2.2c, no label designates Antigua and Barbuda, Belize, Dominica, Grenada, Guyana, St. Kitts and Nevis, St. Lucia, St. Vincent, Suriname. For the purpose of readability, the countries excluded are Brazil, Argentina, Peru, Venezuela, Chile, Colombia, Mexico, and Puerto Rico.

32 countries for which data were available; it was less than 5 percent of total output in Antigua, Mexico, Puerto Rico, St. Kitts, Trinidad and Tobago, and Venezuela. However, agriculture is still a significant sector in some countries—especially in Belize, Guatemala, Guyana (31 percent of total output in 2002), Haiti (30 percent of total output in 2002), and Paraguay (about 23 percent of total output in 2002). With the exception of Mexico, most of the countries of Mesoamerica rely more on agriculture, on average, than do the countries of the LAC region.

From 1961 to 2002, livestock output grew faster (3.4 percent per year) than overall agricultural output (2.9 percent per year), while crop production expanded more slowly than the total (2.5 percent per year) (Table 2.1). Both crop and livestock production contracted in the Caribbean. The rate of growth in livestock production for the Southern Cone (excluding Brazil) was also mediocre, averaging just 1.6 percent yearly, although crop output grew briskly throughout the Southern Cone (4 percent per year—excluding Brazil, which grew by 2.3 percent). In contrast with other Southern Cone countries, the livestock sector in Brazil (as well as livestock in Mexico and the Andean subregion) put in a strong performance. For LAC overall, growth in the livestock sector slowed notably in recent times (1993–2002 in Table 2.1). compared with longer run (1961–2002) rates of growth—the reverse of global trends.

Figure 2.3 Agricultural share of gross domestic product



Sources: World Bank 2004.

Notes: Beginning and ending years are as shown with following exceptions: 1971 estimate refers to 1977 for Dominica, Grenada, St. Vincent, and St. Kitts and Nevis; 1978 for Belize; 1929 for St. Lucia; and 1980 for Panama; the 2002 estimate refers to 2001 for Puerto.Rico and the World. No data were available for Cuba. Haiti is reported at approximately 30 percent. No AgGDP data were available for Aruba, Bahanas, Cayman, Netherlands Antilles, or the Virgin Islands.

Commodity Details

In Table 2.2 we present output value shares for 164 commodities summed into 16 commodity groups. Meat, oil crops, and cereals are the top three output categories, accounting for a combined 57 percent share of the value of output in 2002. The value shares of each of these categories have inched up since 1961, but the most dramatic gains are for oil crops—in eighth place on the list in 1961 and now ranked second, with a corresponding growth in value share from 3.5 to 12.1 percent. Beverage crops (including coffee, tea, cocoa, and mate (a caffeinated drink prepared from the dried leaves of *yerba mate*) slipped in importance and now account for just 3.1 percent of the region's agricultural output compared with 6.8 percent in 1961.

The Crop Sector

Table 2.3 provides value shares on a crop-by-crop basis for the whole of Latin America since 1961. Among the 134 crops represented by these figures, just three crops—soybeans, maize, and sugarcane—account for 41 percent of total crop production. The top 10 crops listed separately in the table have typically accounted for two-thirds of the region's crop production by value.

Soybeans, maize, and sugarcane were also the dominant commodities within their respective crop categories (as reported in Table 2.4): in 2002, soybeans accounted for 80 percent of the value of oil crops, maize for 54 percent of cereals, and sugarcane for 99 percent of total sugar production. Soybean production has skyrocketed, increasing its value share of total crop output from 0.2 percent in 1961 to 19.4 percent in 2002. In that same year, 30 million hectares produced 76.9 million tons of soybeans throughout the region, with Brazil and Argentina accounting for 54 and 39 percent respectively of that total. Oranges and tomatoes also accounted for a greater proportion of total crop value over time, while the production shares for coffee, beans, and cassava shrank. Notably, the production value shares of traditional export crops like coffee and fibers also declined over time.

Table 2.4 provides information on the pattern of crop production in Latin America for 2002. Reading from left to right, commodity groups are arranged in descending order of importance. There was US$21 billion (1989–91 international dollars) of oil crop production in 2002, accounting for 22.6 percent of the total value of crop production, compared with US$1.4 billion of fiber crops production, or just 1.6 percent of the crop output. Within a commodity column, countries are ranked in descending order according to their respective value of production shares. Typically the top 5 producers in any crop category account for more than 70 (and often more than 80) percent of the value of production; the top 10 countries produce more than 90 percent of the region's output. The strongest spatial concentration is found in oil crops: just five countries were responsible for 97 percent of the region's oil crop production in 2002.

Brazil was the leading producer in all crop categories, and especially so in the case of oil crops, sugar, pulses, tobacco and spices, and fiber crops. In these five com-

Table 2.2 Commodity composition of agricultural output in Latin America, 1961–2002

Commodity category	1961	1971	1981	1991	2002
			(percentage)		
Meat and meat products	30.7	28.6	31.0	31.9	34.0
Oil crops	3.5	4.4	6.8	7.8	12.1
Cereals	12.2	13.8	14.0	11.6	11.0
Fruits	10.4	11.8	11.1	11.8	10.4
Milk and milk products	8.9	9.4	9.1	9.0	9.0
Sugar	6.8	6.1	6.1	6.8	5.7
Vegetables	3.3	3.5	3.5	4.0	4.4
Eggs	1.7	2.1	2.6	3.2	3.1
Beverage crops	6.8	4.6	4.4	3.6	3.1
Roots and tubers	4.8	5.5	3.7	3.1	2.6
Pulses	3.4	3.6	2.7	2.6	2.0
Tobacco and spices	1.3	1.3	1.2	1.1	1.1
Fibre crops	3.6	3.5	2.3	2.1	0.8
Animal fibres	2.1	1.5	1.1	0.8	0.3
Crop not elsewhere specified	0.2	0.2	0.2	0.3	0.3
Livestock not elsewhere specified	0.3	0.2	0.3	0.3	0.2
Total	100	100	100	100	100

Sources: Compiled by authors from FAO 2004.

Notes: Shares based on value of production estimated by weighting amount of commodity produced by the respective international agricultural price for 1989-91. Commodities grouped as follows:

Meat and meat products. **Beef and veal, mutton and lamb, goat meat, pigmeat, chicken meat, duck meat, goose meat, turkey meat, horsemeat, rabbit meat, meat of other rodents, meat of other camelids, game meat, and meat not elsewhere stated (NES).**

Cereals. **Paddy rice, maize, sorghum, wheat, barley, rye, oats, millet, canary seed, quinoa, cereals NES, buckwheat, and triticale.**

Fruits. **Bananas, plantains, oranges, berries NES, mangoes, avocados, pineapples, papayas, fruit fresh NES, lemons and limes, citrus fruit NES, apples, strawberries, raspberries, blueberries, grapes, grapefruit and pomelo, pears, quinces, apricots, cherries, peaches and nectarines, plums, figs, dates, fresh fruit tropical NES, and persimmons.**

Milk and milk products. **Whole cow milk, goat milk, and sheep milk.**

Oil crops. **Soybeans, groundnuts in shell, coconuts, palm kernels, palm oil, sesame seed, olives, castor beans, oilseeds NES, sunflower seed, rapeseed, safflower seed, mustard seed, linseed, tung nuts, hempseed, melon seed, oil of cotton seed, and cake of cotton seed.**

Sugar. **Sugarcane and sugar beets.**

Vegetables. **Cabbages, artichokes, tomatoes, dry onions, fresh vegetables NES, cantaloupes, melons, cucumbers and gherkins, chillies and green peppers, watermelons, lettuce, cauliflower, garlic, green broad beans, okra, pumpkins, squash, gourds, eggplants, carrots, asparagus, spinach, green onions and shallots, green beans, green peas, green string beans, and corn.**

Eggs. **Hens' eggs and eggs excluding hens' eggs.**

Roots and tubers. **Potatoes, cassava, roots and tubers NES, sweet potatoes, yautia (cocoyam), yams, and taro (coco yam).**

Beverage crops. **Hops, green coffee, cocoa beans, tea, and mate.**

Pulses. **Dry beans, dry broad beans, pulses NES, dry peas, chickpeas, lentils, pigeon peas, dry cowpeas, lupins, and vetches.**

Tobacco and spices. **Tobacco leaves, white/long/black pepper, nutmeg, mace, cardamon, anise, badian, fennel, spices NES, pimento, allspice, vanilla, cinnamon (canella), ginger, cloves whole and stems.**

Fibers crops. **Cotton lint, abaca (manila hemp), jute like fibres, agave fibers NES, sisal, fiber crops NES, jute, flax fiber and tow, ramie, and hemp fiber and tow.**

Animal fibers. **Greasy wool and reelable cocoon fibers.**

Crops NES. **Nuts NES, natural rubber, cashew nuts, oil of citronella, essential oils NES, almonds, walnuts, pistachios, carob, natural gums, brazil nuts, chestnuts, pyrethrum, dried flowers, peppermint.**

Livestock NES. **Honey and beeswax.**

Oil and fiber crops. **Area of seed cotton (source of cotton seed [oil crop] and cotton lint [fiber crop]) is used both in oil and fiber crops.**

Table 2.3 Top 10 crops in Latin America and the Caribbean, 1961–2002

Rank	Commodities	Share of total value of production 1961	1971	1981	1991	2002	Growth rate 1961–2002
				(percent of total)			*(percent per year)*
1	Soybeans	0.2	1.4	8.4	9.9	19.4	13.5
2	Maize	9.9	11.7	11.9	9.9	10.8	2.8
3	Sugarcane	12.1	10.4	10.7	12.3	10.5	2.7
4	Oranges	2.4	3.1	5.1	6.4	5.0	5.2
5	Coffee, green	10.9	6.8	6.9	5.6	4.8	1.1
6	Rice, paddy	5.1	4.9	5.3	4.9	4.6	2.4
7	Bananas	5.6	6.3	4.4	4.7	3.9	1.7
8	Beans, dry	5.3	5.5	4.4	4.2	3.4	1.1
9	Wheat	4.5	3.9	3.9	4.1	3.3	2.1
10	Cassava	4.8	5.8	3.7	3.1	2.4	0.1
	Other crops	39.2	40.0	35.3	34.8	31.8	2.0
	Total	100	100	100	100	100	

Sources: Compiled by authors from FAO 2004.
Notes: Commodities are ranked according to their 2002 value of production shares.

modity groups, Brazil produced more than 50 percent of the region's total output in 2002. Vegetable production was the exception: Mexico had a dominant share.

Moving to a commodity-by-commodity assessment of crop performance gives a level of detail that is especially helpful in identifying priorities for investments of all kinds in agriculture, including R&D. Supplementary Table S2.1 reports longer and shorter run rates of growth for 66 crops (representing 99 percent of the region's value of crop production) grouped into various crop categories and ranked within each category by descending order of economic importance. The four panels in Figure 2.4 present these same rates of change data for all 66 crops for the 1960s, 1970s, 1980s, and 1990s respectively.

The general picture to emerge is that expanding area harvested rather than increasing crop yields has been the dominant source of growth in crop production over the long run (1961–2002). In fact, more than 50 percent of the increase in production was attributable to area expansion for 40 of the 66 crops produced in the region, and yield growth outpaced area expansion for just 26 crops. Only 9 of the crops with dominant yield effects—maize, rice, potatoes, tea, sugar beets, tomatoes, watermelons, onions, and garlic—recorded yield increases averaging more than 2 percent per year.

Notwithstanding the general long-run dominance of area expansion effects, yield gains are gradually becoming a more important source of output growth in the region. Among the 66 crops, yield increases were the primary source of output growth for 18 crops in the 1960s, increasing to 26 crops during the 1900s and early 2000s. Moreover, the rate of gain in yields has trended upward for greater numbers of crops: 28 crops had higher rates of yield growth in the 1970s compared with the

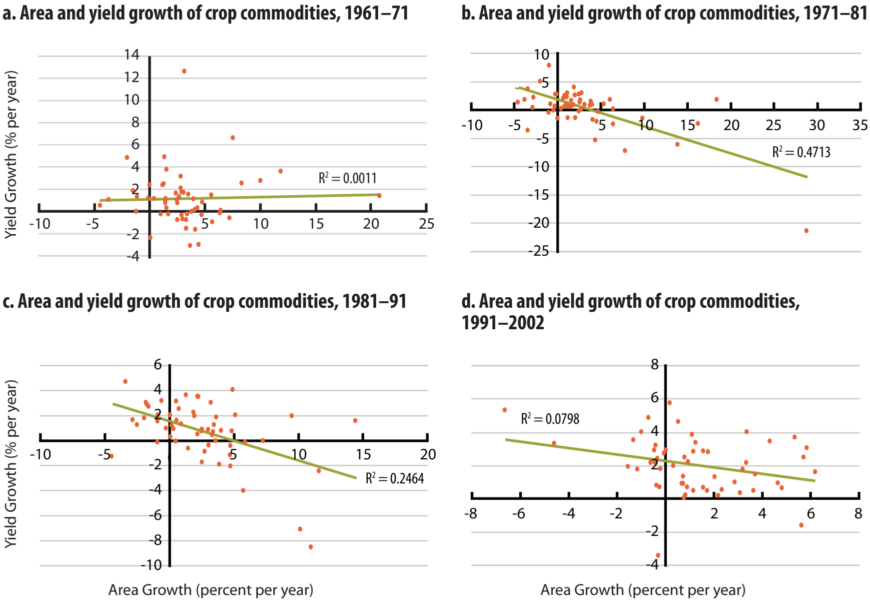
Table 2.4 Spatial pattern of crop production in Latin America and the Caribbean, 2002

	Oil crops		Cereals		Fruits		Sugar		Vegetables		Beverage crops		Roots and tubers		Pulses		Tobacco and spices		Fiber crops	
Rank	Country	Share	Country	Share	Country	Share	Country	Share	Country	Share	Country	Share	Country	Share	Country	Share	Country	Share	Country	Share
		(percentage)		*(percentage)*		*(percentage)*		*(percentage)*		*(percentage)*		*(percentage)*		*(percentage)*		*(percentage)*		*(percentage)*		*(percentage)*
1	Brazil	50.2	Brazil	36.8	Brazil	32.4	Brazil	62.3	Mexico	28.7	Brazil	52.4	Brazil	43.3	Brazil	47.2	Brazil	60.1	Brazil	72.5
2	Argentina	40.3	Argentina	22.4	Mexico	16.8	Mexico	7.8	Brazil	19.4	Colombia	13.1	Peru	10.9	Mexico	29.8	Argentina	10.8	Argentina	5.9
3	Paraguay	4.0	Mexico	19.2	Argentina	11.1	Colombia	6.1	Argentina	9.4	Mexico	6.2	Colombia	10.5	Argentina	4.8	Mexico	9.9	Mexico	4.6
4	Bolivia	1.6	Peru	3.3	Chile	7.3	Cuba	5.9	Peru	8.4	Argentina	4.4	Paraguay	6.9	Nicaragua	3.0	Guatemala	3.9	Peru	3.9
5	Mexico	1.1	Colombia	3.3	Ecuador	6.0	Guatemala	3.0	Cuba	8.1	Peru	3.5	Argentina	6.0	Colombia	2.2	Cuba	2.8	Paraguay	3.8
6	Colombia	0.6	Chile	2.4	Colombia	5.5	Argentina	2.8	Chile	7.5	Honduras	3.3	Mexico	4.0	Peru	1.8	Peru	2.7	Colombia	3.5
7	Ecuador	0.4	Venezuela	2.0	Costa Rica	3.4	Peru	1.6	Colombia	3.8	Guatemala	3.3	Bolivia	3.4	Guatemala	1.8	Colombia	2.1	Bolivia	2.4
8	Uruguay	0.3	Ecuador	1.7	Peru	3.2	Chile	1.2	Venezuela	3.3	Costa Rica	2.5	Chile	3.2	Cuba	1.7	Dominican Republic	1.6	Ecuador	0.9
9	Venezuela	0.2	Uruguay	1.4	Venezuela	2.3	Venezuela	1.2	Guatemala	2.4	Ecuador	2.5	Cuba	2.8	El Salvador	1.3	Jamaica	1.4	Venezuela	0.6
10	Guatemala	0.2	Bolivia	1.0	Guatemala	1.9	Ecuador	1.0	Bolivia	1.6	El Salvador	1.6	Venezuela	2.1	Chile	1.0	Paraguay	0.8	Cuba	0.6
	Top 5	97.2		85.0		73.6		85.2		74.0		79.6		77.6		87.0		87.5		90.8
	Top 10	98.9		93.6		89.7		93.0		92.6		92.9		93.2		94.4		96.1		98.8
Total LAC value (million international 1989–91 dollars)																				
		20,948.0		18,999.3		18,057.7		9,847.4		7,641.5		5,338.3		4,517.0		3,494.6		1,837.1		1,444.5
Crop category value shares (percentage)																				
		22.6		20.5		19.5		10.6		8.3		5.8		4.9		3.8		2.0		1.6

Sources: Compiled by authors from FAO 2004.

Notes: See Table 2.2. Percentages represent the 2002 quantity of production weighted by the respective 1989–91 international agricultural prices received by farmers for each commodity in each commodity group.

Figure 2.4 Rate of change in yield and area harvested for 56 crops, 1961–2002



Sources: Developed by authors from FAO 2004.
Notes: Each point in each graph represents a specific crop.

previous decade, yields for 30 crops grew faster in the 1980s than the 1970s, and 47 crops increased yields more quickly in the 1990s than the 1980s. The stylized view of world food production—that yield growth has slowed in recent years (Conway 1998; Mann 1999; and Pingali and Heisey 2001)—is not supported by a close scrutiny of the LAC data.

Aside from the 1960s, oil crops outperformed all other crop categories in terms of production and area expansion effects, but not in terms of yield growth (Table 2.5). Growth in oil crop production was particularly rapid during the 1970s, averaging nearly 9 percent per year. During the 1980s the rate leveled to around 4.5 percent per year and increased again in the 1990s to 7 percent. Soybeans accounted for most of this growth. Since 1961 soybean production grew at the spectacular rate of 13.5 percent per year, outpacing all other commodities. While technology undoubtedly played its part in expanding soybean production, Reca and Diaz Bonilla (1997) point to a strong export demand and an especially supportive policy environment (particularly in Brazil, which accounted for about 55 percent of the region's soybean production in 2002) as two factors contributing to this growth. The evolution, adoption, and economic impact of soybean technologies (and, especially, improved crop

Table 2.5 Yearly growth rate of crop production, area, and yield, 1961–2002

	Production					Area					Yield				
Category	1961–1971	1971–1981	1981–1991	1991–2002	1961–2002	1961–1971	1971–1981	1981–1991	1991–2002	1961–2002	1961–1971	1971–1981	1981–1991	1991–2002	1961–2002
								(percentage)							
Cereals	3.99	3.25	0.08	2.56	2.51	2.65	0.72	−0.75	0.06	0.38	1.30	2.51	0.84	2.51	2.11
Fruits	4.09	2.98	2.84	2.08	2.92	3.68	2.99	3.73	1.16	3.04	0.40	−0.01	−0.86	0.91	−0.12
Oil crops	4.47	8.89	4.73	7.16	5.93	4.18	5.76	2.47	3.81	3.25	0.28	2.96	2.21	3.23	2.60
Sugar	2.64	3.94	2.75	1.63	2.74	1.46	2.52	2.17	0.89	1.94	1.16	1.38	0.57	0.74	0.78
Vegetables	3.33	3.72	3.49	4.56	3.54	0.45	0.76	2.17	1.82	1.31	2.87	2.94	1.30	2.70	2.20
Roots and tubers	4.40	−0.30	0.69	1.74	0.71	2.94	0.01	−0.38	−0.07	0.10	1.42	−0.31	1.08	1.81	0.61
Beverage crops	−2.12	2.32	0.96	1.70	1.26	−3.11	1.59	1.64	−0.38	0.28	1.02	0.72	−0.68	2.08	0.98
Pulses	3.23	−0.07	0.55	0.45	1.06	2.56	1.03	0.34	−1.60	0.58	0.65	−1.09	0.21	2.08	0.48
Fiber crops	1.58	−0.89	1.64	−2.08	−1.03	4.10	−0.76	−3.40	−6.00	−2.48	−2.42	−0.13	5.22	4.17	1.48

Sources: Compiled by authors from FAO 2004.

Notes: See Table 2.2.

varieties) in Brazil—many of which originated in the United States—are also a significant source of production growth over this period (Pardey et al. 2004).

Cereals and fruits, the two most important crop categories in terms of value shares of production, grew quickly between 1961 and 1971, both averaging rates of output growth of around 4 percent per year (Table 2.5). However, longer run patterns of growth have been quite uneven. Cereal production grew quickly during the 1960s (4 percent per year), slowing to 3.2 percent during the 1970s and 0.08 during the 1980s, but rebounded during the 1990s to grow by 2.6 percent per year. Fruit production expanded by 4.1 percent per year in the 1960s, 3.0 percent per year during the 1970s and 1980s, and 2.1 percent per year in the 1990s. During the 1961–2002 period, buckwheat and sorghum output grew fastest among the cereals; papaya, and lemons and limes were the fastest growing fruit crops.

Vegetables constitute the only crop category that maintained a consistently high rate of output growth since 1961, and yield gains were the dominant source of output growth for more than half the vegetable crops during the 1960s and 1970s. However, area expansion became the primary source of output growth for most vegetables during the 1980s and 1990s. During the past two decades, asparagus production expanded at a greater rate than any other vegetable crop, followed by okra and spinach.

The production performance of traditional export crops like cocoa and coffee was lackluster: cocoa output grew by 1.5 percent per year after 1961 and coffee production expanded by only 1.1 percent per year. A striking feature of the data in Table 2.5 is the modest and generally uneven growth performance of some of the basic food crops. Root and tuber production expanded by 4.4 percent per year during the 1960s, but contracted by 0.3 percent in the decade that followed (the result of a contraction in both area and yields). Their production recovered a little in the 1980s and further still in the 1990s, but overall growth in output since 1961 has averaged just 0.7 percent per year. Likewise, pulse production declined during the 1970s. Growth was negligible in the 1980s and remained so during the 1990s, averaging just 1.1 percent per year since 1961.

Among all the crop categories listed in Table 2.5, only fiber crop production declined continuously since the 1970s, reflecting a substantial reduction in area harvested (from 4.5 million hectares in 1961 to 1.7 million hectares in 2002).[6] Papaya, pineapples, and oranges were the only crops with higher rates of output growth in successive decades (Supplementary Table S2.1). Watermelons and chickpeas were the only crops to have higher rates of yield growth in successive decades, while the yields of castor beans and apricots declined successively in every decade since the 1960s.

6 This decline occurred, notwithstanding the commercial success of transgenic cotton varieties first introduced into Mexico in 1996 (Traxler and Godoy-Avila 2004).

Table 2.6 Top 10 livestock products in Latin America, 1961–2002

		Share of total value of production					Growth rate
Rank	Commodities	1961	1971	1981	1991	2002	1961–2002
		(percent of total)					*(percent per year)*
1	Beef and Veal	54.0	49.2	48.5	47.7	41.7	2.4
2	Chicken Meat	2.6	5.1	9.2	12.8	21.4	8.2
3	Cows' milk, whole, fresh	19.9	22.1	20.3	19.8	19.1	2.8
4	Pigmeat	8.7	9.3	9.7	7.4	7.8	2.6
5	Hens' eggs	3.8	4.9	5.9	7.1	6.6	4.7
6	Mutton and Lamb	3.1	2.8	1.4	1.2	0.8	–0.5
7	Wool, greasy	4.7	3.5	2.4	1.7	0.6	–1.4
8	Honey	0.5	0.5	0.6	0.6	0.4	2.6
9	Turkey meat	0.1	0.1	0.2	0.2	0.4	6.0
10	Horsemeat	0.8	0.9	0.5	0.4	0.3	0.1
	Other livestock	1.7	1.5	1.3	1.2	0.9	1.4
	Total	100	100	100	100	100	100

Sources: Compiled by authors from FAO 2004.
Notes: Commodities are ranked according to their 2002 value of production shares.

The Livestock Sector

Table 2.6 presents the top 10 livestock commodities ranked by their 2002 production value shares. There is an even more pronounced pattern of commodity concentration in livestock commodities than in crops. In 2002, cattle meat accounted for 42 percent of the region's total value of livestock production: cow milk and chicken meat ranked second and third, accounting for 21 percent and 19 percent of the value of livestock output respectively.

Among the top 10 livestock commodities, only hen eggs, chicken meat, and turkey meat have increased their production value shares since 1961. The greatest gains were for chicken meat, which increased its share of the value of livestock output from less than 3.0 percent in 1961 to over 21 percent in 2002. During the same period, the value of cattle meat production slipped from 54 to 42 percent of the total value of livestock production.

Table 2.7 has the same structure as Table 2.4, but this time it is the spatial patterns of livestock, not crops, that are being portrayed. For ease of interpretation, 23 livestock commodities have been grouped into 9 livestock classes (or species). For all 9 classes, the top 10 countries produced more than 90 percent of the value of livestock output, with the leading 5 producers accounting for between 78 percent of the sheep and goat output. Moreover, with the exception of sheep and goats, the top 2 producing countries accounted for more than half of the total production in all categories.

Once again, Brazil is a big producer, ranking first for six of the nine livestock classes reported in Table 2.7 for 2002. Although Uruguay has little regional significance in terms of crop production (the exception being cereals, especially rice, of

Table 2.7 Spatial pattern of livestock production in Latin America and the Caribbean, 2002

Rank	Cattle meat		Chicken		Cattle milk		Pig meat		Sheep & goat meat		Other poultry		Bee products		Horses		Other livestock	
	Country	Share	Country	Share	Country	Share	Country	Share	Country	Share	Country	Share	Country	Share	Country	Share	Country	Share
	(percentage)		(percentage)		(percentage)		(percentage)		(percentage)		(percentage)		(percentage)		(percentage)		(percentage)	
1	Brazil	49.7	Brazil	45.2	Brazil	37.8	Brazil	45.0	Brazil	21.0	Brazil	70.0	Argentina	41.4	Mexico	41.2	Argentina	59.0
2	Argentina	18.8	Mexico	19.8	Mexico	16.1	Mexico	22.9	Argentina	20.1	Mexico	15.2	Mexico	28.0	Argentina	29.0	Peru	21.3
3	Mexico	10.1	Argentina	6.5	Argentina	13.7	Chile	7.5	Uruguay	15.5	Argentina	12.9	Brazil	11.1	Brazil	11.0	Mexico	5.8
4	Colombia	4.7	Venezuela	5.7	Colombia	10.0	Argentina	4.6	Mexico	14.3	Paraguay	0.8	Uruguay	5.3	Chile	5.8	Colombia	4.6
5	Venezuela	3.4	Colombia	4.8	Ecuador	4.1	Venezuela	2.7	Peru	8.1	Haiti	0.3	Chile	4.4	Uruguay	3.9	Bolivia	3.8
6	Uruguay	2.9	Peru	4.1	Chile	3.6	Ecuador	2.5	Bolivia	5.9	Bolivia	0.3	Cuba	2.4	Haiti	2.9	Brazil	3.1
7	Paraguay	1.6	Chile	2.6	Uruguay	2.5	Colombia	2.4	Chile	5.6	Uruguay	0.2	Dominican Republic	1.1	Colombia	2.9	Ecuador	1.3
8	Chile	1.4	Ecuador	1.5	Venezuela	2.2	Cuba	1.9	Colombia	2.2	Ecuador	0.1	El Salvador	0.9	Guatemala	1.2	Uruguay	1.0
9	Ecuador	1.3	Dominican Republic	1.4	Peru	2.0	Paraguay	1.9	Ecuador	1.7	Guadeloupe	0.0	Colombia	0.9	Nicaragua	1.0	Martinique	0.1
10	Bolivia	1.1	Guatemala	1.2	Costa Rica	1.3	Peru	1.8	Haiti	1.4	Suriname	0.0	Paraguay	0.9	Cuba	0.6	Guadeloupe	0.1
		86.8	Top 5	82.0		81.6		82.7		78.9		99.2		90.2		90.8		94.5
		95.1	Top 10	92.8		93.3		93.1		95.7		100.0		96.5		99.4		100.0
Total LAC value (million international 1989–91 dollars)																		
		33,682.1		22,565.3		15,425.5		6,267.4		1,531.4		431.6		396.4		274.2		115.4
Livestock category value shares (percentage)																		
		41.7		28.0		19.1		7.8		1.9		0.5		0.5		0.3		0.1

Sources: Compiled by authors from FAO 2004.

Notes: See Table 2.2.

which it is a sizable producer), in 2002 it was the ranked third as a producer of sheep and goats, fourth in bee products, fifth in horse production, sixth in cattle meat, and seventh in other poultry production.

Agricultural Inputs

Using available input data to assess both sources of production and productivity changes—that is, growth in output net of measured growth in inputs—and the impacts of agricultural R&D is especially problematic. Not least among the problems is accounting for variations in the quality and intensity of use of tractors, combines, and other capital inputs; the attributes of labor and land; the chemical composition of fertilizer; and the site- and time-specific aspects of climate and weather that are either missing or mis-measured in most economic assessments of production agriculture.[7] The horsepower rating of tractors or the size of combines can vary markedly over time and among locales; labor varies in terms of its age, educational status, and farming skills; and land has different slope, elevation, and soil type attributes. Failing to adjust for these quality differentials has potentially profound consequences on measures of input use and the magnitude and sources of productivity change in agriculture. Moreover, and of particular relevance for our purposes, unmeasured input-quality differentials can significantly affect estimates of the returns to investments in agricultural R&D. As Craig and Pardey (1996) described by way of example, if labor quality in agriculture has improved over time in ways not captured by the measure of the agricultural work force, some of the increase in output will be attributed inappropriately to other variables that are correlated with the unmeasured labor quality information. Likewise, any multifactor productivity index will have a larger unexplained productivity increase when labor force measures do not reflect labor quality improvements. In both cases, the research-spending variable may be credited with an impact on output that should more properly be attributed to other inputs. Notwithstanding these considerable and important measurement issues, getting a quantitative handle on uses of agricultural inputs is a necessary step to understanding the productivity patterns described in Chapter 4 of this volume.

Agricultural Labor

Consistent with the shrinking share of agriculture in total GDP, the amount of labor employed in agriculture has declined as a share of the total labor force. Agriculture accounted for 48 percent of LAC's economically active population in 1961, but only 19 percent by 2002 (Table 2.8), placing it much closer to the developed-country average (6.8 percent employed in agriculture in 2002) than the developing-country average (54 percent employed in agriculture in 2002).

There is a large disparity among countries in the share of total employment accounted for by agriculture. In 2002, about one-third of the labor force was em-

7 See Andersen, Alston, and Pardey (2006) for evidence on the effects of changing intensity of capital use on measures of agricultural productivity.

Table 2.8 Agriculture's share of the total labor force

Country/region	1961	1971	1981	1991	2002
			(percentage)		
Mexico	54.0	43.1	35.4	27.1	20.2
Mesoamerica excluding Mexico	62.2	55.2	45.3	38.0	30.2
Mesoamerica	56.2	46.4	38.0	29.8	22.9
Caribbean	49.4	41.2	33.0	27.6	22.6
Andean Countries	49.4	43.2	35.1	27.1	21.2
Brazil	54.4	46.2	35.3	22.5	15.6
Southern Cone excluding Brazil	24.0	19.6	17.1	15.7	13.0
Southern Cone	44.4	38.4	30.6	20.9	14.9
Latin America and the Caribbean	48.3	41.3	33.4	24.8	18.8
Asia	75.7	70.7	66.1	61.9	55.8
Sub-Saharan Africa	84.5	81.3	75.4	71.1	64.9
Developing Countries	76.4	71.6	66.0	60.8	54.2
United States	6.4	4.2	3.4	2.7	2.0
Western Europe	19.7	12.8	9.1	6.2	4.0
Developed Countries	26.2	17.6	13.0	9.9	6.8
World	60.7	55.8	51.7	48.5	43.9

Sources: Compiled by authors from FAO 2004.

Notes: Agricultural labor and total labor force refer to economically agricultural active population and total economically active population respectively.

ployed in agriculture in Mesoamerica (excluding Mexico); in the Caribbean and the Andean subregions, one-quarter was employed in agriculture, while the comparable fraction was less than one-fifth in the Southern Cone.

In developed countries, agricultural labor is declining in both absolute and relative terms. Agricultural labor in LAC is declining in relative terms because it represents a shrinking share of the labor force. Nonetheless, and in keeping with developing-country patterns generally, the amount of agricultural labor continued to grow in LAC for most of the post–World War II period, albeit at progressively slower rates. Looking at the whole 1961–2002 period, agricultural labor grew by only 0.4 percent per year in LAC, well below the world and developing-country averages of 1.3 percent and 1.6 percent, respectively. The slowest growth in agricultural labor was in the Caribbean (slightly under 0.1 percent per year), the Southern Cone (which shrank by 0.1 percent per year) and Brazil (which shrank by 0.3 percent per year).

In 1961 there were 36.9 million persons employed in agriculture; by 1991 that figure had grown to 44.7 million (an average rate of growth of 0.76 percent per year). In 2002, the economically active agricultural population had actually shrunk slightly to 43.5 million, implying an almost imperceptible 0.05 percent per year rate of decline for the 1990s.

Table 2.9 Land use patterns in Latin America and the Caribbean and the World, 2001

Country/region	Total land	Agricultural Land: Area	Agricultural Land: Share of total land	Share in agriculture of: Pasture	Share in agriculture of: Cropland	Share in cropland of: Irrigated land
Land use patterns, 2001		*(thousand hectares)*			*(percentage)*	
Mexico	190,869	107,300	56.2	74.6	25.4	23.2
Mesoamerica excluding Mexico	51,073	21,382	41.9	63.8	36.2	6.4
Mesoamerica	241,942	128,682	53.2	72.8	27.2	19.5
Caribbean	68,211	16,117	23.6	47.7	52.3	17.9
Andean countries	456,197	144,013	31.6	87.5	12.5	20.4
Brazil	845,651	263,465	31.2	74.8	25.2	4.4
Southern Cone excluding Brazil	405,781	231,928	57.2	82.0	18.0	8.9
Southern Cone	1,251,432	495,393	39.6	78.2	21.8	6.1
Latin America and the Caribbean	2,017,782	784,205	38.9	78.4	21.6	11.0
South Asia	412,917	224,945	54.5	8.5	91.5	38.3
East and Southeast Asia excluding China	614,593	246,376	40.1	59.4	40.6	19.8
China	932,742	555,276	59.5	72.0	28.0	35.3
Asia	2,688,158	1,388,785	51.7	61.4	38.6	33.2
Sub-Saharan Africa excluding South Africa	2,267,370	910,134	40.1	81.9	18.1	3.2
Developing countries	7,603,818	3,178,554	41.8	71.9	28.1	22.9
Transition markets	2,312,223	633,631	27.4	60.0	40.1	9.8
Japan	36,450	5,199	14.3	7.8	92.2	54.8
Australia and New Zealand	795,029	472,735	59.5	88.6	11.4	4.9
United States	915,896	411,259	44.9	56.9	43.1	12.7
Western Europe	357,987	145,270	40.6	41.0	59.0	15.2
Developed Countries	5,463,848	1,843,180	33.7	65.4	34.6	10.7
World	13,067,670	5,021,734	38.4	69.5	30.5	17.8

(continued)

Agricultural Land

In 2001, LAC accounted for about 15 percent of the world's agricultural land, 11 percent of the total arable and permanently cropped land, and 7 percent of the area under irrigation (Table 2.9; Supplementary Table S2.2). Nearly 40 percent of LAC's total land area of 20.2 million square kilometers was used in agriculture (principally cropland and pastures), 49 percent was in forests, and 12 percent was used for others purposes. The Southern Cone countries accounted for 63 percent of LAC's agricultural land. The Andean and Mesoamerican subregions each accounted for about 17 percent, while the Caribbean made up only 2 percent of the total. But these regional figures mask the striking importance of just three countries, Argentina, Brazil, and Mexico, accounting for a total of 70 percent of LAC's agricultural land.

Most LAC land is used for nonagricultural purposes. In only 13 of a total of 42 countries did agriculture account for more than half of the total land area in 2001.

Table 2.9 (continued)

Country/region	Agricultural Land	Pasture	Cropland	Irrigated Land
Land-use growth rates, 1961–2001		*(percentage)*		
Mexico	0.27	0.21	0.47	2.02
Mesoamerica excluding Mexico	1.01	1.14	0.81	2.92
Mesoamerica	0.38	0.33	0.54	2.08
Caribbean	0.64	0.05	1.34	2.52
Andean countries	0.39	0.36	0.55	1.79
Brazil	1.26	1.07	1.91	5.06
Southern Cone excluding Brazil	0.13	0.11	0.19	1.44
Southern Cone	0.67	0.56	1.14	2.58
Latin America and the Caribbean	0.57	0.47	0.94	2.22
China	1.39	1.53	1.03	1.29
South Asia	0.11	−0.39	0.17	2.09
East and Southeast Asia excluding China	0.07	−0.38	0.84	2.07
Asia	0.76	0.93	0.51	1.76
Sub-Saharan Africa excluding South Africa	0.13	0.01	0.78	1.92
Developing countries	0.50	0.45	0.65	1.83
Transition markets	0.11	0.40	−0.25	2.42
Japan	−0.79	−2.71	−0.56	−0.51
Australia and New Zealand	−0.08	−0.19	0.89	2.15
United States	−0.15	−0.25	−0.01	1.22
Western Europe	−0.39	−0.47	−0.34	1.76
Developed Countries	−0.03	−0.01	−0.07	1.67
World	0.29	0.28	0.32	1.79

Sources: Compiled by authors from FAO 2004.

Nonetheless, there is much cross-country variation in the share of land used for agriculture. Uruguay, El Salvador, and the Dominican Republic are exceptional, with agricultural land accounting for about 80 percent of their total land areas. But 91 percent of agricultural lands in the case of Uruguay, 47 percent in El Salvador, and 57 percent in the Dominican Republic are under pasture. By contrast, Chile has the smallest share of its total land base in agriculture in the region—just 20 percent.

In 2001, about 22 percent of the region's agricultural land was classified as cropland. Cropland accounts for more than half of the agricultural land in 20 of 42 Latin American countries for which data were available. Except for El Salvador, all of these 20 countries were in the Caribbean. In the remaining countries, permanent pastures accounted for the majority of agricultural land.

Land in agriculture expanded more rapidly in LAC (0.6 percent per year) than the world more generally (0.3 percent per year). Growth in agricultural land in the Southern Cone (0.7 percent) and the Caribbean (0.64 percent) exceeded the Latin American average, whereas the opposite was true for the Andean subregion and Mesoamerica (both 0.4 percent). Some of these subregional averages are heavily

Table 2.10 Land–labor ratios, 1961–2001

Country/region	1961	1966	1971	1976	1981	1986	1991	1996	2001
	(hectares per unit of agricultural labor)								
Mexico	14.1	14.1	13.4	11.9	11.3	10.8	11.0	11.4	11.3
Mesoamerica excluding Mexico	4.7	4.6	4.5	4.5	4.5	4.6	4.6	4.4	4.1
Mesoamerica	11.2	11.1	10.5	9.6	9.2	8.9	8.9	9.0	8.9
Caribbean	2.7	2.8	2.9	2.9	2.9	3.1	3.1	2.9	2.8
Andean Countries	16.9	16.4	16.0	15.2	14.8	14.3	14.0	13.7	13.5
Brazil	10.6	11.1	12.0	12.4	12.7	14.0	15.8	17.0	19.2
Southern Cone excluding Brazil	66.9	69.2	71.7	71.9	71.2	68.9	65.7	66.1	65.9
Southern Cone	20.5	20.5	20.9	21.0	21.1	22.6	24.6	26.4	28.8
Latin America and the Caribbean	15.7	15.7	15.7	15.3	15.2	15.4	15.9	16.3	16.9
Asia	1.7	1.6	1.5	1.5	1.4	1.4	1.4	1.4	1.3
Sub-Saharan Africa	6.7	6.5	6.2	5.9	5.5	5.1	4.7	4.3	4.0
Developing Countries	3.4	3.3	3.1	2.9	2.8	2.7	2.5	2.5	2.4
United States	71.7	78.5	87.2	89.2	91.8	91.1	94.4	103.8	112.1
Western Europe	4.8	5.7	6.9	7.7	8.8	10.2	11.7	13.5	15.9
Developed Countries	14.0	15.9	18.3	20.2	22.3	23.8	25.9	29.7	33.7
World	4.8	4.7	4.5	4.3	4.1	3.9	3.7	3.6	3.5

Sources: Compiled by authors from FAO 2004.
Notes: Land includes area harvested and permanent crops. Labor refers to economically active persons engaged in agriculture.

influenced by developments in the "big three" countries of Argentina, Brazil, and Mexico: for example, the growth in agricultural land increased 1 percent per year in Mesoamerica, when Mexico was excluded; growth dropped to 0.1 percent per year in the Southern Cone, when Brazil was omitted.[8]

Land–Labor Ratios

Having just examined trends in agricultural labor and land, we see that a striking feature of the data in Table 2.10 is that land–labor ratios throughout Latin America are much higher than for other regions of the world (16.9 hectares per unit of labor in 2001 compared with 2.4 hectares in the developing world and a global average of 3.5 hectares. This reflects a comparatively low population density; an expansion in the area under agriculture; the recent slow growth of agricultural labor; and a commodity mix biased toward livestock products, which have been growing fastest of all the agricultural commodity groups in LAC. And since 1981, land–labor ratios have increased, while for the developing countries as a group they have drifted down. Moreover, land–labor ratios among LAC countries vary markedly—114.8

8 The readily available land-in-agriculture measures are "stock" measures and thus do not indicate the actual area cropped, to the extent that they fail to account for variations in cropping intensities. Smaller rates of increase in agricultural land may mask higher rates of increase in cropping intensities.

hectares per unit of labor in Argentina in 2001 compared with just 0.7 hectares per worker in Haiti (Supplementary Table S2.3).

Purchased Inputs: Fertilizer, Irrigation, and Tractors

Fertilizerr. Between 1961 and 2001, fertilizer consumption grew at an yearly average rate of 5.9 percent in LAC—well above the global average of 3.4 percent per year, but less than the developing-country average of 8.0 percent per year (Appendix Table 2A.1). Fertilizer application rates in LAC grew by nearly 8 times after 1960 to average 104 kilograms per hectare of harvested area in 2001. Despite this growth, application rates lagged behind Asian rates in 2001 (whereas in 1961, LAC's rates exceeded those of Asia). In fact, the intensity of fertilizer use in LAC is now lower than for any other region of the world except Sub-Saharan Africa. For example, in 2001, developing countries applied around 105 kilograms of fertilizer per hectare of harvested area compared with a global average of 116 kilograms and a developed-country average of 142 kilograms. The most heavily fertilized areas in LAC are in Mesoamerica (excluding Mexico), where an average of 117 kilograms per hectare was applied in 2001, more than twice the rates for Southern Cone (excluding Brazil). This high application rate suggests that LAC's low average rates of fertilizer application are largely a consequence of the substantial share of agricultural land devoted to pastures—78 percent in LAC compared with 61 percent in Asia and 65 percent in the entire developed world.

Irrigation. Throughout much of the region the amount of agricultural land under irrigation expanded since 1961, especially in Brazil and Mesoamerica (excluding Mexico). In fact, the growth in irrigated area surpassed the average growth in both the developed and developing worlds. Nonetheless, by 2001, 11 percent of the cropland in LAC was irrigated compared with 23 percent in developing countries (33.2 percent in Asia) and 10.7 percent in the developed world. Again, this probably reflects the large share of agricultural land devoted to permanent pastures.

Tractors. The use of tractors grew too, at a faster rate throughout LAC (4.1 percent per year) than the world more generally (2.2 percent per year), but slower than in the developing world on average (6.5 percent per year). Much of the developing world growth took place in Asia, where tractor numbers grew at 9 percent per year after 1960. Brazil increased its use of tractors faster than any other country in LAC. Much of this growth occurred during the 1970s and 1980s, partially reflecting the effects of government subsidies for tractor purchases and overvalued exchange rates that stimulated tractor imports (Arnade 1992).

Despite the rapid growth in the use of tractors, the intensity of tractors throughout Latin America is low by world standards. In 2001, there were 23 tractors per 1,000 hectares of harvested area in the world, compared with just 14 tractors in LAC. Caribbean agriculture, with its relative emphasis on crops such as sugarcane, bananas, citrus, and coffee was the most intensive user of tractors in LAC, followed by the Southern Cone. Ratios of tractors per unit of land quadrupled in the Caribbean,

nearly quadrupled through Mesoamerica, and nearly tripled in the Southern Cone since 1961. Tractor intensities barely budged in the Andean subregion. Accounting for nearly half the total harvested area in LAC (and 46 percent of its tractors), Brazil increased its tractor-to-harvested area ratio by more than five times since 1961.

Population and Food Consumption Patterns

Population

Latin America was home to 535 million people in 2002. Slightly more than half the region's inhabitants live in just two countries—Brazil has 33 percent of the total and Mexico has 19 percent. There are also numerous small countries: just 5.4 percent of the total population lives in 26 of the 42 countries of the region considered here, including 1 Southern Cone country, 4 Mesoamerican countries, and 22 Caribbean countries.

By global standards, population growth has been quite high, averaging 2.2 percent per year since 1961 (compared with a global average of 1.7 percent per year). The population of some Latin American countries, including French Guiana, the Cayman Islands, Honduras, and Nicaragua, grew by 3.0 percent per year or more during 1961–2001. UNFPA (1996) pointed to the region's increasing rates of urbanization as a contributing factor to LAC's comparatively high rates of population growth (although the causality could easily run in the other, or both, directions). Government policies favoring urban over rural areas and agricultural industries reinforced the population shift from rural to urban areas. It is also likely that rural–urban income disparities and stalled land reforms accentuated the rural-to-urban flow of people.

In terms of the typically cited, "official" rates of urbanization, LAC now looks more like the United States and western Europe than other developing regions of the world (Table 2.11). The official statistics indicate that the Southern Cone (Brazil, Argentina, Chile, Paraguay, and Uruguay) was the most urbanized in LAC, with just 17 percent of its population living in rural areas, followed closely by the Andean subregion (24 percent), and Mesoamerica (25 percent). Just half of LAC's population was urbanized in 1961; by 2001, three-quarters (of a much bigger total population) was urbanized. According to FAO (2004), the share is expected to keep growing to around 84 percent by 2030, with urban populations doubling in Guatemala, Haiti, Honduras, Nicaragua, and Paraguay.

But, as de Ferranti et al. (2005) recently observed, the designation of rural versus urban data (including population) reported in the official statistics for LAC must be taken with a grain of salt. Official LAC statistics use various and often inconsistent criteria to determine who lives in rural communities, including the population size of any given settlement regardless of its territorial dimensions, or the extent of availability of basic services such as water and electricity. In contrast, the countries of the Organisation for Economic Co-operation and Development (OECD) typically

Table 2.11 Urbanization patterns, 1961–2002

Country/region	1961	1971	1981	1991	2002
			(percentage)		
Mexico	51.6	59.8	67.0	72.8	74.7
Mesoamerica excluding Mexico	34.5	38.7	42.6	46.3	52.5
Mesoamerica	47.3	54.5	61.0	66.1	68.7
Caribbean	40.9	47.6	54.1	59.2	63.5
Andean Countries	48.9	57.3	64.2	70.1	75.6
Brazil	46.7	57.6	67.7	75.5	82.3
Southern Cone excluding Brazil	71.2	75.8	80.2	83.1	85.3
Southern Cone	54.2	62.8	71.1	77.5	83.1
Latin America and the Caribbean	50.3	58.3	65.7	71.6	76.2
Asia	20.8	23.1	26.9	32.6	38.4
Sub-Saharan Africa	12.2	16.8	21.7	26.8	33.6
Developing countries	21.5	24.8	29.4	35.2	41.2
United States	70.3	73.7	73.8	75.4	77.7
Developed countries	61.0	66.8	70.0	71.8	73.5
World (246 countries)	34.1	37.0	40.0	43.9	48.1

Sources: Compiled by authors from FAO 2004.

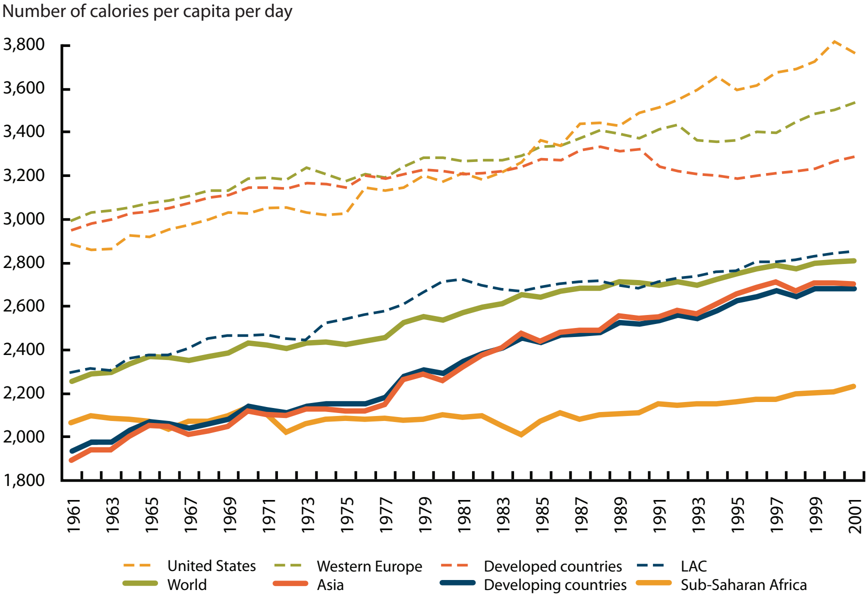
adhere to a comparable (and, for many economic purposes, much more desirable) set of criteria based on population density and distance to major urban center. Applying these OECD criteria to the available data for LAC, de Ferranti et al. (2005) find that the rural population in LAC in 2001 was around 42 percent of the total, not the roughly 24 percent reported in the official statistics cited in Table 2.11.[9] This recalibration suggests that rural nonfarm activities may be a more important aspect of the region's economies than has hitherto been considered the case.

Food Consumption

In thinking about agricultural research investment priorities, changes in the patterns of food consumption are important considerations. The commodity composition of consumption is not only affected by taste and tradition but also economic variables such as prices and per capita incomes, variables that in turn are affected by technical changes in agriculture and elsewhere in the economy. Figure 2.5 plots changes since 1961 in overall LAC food availability, a proxy measure of consumption defined as the per capita calorie equivalent per day of [production + imports – exports + stocks], or (equivalently) [total food supply – feed – seed – industrial uses – waste].

9 In an earlier study, Hertford and Echeverri (2003) note that a village of 400 families and 20 square blocks—large enough to exceed the 2,500 population cap placed on the definition of rural populations in most of LAC—is simply not predominantly an urban population. They reclassified population clusters as rural, except when 100,000 or more people resided in them. This reduced the proportion of LAC's population considered urban from 52 to 28 percent in 1998.

Figure 2.5 Food availability: Calories per person per day, 1961–2001



Sources: Compiled by authors from FAO 2004.

In these terms, food availability has trended upward for all regions of the world at a reasonably steady pace, but barely so for Sub-Saharan Africa. The LAC trend shows a more rapid increase in per capita food availability during the 1960s and 1970s (0.8 percent per year) than for the subsequent two decades (0.02 percent). By 2001, people in the United States consumed an average of 3,766 calories per capita per day (with consequent rapidly rising rates of obesity [see Philipson and Posner 2003]) compared with 2,852 calories per capita per day in LAC, representing just about the average world rate of consumption of 2,807 calories daily.

Where do these calories come from? Appendix Table 2A.2 gives the commodity composition of the daily intake of calories for 1961 and 2001 for LAC and the developing world.[10] Diets have clearly changed, and the changes in consumption have been quite profound for LAC. In 1961, maize was the most important source of calories (as it was and still is for Africa), accounting for 16.5 percent of the average intake. By 2001 it ranked second at 13.9 percent of the calories consumed, with sugar becoming the primary source of calories (as it is in the United States, but not in western Europe). Beans and cassava are now less significant sources of calories than they were in 1961, but still rank among the 11 most important sources. Bananas and potatoes are less significant in LAC diets now, too, and no longer

10 See also Supplementary Table S2.4 for comparative developed-country data.

rank among the top 11 calorie sources. Soybean oil is now the fifth most important source of calories: it was not even in the top 11 in 1961. Poultry meat is also a new entrant on the list, ranking eighth in 2001. More generally, 15.9 percent of the daily calorie intake of the region's population came from animal products in 1961. This share grew to 18.6 percent by 2001 and is likely to continue to grow. In 2001, the comparable share for the United States was 26.5 percent, and for western Europe it was 29.1 percent.

Clearly, reliance on present patterns of consumption (or food deficits) is an inappropriate basis for setting research priorities whose effects are generally not felt for years to come. Moreover, the productivity and relative price consequences of such investments can cause consumption patterns to change, as is undoubtedly the case with soybeans and poultry meat in LAC, to name but two examples.

Moreover, different crops are used with different intensities as a source of feed for livestock, with direct consequences for the income elasticity of demand for these crops and, thus, consequences for R&D priorities, given likely changes in consumption patterns. Figure 2.6 reveals substantial differences among crops in their feed usage, and some significant changes over time in the proportion of crop production going for animal feed uses. Potatoes, rice, and (to a slightly lesser extent) wheat are negligible sources of animal feed. Much more soybean production was destined for feed use in the 1960s than is the case now. More of this crop is now apparently used for oils directly consumed by humans. Almost 50 percent of the cassava crop, nearly 60 percent of the corn crop, and almost all the sorghum and millet crops are used for animal feed in LAC.

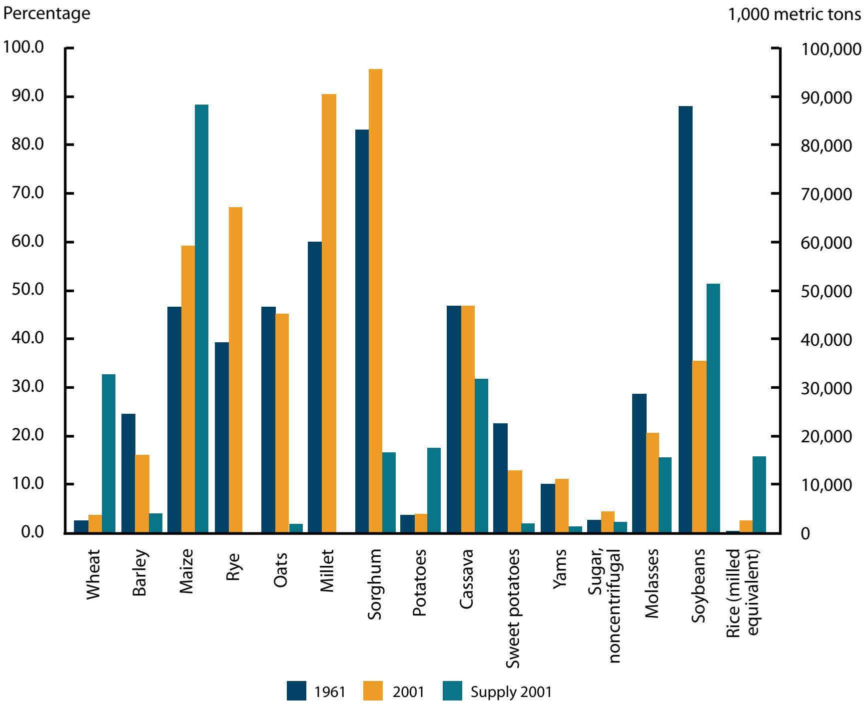
Agricultural Trade Trends

Differences between domestic production and consumption are reflected in changes in stocks, but mainly changes in the balance of trade. Trade allows countries to exploit their comparative advantages and to reap gains from specialization. Technical change can reinforce or reshape these important sources of growth.

General Patterns

The massive increase in global trade over the past several decades is well known. Agriculture has shared in that trade expansion, including Latin American agriculture. Figure 2.7a shows that total agricultural imports and exports have grown substantially since 1961, but not consistently so. In real terms, agricultural exports from Latin America now total US$53.3 billion (2002 dollars) compared with US$24.7 billion in 1961, an average rate of growth of 1.8 percent per year. Agricultural imports grew from US$7.1 billion in 1961 to US$29.3 billion in 2002 (a 3.6 percent per year rate of increase). The rate of growth for both imports and exports was most rapid during the 1970s, followed by a downturn in the 1980s. Imports began steadily growing again during the decade after 1987, turned down in 1988–89, and

Figure 2.6 Crops as a source of animal feed, 1961 and 2001



Sources: Compiled by authors from FAO 2004.

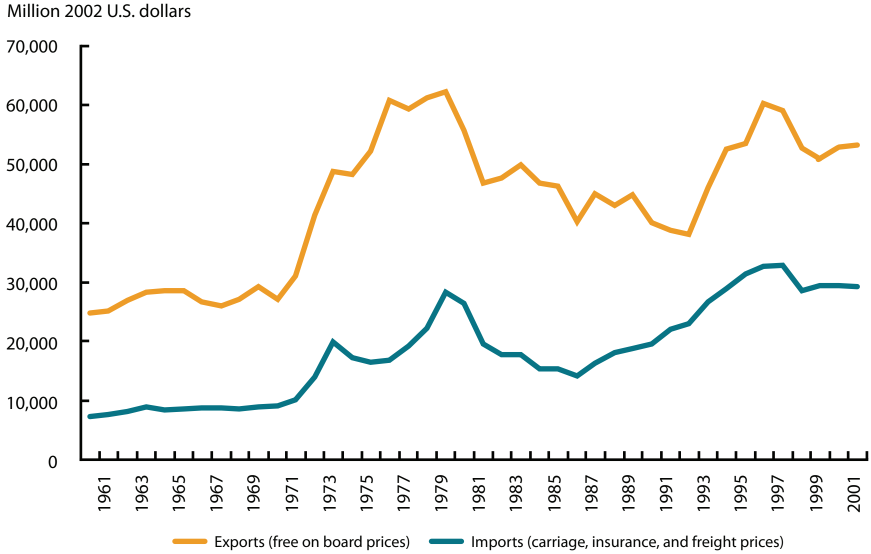
Notes: Percentages indicate the share of domestic supply used for animal feed in 1961 and 2001. Domestic supply relates to the quantity produced and added to net trade (imports minus exports), adjusted to change in stocks. The right y-axis (1,000 metric tons) refers to the domestic supply quantities for 2001.

remained steady for three years thereafter. Exports failed to pick up until 1994, but their rate of recovery was rapid, growing by an average of 6.6 percent per year from 1994–98 but slumping thereafter to average growth of only 0.6 percent per year from 1998–2002.

Figure 2.7b provides agricultural import and export ratios for 36 countries for 2002, with the corresponding 1961 ratios in a lighter shade. Confirming the broad trends identified in Figure 2.7a, imports have become a more significant component of total agricultural trade for most countries. Agricultural import–export ratios have declined for 25 (or 70 percent) of the countries in the region. There is also a significant spread in the trade orientation among countries. Figure 2.7b presents countries in ascending order, according to the degree to which agricultural exports dominate their agricultural import totals in 2002 (beginning with the British Virgin Islands). Countries like Argentina and Brazil generated more than $22 and $5 in agricultural exports, respectively, for every dollar spent on agricultural imports that

Figure 2.7 Overall trade trends for Latin American and Caribbean agriculture

a. Trends in total value of agricultural exports and imports, 1961–2002



Sources: Compiled by authors from FAO 2004 and World Bank 2004.

(continued)

year, whereas Cuba, the Dominican Republic, Mexico, and Peru had negative trade balances, spending more on agricultural imports than they received from agricultural exports.[11]

Notwithstanding the overall growth in agricultural trade, trade in mining and manufacturing products expanded even faster, so agricultural exports dropped as a share of total merchandise trade.[12] In 1962, agricultural exports (raw products and food) constituted over half of all merchandise exports from LAC; in 2001, they were just one-quarter of the total. The magnitude of changes in the trade shares of agricultural imports was also sizable but less dramatic. Agricultural imports declined from 16 percent of total imports in 1962 to 10 percent in 2002.

Spatial Patterns

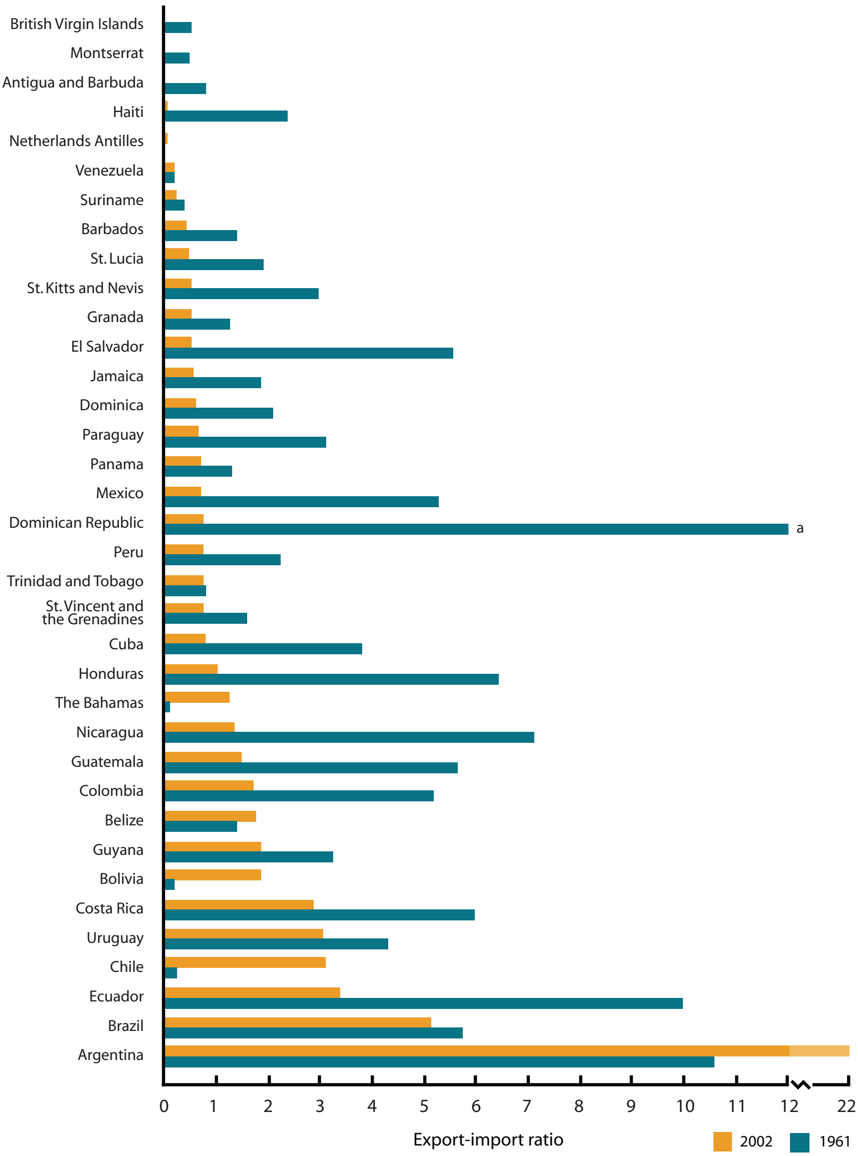
How did LAC trade in agriculture perform on a global basis? Who are the major importing and exporting countries? And what is the predominant country-to-country pattern of agricultural trade? Figure 2.8 identifies the principal exporting and im-

11 Here, agricultural trade refers only to trade in crop and livestock products. Fish and forest products are excluded from these data.

12 Merchandise trade excludes trade in services and construction.

Figure 2.7 (continued)

b. Export-import ratios for 36 countries, 1961 and 2002

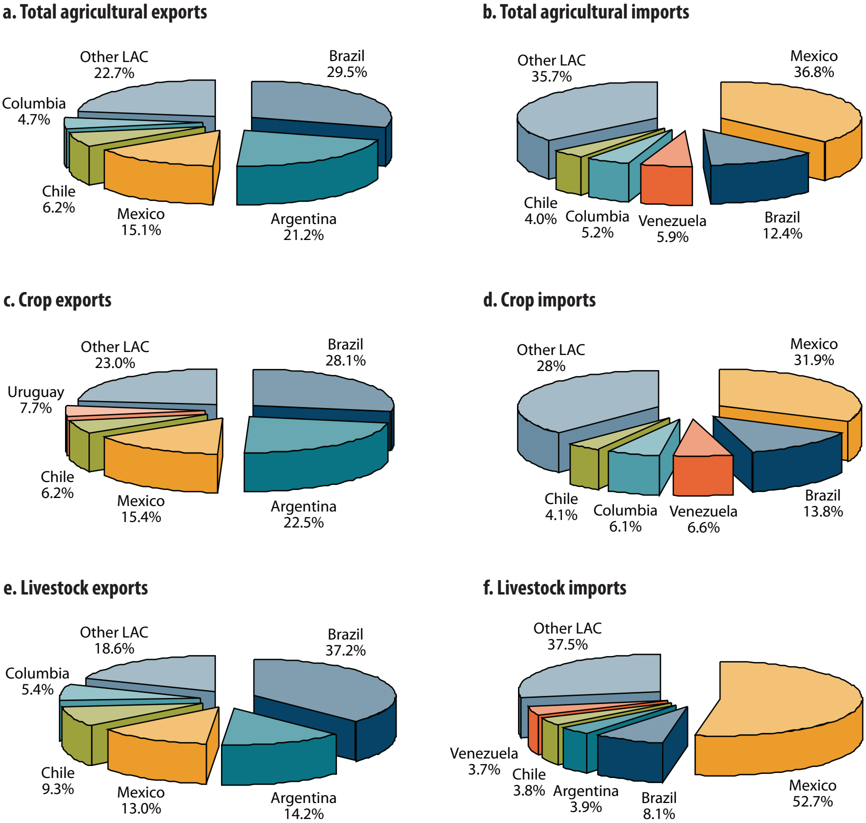


Sources: Compiled by authors from FAO 2004.

Notes: The value for the Dominican Republic in 1961 is 15.7.

[a] In 1961: 15.7 for Dominican Republic

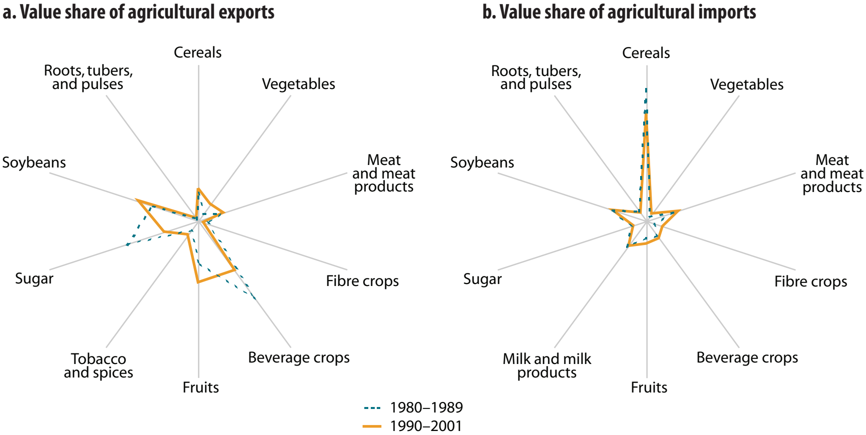
Figure 2.8 Value share of total agricultural, crop, and livestock exports and imports, 2000–02 average



Sources: Compiled by authors from FAO 2004 and World Bank 2004.

porting countries for crops, livestock, and total agriculture. As expected, Argentina, Brazil, and Mexico feature prominently in most aspects of agricultural trade, but not uniformly so. Taken as a group, these three countries accounted for 66 percent of the region's 2000–02 agricultural exports. A total of 55 percent of all agricultural imports are made by Brazil, Mexico, and Venezuela—a new player in the import market, surpassing Argentina. Brazil is the biggest exporter of agricultural products, and Mexico is the biggest importer. Brazil exports more crop and livestock products than any other country in the region. Mexico emerges as the third-ranked exporter of livestock commodities, edging out Colombia, which is fourth-ranked and close to the total value of livestock exports from Argentina. Beef is the predominant export

Figure 2.9 Agricultural export and import commodity shares in Latin America and the Caribbean



Sources: Compiled by authors from FAO 2004.
Notes: Values along each axis indicate the relative share of the stated crop in the LAC regional total of (a) exports or (b) imports.

from Argentina, Colombia, and Mexico and is the second-largest after Brazil, where poultry exports dominate.

Trade Directions and Commodity Composition

The two panels in Figure 2.9 compare the value shares of exports and imports for 10 commodity groups during the 1980s with the corresponding 1990s figures. Large differences in the directions of trade flows and among commodity groups can be observed, especially in the case of exports. During the 1980s, beverage crops, cereals, fruits, soybeans, and sugar were the main exports; there were comparatively few exports of vegetables, cattle, pork, and chicken meat. Even though vegetables gained substantial ground as an export item between the two decades, they were starting from a small base in the 1980s. Sugar and beverage crop exports shrank markedly in the 1990s in relation to their averages in the 1980s, and fruits expanded significantly, along with soybeans. Pork and chicken meat increased their value shares of exports modestly. Imports were dominated by cereals (mainly wheat and maize) in both the 1980s and the 1990s, and the composition of imports remained largely unchanged between the two periods.

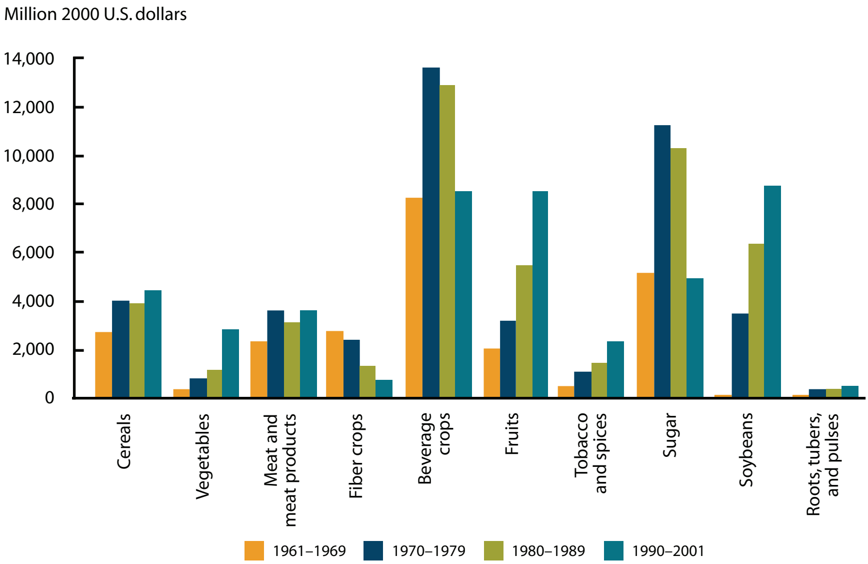
Figure 2.10 provides data on the average yearly value of exports and imports for four decades, beginning with the 1960s, including all major crop groups (and hence the individual crops) scrutinized in more detail later in this report. All crop groups are both imported and exported, and the value of these exports and im-

ports has increased over time. International trade in potatoes, cassava, and beans is modest, while rice, maize, sorghum, and especially wheat imports have risen faster than exports. Soybeans is the only crop in this sample to gain a substantial, positive net trade balance. By 1975 the value of exports reached six times the value of imports.[13] However, after 1975, this spread in the value of exports and imports narrowed. By 1997 the value of soybean exports was only three times more than the value of imports.

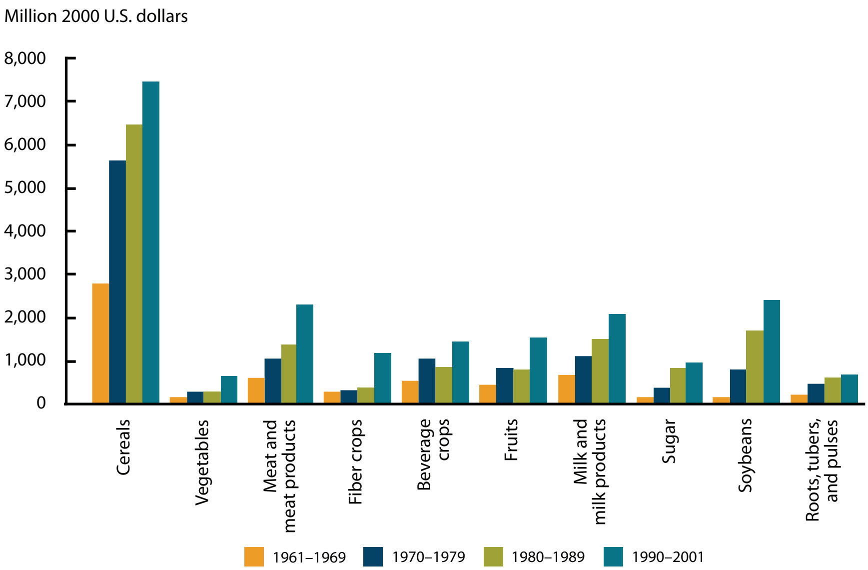
13 For most countries, exports are valued using FOB (free on board) prices, imports are valued in CIF (cost, insurance, freight) prices. FAO (2004) reports that CIF prices worldwide average 12 percent higher than corresponding FOB prices. This means that our net export values (that is, value of exports minus imports) overstate the implied *quantity* of net exports by about 12 percent on average.

Figure 2.10 Commodity orientation of agricultural exports and imports in Latin America and the Caribbean

a. Composition of exports



b. Composition of imports



Sources: Compiled by authors from FAO 2004 and World Bank 2004.

Appendix 2A. Data Sources and Treatments

FAO's online agricultural statistical database (FAOSTAT), and to a lesser extent the World Bank's development indicators database, are the main data sources used for this chapter. Although the best, the currently available statistics generated in developing countries are generally compromised by a lack of statistical resources and well-established national data systems. Moreover, the absence of standardized definitions, data compilation methods, and reporting affect the comparability of the data among countries. This section draws from and adds to the statistical notes accompanying the FAOSTAT and World Bank datasets to highlight the main problems and issues to be kept in mind when reading this chapter.

Agricultural Production

Reliability and consistency of agricultural production data can be affected in many ways. First, agricultural production data are often estimated because of incomplete or missing data, or in the absence of any other sources of information. In the case of milk, for example, FAO noted that estimates of the quantity *produced* sometimes rely on food *consumption* surveys and other indicators and that reliable statistics only exist for major milk-producing countries. Second, as mentioned above, differences in concepts, definitions, coverage, and classification of data between countries significantly affect the quality and comparability of the data. To illustrate, FAO notes that the concept of crop production can relate to (a) biological (or biomass) production of plants in situ; (b) harvested production, which excludes harvesting losses and production not harvested; or (c) marketed production, which excludes own consumption by farmers.

In the case of livestock, head counts cover all domestic animals irrespective of their age. Further, the timing of surveys can affect estimates since the livestock population is affected by seasonal factors that result in fluctuations in the number of livestock throughout the course of a year. This pattern of variation differs for different species of livestock and also varies from country to country.

Land

The stock of agricultural land reported by FAO consists of permanent pastures, arable land, and permanent cropland. Land of different quality is not accounted for. FAO notes that even distinguishing among permanent pastures, forests, and woodlands is not always a clear-cut task. Moreover, part of the arable area may not be cropped, or may be cropped more than once in a given year. As a consequence, the cropland area estimates may not represent the area actually cultivated within a given year. Mixed cropping practices also complicate the estimation of area cropped (per crop).

Population

FAOSTAT reports the United Nations Population Division estimates of total, rural and, urban population; and the International Labor Organization (ILO) estimates of the economically active agricultural population.

Yearly total population estimates are usually based on, and interpolated from, census data whose frequency and quality vary by country. When census data are not available, population estimates can be based on fertility, mortality, and net migration data collected from sample surveys. In contrast, yearly estimates of rural, urban, and economically active agricultural population are derived by applying yearly ratios of urban-to-rural population, and agricultural-to-total economically active population, to the corresponding population and economically active population totals.

The main difficulty associated with rural and urban population estimates relates to the various definitions of rural and urban areas used by various countries, on which urban and rural populations are based. The size of localities, type of local government, number of inhabitants, or proportion of population engaged in agriculture are examples of criteria used to classify urban and rural areas.

Economically active populations in agriculture represent the part of the economically active population engaged in or seeking work in agriculture, hunting, fishing or forestry. As such, this measure does not represent the flow of labor services. The number of hours worked in agriculture would be a greatly preferred measure of agricultural labor.

Agricultural Inputs

Total fertilizer consumption in agriculture is expressed in metric tons of primary, chemical plant nutrients (nitrogen, phosphorous, and potassium). Therefore, nutrients derived from traditional sources like animal and green manures are not included. The number of tractors in use in agriculture includes total wheel and crawler tractors and does not take into account quality differentials, depreciation, age, or power. Moreover, tractor counts fail to adjust for year-to-year variations in the intensity of use, and so for all these reasons, among others, can only be viewed as a rough approximation of the capital services use in agriculture.

Appendix Table 2.1 Input use in Latin American and Caribbean agriculture, amount and growth rates 1961–2001/2

Country/region	1961	1971	1981	1991	2002	1961–2002 Growth rates
Agricultural labor			*(1,000s persons)*			*(percent per year)*
Mexico	6,156	6,700	8,093	8,553	8,510	0.95
Mesoamerica excluding Mexico	2,671	3,220	3,580	3,985	4,562	1.22
Mesoamerica	8,827	9,920	11,673	12,538	13,072	1.04
Caribbean	4,044	4,005	4,023	4,143	4,082	0.08
Andean countries	6,967	7,815	8,904	9,748	10,311	1.02
Brazil	14,034	16,242	17,420	15,067	12,673	–0.31
Southern Cone excluding Brazil	3,006	2,836	2,919	3,224	3,365	0.42
Southern Cone	17,040	19,078	20,339	18,291	16,038	–0.18
Latin America and the Caribbean	36,878	40,818	44,939	44,720	43,503	0.42
Asia	612,553	708,095	829,506	962,718	1,042,698	1.40
Sub-Saharan Africa excluding South Africa	86,224	103,313	123,193	152,205	185,444	1.93
Developing countries	735,581	857,486	1,008,319	1,171,809	1,288,055	1.46
United States	4,942	3,850	3,875	3,578	2,906	–0.97
Developed countries	114,459	87,349	73,448	60,830	45,274	–2.10
World	850,040	944,835	1,081,767	1,232,639	1,333,329	1.20
Agricultural area			*(1,000 hectares)*			*(percent per year)*
Mexico	98,244	97,779	99,187	104,000	107,300	0.27
Mesoamerica excluding Mexico	15,056	16,378	18,421	20,519	21,382	1.01
Mesoamerica	113,300	114,157	117,608	124,519	128,682	0.38
Caribbean	12,401	14,069	15,404	16,545	16,117	0.64
Andean Countries	124,101	130,671	137,901	141,551	144,013	0.39
Brazil	150,531	199,632	225,824	244,941	263,465	1.26
Southern Cone (excluding Brazil)	218,460	221,885	223,053	226,469	231,928	0.13
Southern Cone	368,991	421,517	448,877	471,410	495,393	0.67
Latin America and the Caribbean	618,793	680,414	719,790	754,025	784,205	0.57
Asia	1,056,385	1,104,329	1,161,768	1,306,609	1,388,785	0.76
Sub-Saharan Africa excluding South Africa	865,084	874,256	883,160	905,286	910,134	0.13
Developing countries	2,624,478	2,750,208	2,854,367	3,057,540	3,178,554	0.50
United States	447,509	433,300	428,163	426,948	411,259	–0.15
Developed countries	1,880,102	1,882,421	1,885,583	1,859,833	1,843,180	–0.03
World	4,504,580	4,632,629	4,739,950	4,917,373	5,021,734	0.29

(continued)

Appendix Table 2A.1 (continued)

Country/region	1961	1971	1981	1991	2001	1961–2001 Growth rates
Irrigated area			*(1,000 hectares)*			*(percent per year)*
Mexico	3,000	3,750	5,020	5,800	6,320	2.02
Mesoamerica (excluding Mexico)	158	242	374	432	496	2.92
Mesoamerica	3,158	3,992	5,394	6,232	6,816	2.08
Caribbean	547	886	1,280	1,453	1,511	2.52
Andean countries	1,954	2,195	2,750	3,332	3,667	1.79
Brazil	490	850	1,700	2,700	2,910	5.06
Southern Cone (excluding Brazil)	2,112	2,612	2,960	3,410	3,709	1.44
Southern Cone	2,602	3,462	4,660	6,110	6,619	2.58
Latin America and the Caribbean	8,261	10,535	14,084	17,127	18,613	2.22
Asia	90,166	111,635	134,046	158,092	177,952	1.76
Sub-Saharan Africa excluding South Africa	2,709	3,171	4,064	4,882	5,221	1.92
Developing countries	101,954	126,227	153,400	182,274	205,064	1.83
United States	14,000	16,170	20,582	20,900	22,500	1.22
Developed countries	37,180	45,580	60,152	66,450	67,988	1.67
World	139,134	171,807	213,552	248,724	273,052	1.79
Total fertilizer application			*(kilograms NPK per hectare harvested)*			*(percent per year)*
Mexico	15.5	40.1	92.6	102.9	111.5	4.74
Mesoamerica excluding Mexico	20.7	60.1	81.9	89.4	117.4	3.61
Mesoamerica	16.6	44.2	90.3	99.7	112.9	4.47
Caribbean	35.8	88.6	160.1	106.1	83.1	0.57
Andean countries	23.4	36.4	59.8	93.6	112.9	3.79
Brazil	10.2	29.3	56.3	65.7	132.2	6.60
Southern Cone excluding Brazil	5.0	15.2	12.8	25.9	49.6	4.92
Southern Cone	8.1	24.5	42.8	53.8	101.2	6.18
Latin America and the Caribbean	13.5	33.3	59.1	69.1	103.8	4.65
Asia	9.1	28.8	66.8	116.0	139.3	7.03
Sub-Saharan Africa excluding South Africa	1.9	5.0	11.0	9.8	7.7	3.52
Developing countries	6.3	23.2	55.6	88.3	104.8	7.04
United States	85.7	168.6	164.4	190.5	199.6	1.25
Developed countries	70.2	148.9	178.6	173.4	141.8	1.23
World	32.1	70.6	102.8	116.9	116.0	2.89

(continued)

Appendix Table 2A.1 (continued)

Country/region	1961	1971	1981	1991	2001	1961–2001 Growth rates
Tractor intensity		*(tractors per 1,000 hectares harvested)*				*(percent per year)*
Mexico	5	6	8	20	19	4.59
Mesoamerica excluding Mexico	2	4	6	6	6	2.01
Mesoamerica	4	6	8	17	16	4.26
Caribbean	5	15	18	19	20	2.43
Andean countries	5	6	9	9	8	1.45
Brazil	3	5	12	14	16	4.87
Southern Cone excluding Brazil	11	12	13	16	13	0.67
Southern Cone	6	7	12	15	15	2.76
Latin America and the Caribbean	5	7	11	15	14	2.91
Asia	0	2	8	11	14	8.76
Sub-Saharan Africa excluding South Africa	1	1	1	1	1	1.24
Developing countries	1	2	5	7	9	5.53
United States	53	57	40	49	49	–0.56
Developed countries	27	39	44	53	54	1.70
World	12	16	20	23	23	1.69

Sources: Compiled by authors from FAO 2004.

Appendix Table 2A.2 Sources of calories consumed, 1961 and 2001

		Shares			Growth rates				
Rank		1961		2001	1961–1971	1971–1981	1981–1991	1991–2001	1961–2001
		(percentage)		*(percentage)*	*(percentage per year)*				
Latin America and the Caribbean									
1	Maize	16.5	Sugars	16.1					
2	Sugars	15.4	Maize	13.9					
3	Wheat	14.3	Wheat	13.2					
4	Rice	9.0	Rice	8.8					
5	Beans	4.9	Soyabean oil	5.3					
6	Bovine meat	4.8	Milk, whole	4.9					
7	Milk, whole	4.1	Bovine meat	3.7					
8	Cassava	3.7	Poultry meat	3.3					
9	Potatoes	2.1	Beans	3.0					
10	Pigmeat	2.0	Pigmeat	2.2					
11	Fats, animals, raw	1.8	Cassava	2.0					
Total calories (kcal/pers/day)		2,292		2,852	0.83	1.11	0.02	0.02	0.52
Calories from livestock		15.9		18.6					
Developing countries									
1	Rice	28.1	Rice	25.7					
2	Wheat	11.9	Wheat	17.7					
3	Maize	8.4	Sugars	7.3					
4	Sugars	6.1	Maize	6.2					
5	Sweet Potatoes	5.2	Pigmeat	4.0					
6	Sorghum	4.3	Milk, whole	2.2					
7	Millet	3.7	Vegetables, other	2.2					
8	Pulses, Other	3.3	Cassava	2.1					
9	Cassava	2.9	Soyabean oil	2.1					
10	Milk, Whole	2.0	Palm oil	2.0					
11	Barley	1.9	Sorghum	1.5					
Total calories (kcal/pers/day)		1,929		2,675	0.88	1.07	0.72	0.72	0.86
Calories from livestock		6.6		12.2					

(continued)

Appendix Table 2A.2 (continued)

Rank	Shares				Growth rates				
	1961		2001		1961–1971	1971–1981	1981–1991	1991–2001	1961–2001
	(percentage)		*(percentage)*		*(percentage per year)*				
Developed countries									
1 Wheat		26.7	Wheat	22.5					
2 Sugars		11.2	Sugars	12.7					
3 Milk, whole		7.1	Milk, whole	4.9					
4 Potatoes		5.6	Soyabean oil	4.9					
5 Rice		4.5	Pigmeat	4.4					
6 Pigmeat		3.6	Potatoes	4.0					
7 Rye		3.3	Rice	3.5					
8 Fats, animals, raw		3.0	Maize	2.9					
9 Butter, ghee		2.8	Cheese	2.9					
10 Bovine meat		2.6	Poultry meat	2.7					
11 Maize		1.9	Sunflowerseed oil	2.7					
Total calories (kcal/pers/day)		2,994		3,285	0.65	0.27	0.31	0.31	
Calories from livestock		24.9		24.7					
World									
1 Rice		18.2	Rice	20.1					
2 Wheat		18.1	Wheat	18.9					
3 Sugars		8.3	Sugars	7.9					
4 Maize		5.7	Maize	5.4					
5 Milk, whole		4.1	Pigmeat	4.1					
6 Sweet potatoes		3.1	Milk, whole	2.9					
7 Potatoes		2.9	Soyabean oil	2.8					
8 Sorghum		2.5	Potatoes	2.1					
9 Millet		2.4	Vegetables, other	2.0					
10 Pigmeat		2.0	Poultry meat	1.6					
11 Pulses, other		2.0	Cassava	1.6					
Total calories (kcal/pers/day)		2,255		2,807	0.66	0.68	0.52	0.52	
Calories from livestock		14.2		15.3					

Sources: Compiled by authors from FAO 2004.

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Chapter 3

Spatial Perspectives

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All three sections of this chapter deal with the spatial dimensions of agriculture in LAC. The first section compares the potential for agricultural production in different locations. The second section indicates how agriculture is actually being conducted by looking at land-use trends, the extent and intensity of agriculture, the distribution of crops across the region, and the use of irrigation. The final section integrates the previous evidence to develop a set of agroecological zones (AEZs) for the region that are especially useful in assessing the potential for technologies and production systems to spill across national and regional borders, sometimes over quite a distance.

Most of the land in LAC is comparatively flat and found at lower elevations. About two-thirds of the land area has average yearly temperatures in the 20º to 27º Celsius range, and average yearly precipitation exceeds 1,000 millimeters for almost 70 percent of the region. Eighty percent of the region has growing periods in excess of 120 days (in other words, sufficient length for most rainfed annual crops). These biophysical conditions describe a region with generally favorable natural resource endowments for agriculture, even though areas potentially suitable for temperate crops such as wheat and potatoes are limited. Nevertheless, 55 percent of the land is constrained by soil acidity. High soil pH limits the ability of plants to absorb nutrients and reflects aluminum saturation that reaches toxic levels on about 27 percent of the land. Most importantly, only 12 percent of all LAC soils are predominantly free from soil constraints. As a consequence, quite a high proportion of agricultural land in LAC is under pasture.

Biophysical Potentials for LAC Agriculture

This chapter presents new information on contemporary spatial patterns of the location, extent, intensity, and performance of agriculture within LAC. To a significant extent these patterns are conditioned by the gamut of biophysical conditions that prevail based on location or topographical conditions; variations in radiation, temperature, humidity, rainfall, or soil quality; and the occurrence of frosts, floods, and droughts. Assembling such information in spatially compatible formats and resolutions over comparable time periods, makes it possible to assess the productivity effects of existing and new technologies, policies, programs, and projects with much greater geographic precision than was previously possible. This information is particularly useful when evaluating initiatives developed to expand or intensify agricultural production in areas where biophysical limitations are currently significant—for example, hillsides, the acid savannas, and drought prone areas.

We interpret the biophysical context of LAC agriculture in two ways. First, we make informed comparisons of the conditions under which agriculture is performed in different locations throughout LAC. Second, we define the biophysical ranges within which *specific* commodities (or *specific* technologies) are likely to perform better or worse. This allows us to generate spatial perspectives, maps, of the *biophysical* suitability of production. This spatially explicit perspective provides a basis for anticipating the feasibility of applying technologies in locations distant from those in which they were developed and tested (a process we term "technology spillover").

In the following four subsections we describe:

- the data used to characterize physiography and climate;
- the interpretation of these basic data to generate agriculturally relevant measures of climate conditions;
- the development of crop-specific, agroclimatic suitability maps; and
- the nature and distribution of soil-related constraints to agricultural production.

Physiography and Climate

Two of the biophysical factors that most markedly influence agricultural production and the adoption of specific production practices are physiography and climate. The flat, subtropical grasslands of the *Pampas*; the subtropical, humid hillsides of Central America; the flat to rolling, humid tropical savannas; and the semi-arid sierra and *altiplano* of the Andean chain are just some of the important geographic building blocks of LAC and its agriculture. While the names *Pampas*, *Chaco*, *Cerrados*, and *Llanos* demarcate commonly understood locations and landscapes, they are not sufficient to provide a systematic and quantitative framework for comparing locations. For technology adoption and assessment purposes, locations are best com-

pared by characterizing them with a common set of relevant descriptors. Supplementary Figure S3.1 shows the spatial variation of the four principal physiography and climate variables that underlie our characterization: elevation, slope, rainfall, and temperature.

Both elevation and slope variables were derived from a global United States Geological Survey (USGS) 1 by 1 kilometer digital elevation dataset (USGS 1998). Elevation was taken directly from the database, while generalized slopes were estimated from elevation differences between adjacent 1 square kilometer cells, which were then aggregated into dominant slope values across a 10 by 10 kilometer grid (IIASA 1999).[1]

Just over half of LAC lies below 300 meters (Supplementary Table S3.1), while about 17 percent lies above 1,000 meters. The Southern Cone occupies almost two-thirds of the subregion but contains less than one-third of the land over 1,000 meters. Forty-four percent of Mesoamerica is above 1,000 meters, significantly more than the equivalent 28 percent of the Andean subregion and far greater than the 8.0 percent of land in the Southern Cone.[2] Above 2,500 meters, most farmers keep livestock adapted to high altitude—for example, llamas and sheep—because annual cropping is limited by short growing seasons and frost, although some crops, such as potatoes, can perform reasonably well at these elevations. Tree planting is limited to a few alpine species that are adapted to high altitude.

Around 41 percent of LAC is essentially flat (less than a 5 percent slope), and just over two-thirds of these flat lands are found in the Southern Cone (Supplementary Table S3.2). A remarkable 55 percent of Mesoamerican land is moderate to steeply sloping (greater than a 16 percent slope) compared with 33 and 13 percent of land in the Andean and Southern Cone subregions, respectively. Slope has many influences on agroecosystem capacity and management options, including drainage needs and soil erosion hazards, as well as mechanization and irrigation potential.

With respect to climate data, yearly average mean temperature and yearly total rainfall were derived from a database of long-term average monthly climate values developed by CIAT at a 10 arc-minute resolution, approximately 20 by 20 kilometers (CIAT 1996; Jones 1993). The data were derived by the spatial interpolation of long-term average values obtained from temperature and rainfall stations throughout LAC.

Around two-thirds of LAC has average yearly temperatures in the range of 20–27° Celsius, with the areas of 20–25° average annual temperature in the South-

1 The 10-kilometer (5 arc minute) grid size coincides with the spatial resolution of the global soil database described in this volume.

2 The Southern Cone region comprises Argentina, Brazil, Chile, Paraguay, and Uruguay; Mesoamerica comprises Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, and Panama; and the Andean region comprises Bolivia, Colombia, Ecuador, Perú and Venezuela. Wood and Pardey (1998) discuss changed over time in the land-area-by-elevation estimates for LAC. Significant land areas have been reclassified as better, satellite-derived, digital elevation data have become available.

ern Cone alone occupying around 25 percent of LAC (Supplementary Table S3.3). The Andean and Southern Cone subregions have similar proportions of cooler areas (18 and 17 percent respectively)—yearly average temperatures of less than 15º Celsius—but for different reasons. Since the Andean countries lie within tropical latitudes, cooler areas exist as a consequence of elevation, while in the Southern Cone cooler areas are largely a result of the southern extensions of Argentina and Chile into more temperate latitudes.

LAC is generally well-endowed with water, as measured by average yearly precipitation. Sixty-eight percent of the region enjoys an average yearly rainfall greater than 1,000 millimeters (Supplementary Table S3.4).[3] Mesoamerica (primarily Mexico) and the Southern Cone (primarily the Atacama Desert) have the largest shares of drier areas (an average of less than 250 millimeters of rainfall per year), occupying 10.0 and 7.6 percent of their lands, respectively.

Agroclimatic Characterization

Our objective is to interpret biophysical variables in ways that are useful in delineating spatial domains within which the impacts of prospective agricultural production technologies would be broadly similar. Several climate classification schemes have already been developed for LAC, including those of Köppen (1923) and Holdridge (1967), but they are based only on yearly climate totals or averages that mask seasonal differences, which have an important bearing on the performance of agriculture and agricultural technologies. While the Papadakis (1966) scheme was specifically designed to characterize agricultural climates, the method is not widely used. FAO later developed an AEZ approach, based on crop-specific climate and soil suitability criteria of relevance to the rainfed production of the world's major crops, which was used to characterize the lands of Mesoamerica and South America (FAO 1981).[4] This AEZ schema was adopted with enhancements for this study, using more contemporary digital climate data.

FAO's basic approach involves the construction of two agroclimatic variables—major climate (MC) and length of growing period (LGP)—that jointly inform the characterization of locations in terms of their (climatic) "suitability" for agriculture. Suitability can be assessed for rainfed agriculture, and if their agroclimatic requirements and tolerances can be quantified, suitability can be defined for specific crops as well.

The major climate variable is constructed in several steps. First, each location (grid cell) is characterized as tropical, subtropical, or temperate. This is done by expressing mean monthly ambient temperatures in each climate grid cell in terms of equivalent sea-level temperatures. Locations with monthly mean sea-level temper-

3 The derivation of a more robust water availability variable, the length of growing season, is described below.

4 The AEZs delineated in these original FAO studies also formed the basis of the more aggregated ecoregional classes used by the CGIAR system (TAC 1992).

atures greater than 18º Celsius throughout the year are classified as tropical. Those remaining locations for which all monthly mean temperatures (sea-level equivalent) are greater than 5º Celsius are classified as subtropical. All other locations are classified as temperate.

These three major climate zones are further spatially subdivided on the basis of the estimated average (ambient) temperature during the LGP at each location and whether the growing period lies within warmer or cooler parts of the year. Supplementary Table S3.5 details the defining characteristics of each major climate division, and Supplementary Figure S3.2 shows the separate spatial elements calculated for LAC.

LGP is defined as the period in days when rainfall exceeds half the potential rate of evapotranspiration, plus an additional period to allow for the consumption of residual moisture in the soil profile at the end of the growing season (up to a maximum of 100mm).[5] A growing period can only occur when the ambient temperature is greater than 5º Celsius. Typically, areas in which the LGP is less than 120 days are considered too arid for crop-based rainfed agriculture. Subhumid (180–270 days LGP) and humid (270–365 days LGP) areas are those most commonly used for rainfed agriculture. Supplementary Figure S3.2 shows the spatial variation of LGP across LAC.

After intersecting the major climate and LGP maps, we can assess how land in LAC is divided into distinct agroclimatic zones based on the combination of thermal and moisture conditions. Table 3.1 summarizes the distribution of LAC land area by agroclimatic classes, helping to confirm that the region is well endowed with water resources given that some 80 percent of the region has growing periods longer than 120 days—sufficient for most rainfed annual crops. Indeed, 39 percent of LAC is considered humid (with greater than 270 day growing periods), under which conditions multiple and even continuous rainfed cropping may be feasible. The warm, humid tropics account for almost 30 percent of LAC land area and constitute two-thirds of the warm tropics, which in turn are found in almost half the region (45 percent).

Agroclimatic Crop Suitability

Crops have specific agroecological requirements: they are better adapted to some ecologies than to others, particularly under rainfed conditions. Thus, the thermal (MC) and moisture (LGP) regimes most appropriate for sugarcane would likely be entirely unsuitable for potatoes. Since our objective is to support commodity-specific evaluations of technical change, we are particularly interested in interpreting the spatial measures of MC and LGP for each commodity among the eight selected in this study: dry beans, cassava, maize, potatoes, rice, sorghum, soybeans, and wheat. In addition to their value in assessing potential technology spillover among

5 In addition to the CIAT rainfall and temperature data, we used a potential evapotranspiration surface for LAC generated by Corbett (1997).

Table 3.1 Land-area distribution by major climates and length of growing period

Region	Major climate	Length of growing period (days): Arid					Semi-arid		Semi-humid			Humid				Total
		0	1–29	30–74	75–89	90–119	120–149	150–179	180–209	210–239	240–269	270–299	300–329	365–	365+	
									(percentage)							
Andean subregion																
	0	1.27	0.02	0.01	0.02	0.02		0.01	0.02	0.01	0.01			0.03		1.42
	1	0.02	0.05	0.05	0.09	0.22	0.35	0.73	0.95	2.52	2.32	1.10	1.05	3.27	4.32	17.05
	2	0.01	0.01	0.02	0.05	0.19	0.09	0.03	0.08	0.17	0.15	0.10	0.11	0.55	0.16	1.73
	3	0.09	0.09	0.26	0.35	0.72	0.11	0.13	0.24	0.14	0.18	0.10	0.10	0.33	0.07	2.94
	4	0.01	0.01	0.01	0.01											0.03
Subtotal		1.41	0.18	0.35	0.52	1.17	0.57	0.90	1.29	2.84	2.67	1.30	1.26	4.18	4.58	23.22
Caribbean																
	0										0.01	0.02		0.02		0.04
	1					0.01	0.01	0.09	0.09	0.15	0.14	1.28	0.49	0.72	0.03	3.00
	2												0.01	0.02		0.04
Subtotal						0.01	0.01	0.09	0.09	0.15	0.15	1.30	0.50	0.76	0.03	3.08
Mesoamerica																
	0	1.07	0.08	0.02	0.01						0.01	0.01	0.01	0.01	0.01	1.24
	1	0.10	0.22	0.36	0.45	0.56	1.04	0.87	0.54	0.36	0.74	0.54	0.21	0.31	0.04	6.34
	2		0.04	0.10	0.33	0.39	0.38	0.30	0.09	0.06	0.06	0.03	0.02	0.05	0.01	1.86
	3				0.01	0.03	0.10	0.12	0.04	0.03	0.02	0.01	0.01	0.01		0.37
	5/6							0.02	0.02					0.01		0.06
	7	0.03	0.57	0.31	0.21	0.09	0.11	0.03	0.01							1.36
	8		0.02	0.03	0.07	0.02	0.05	0.01								0.21
	9					0.01	0.02	0.01								0.05
	11	0.01	0.01	0.03	0.05											0.10
Subtotal		1.22	0.94	0.85	1.14	1.10	1.70	1.36	0.71	0.45	0.83	0.59	0.25	0.39	0.06	11.59

Southern Cone																
	0	5.61	0.15	0.03	0.02		0.01	0.02	0.02	0.01	0.03	0.04	0.02	0.08	0.05	6.09
	1	0.01			0.05	0.51	1.70	2.83	9.13	3.58	6.51	5.87	2.75	4.68	2.72	40.35
	2					0.02	0.01	0.01	0.05	0.15	0.11	0.14	0.05	0.58	0.17	1.30
	3	0.03	0.02	0.06	0.15	0.16	0.05	0.01								0.48
	4	0.01	0.02	0.01												0.03
	5/6							0.03	0.05	0.32	0.54	0.23	1.47	2.74	0.19	5.57
	7	0.01	0.11	0.10	0.29	0.51	0.23	0.24	0.16	0.02						1.66
	8		0.05	0.04	0.04	0.07	0.07	0.04	0.09	0.01						0.41
	9	0.02	0.51	0.24	0.08	0.11	0.11	0.19	0.18	0.17	0.09	0.30	0.16	0.11	0.03	2.33
	10		0.01													0.02
	11	0.09	0.73	0.25	0.18	0.19	0.06	0.16	0.10	0.02	0.08	0.05	0.28	0.60	0.07	2.86
	12	0.01	0.03	0.01												0.05
	13	0.06	0.26	0.16	0.05	0.03	0.02	0.01						0.21	0.14	0.93
	14	0.01	0.02													0.03
Subtotal		5.87	1.91	0.88	0.85	1.61	2.25	3.55	9.77	4.29	7.35	6.64	4.74	9.02	3.37	62.09
LAC total		8.51	3.04	2.09	2.51	3.88	4.54	5.90	11.87	7.73	11.00	9.83	6.74	14.36	8.02	100.00

Sources: Calculated by authors.

Notes: Major climates are designated as follows:

0	**Not assigned, growing period 0 days**	**5/6**	**Warm/moderately cool subtropics (summer rainfall)**	**11**	**Cool subtropics (winter rainfall)**
1	**Warm tropics**	**7**	**Warm subtropics (summer rainfall)**	**12**	**Cold subtropics (winter rainfall)**
2	**Moderately cool tropics**	**8**	**Moderately cool subtropics (summer rainfall)**	**13**	**Cool temperate**
3	**Cool tropics**	**9**	**Cool subtropics (summer rainfall)**	**14**	**Cold temperate**
4	**Cold tropics**	**10**	**Cold subtropics (summer rainfall)**		

locations, crop-specific spatial assessments also constitute a key input into procedures for making plausible spatial allocations of production statistics reported on a geopolitical basis.

Crop-specific agroclimatic suitability maps were generated by applying the agroclimatic suitability rules developed for LAC by FAO (1978, 1981) to the spatial data underlying the MC and LPG maps (Supplementary Figure S3.2). The crop suitability rules are summarized in Supplementary Table S3.6. The table shows four suitability classes for each of two notional levels of external inputs and technology (high and low) for any given combination of MC and LGP. The four suitability classes (VS, very suitable; S, suitable; MS, marginally suitable; and NS, not suitable) correspond to quartile classes of the yields likely to be obtained at each input level. Supplementary Figure S3.3 shows a selection of these commodity-specific, agroclimatic suitability maps generated by applying the crop suitability rules to the MC and LGP map database.[6]

FAO's AEZ crop-suitability rules were derived from a series of region-specific expert consultations that attempted to account not only for the intrinsic productivity of crop germplasm in specific agroclimatic zones, but also for more indirect effects, such as the likely prevalence of pests, diseases, and weeds that might affect both yields and product quality (FAO 1978, 1981).

The proportions of LAC land area that fall into each suitability class for each commodity are summarized in Table 3.2, which shows, for example, that under both high- and low-input assumptions, cassava-based production systems would be suitable from an agroclimatic perspective in just over 60 percent of LAC, with about half of that area being "very suitable" for production. Overall, areas potentially suitable for wheat and potato production are most limited, with up to 90 percent of LAC being unsuited to these two crops because of climatic constraints. Only less than 2 percent of the total land area of LAC is very suited to the production of either potatoes or wheat.[7]

Agroedaphic Characterization

While climate is the highest order determinant of the biophysical capacity of land to support agriculture, the quality of the soil layer is a close second-order consideration. Soils can exhibit significant spatial variability within a single farm—even within a single field or plot—and that variation can greatly influence the choice of economically feasible land uses and land-management practices. For example, soil structure, depth, and drainage determine cultivation options. Acidic, vertic, and or-

6 We did not generate a map for rainfed rice suitability because few new technologies are generated for rainfed rice, and we had other information on the actual location of rice production by technology (CIAT 1996).

7 Since the suitability rules were derived on the basis of broadly recognized crop-adaptability ranges, they probably underestimate the potentially suitable areas. For example, the potato germplasm holdings of indigenous Andean communities include traditional varieties adapted to agroecological niches that often lie beyond the generally construed range of suitability.

Table 3.2 Agroclimatic suitability shares of LAC extent by crop

Commodity	Production system	Area shares by agroclimatic suitability class: Very suitable	Suitable	Marginally suitable	Not suitable	Total
				(percentage)		
Beans	High inputs	18.5	23.4	16.2	41.9	100.0
	Low inputs	6.9	25.7	25.6	41.9	100.0
Cassava	High inputs	30.0	20.0	11.4	38.6	100.0
	Low inputs	30.0	26.2	5.2	38.6	100.0
Maize	High inputs	18.4	24.2	25.4	32.0	100.0
	Low inputs	18.4	36.8	12.8	32.0	100.0
Potatoes	High Inputs	1.6	8.6	5.2	84.6	100.0
	Low Inputs	1.6	8.6	5.2	84.6	100.0
Sorghum	High Inputs	17.5	15.8	10.4	56.2	100.0
	Low Inputs	17.5	14.6	11.7	56.2	100.0
Soybeans	High Inputs	17.5	15.8	10.4	56.2	100.0
	Low Inputs	5.2	41.1	6.1	47.6	100.0
Wheat	High Inputs	1.9	8.1	0.0	90.0	100.0
	Low Inputs	1.9	8.1	0.0	90.0	100.0

Sources: Calculated by authors.

Notes: Table presents the area share of land classified according to its intrinsic biophysical suitability to support production of the specified crop at the specified level of management/inputs. Classes reflect the potential yield level relative to the biophysical maximum; very suitable 75-100% biophysical maximum, suitable 50-75%, marginally suitable 25-50%, and not suitable 0-25%.

ganic soil types can be quite productive but require a variety of specialized and intensive soil-management interventions for productivity to endure over the long-term.

As a means of assessing the intrinsic capacity of soils to support agriculture, we have applied the Fertility Capability Classification (FCC) system, developed by Sanchez et al (1982), and based in part on extensive fieldwork in South America. The FCC approach condenses a wide range of information on soil properties into a set of up to 20 individual "flags," indicating the presence of likely constraints to agricultural use. We applied the 1997 version of the FCC rules to the LAC mapping units of the FAO Digital Soil Map of the World (FAO 1995) and estimated the proportional area of each soil constraint for each 5 by 5 minute grid cell.[8] Two constraints, cat clay and organic soils, were of minor importance in LAC and hence were not reported further.[9] The FCC "dry soil" constraint was also omitted because that property is cap-

8 A soil-mapping unit can contain up to eight soil types, each occupying a known share of the unit area. However, the spatial location of each soil type within the mapping unit is unknown. Where a single soil-mapping unit spans multiple 5-minute grids (which is normally the case), it is assumed that each soil type occurs within each grid cell according to the area shares for the entire mapping unit. If, in reality, soils within a mapping unit are not spatially heterogeneous, this assumption can give a misleading interpretation. Across all grid cells in any given soil-mapping unit, however, the interpretation will be correct.

9 Cat clay soils turn extremely acid when drained.

tured by the LGP variable. Likewise, the "erosion risk" modifier was omitted because its determining variable, slope, was included separately.

Supplementary Figure S3.4a indicates the proportion of each of the 5 by 5 kilometer cells that is free of soil constraints, while Supplementary Figure S3.4b shows the dominant constraint within each cell. A summary of the dominant constraints by region is presented in Table 3.3. Some areas have multiple constraints, but the figures and tables only report the dominant constraint in any location. Moreover, in the case of LAC, constraints are often related. For example, in many parts of the vast areas of the tropical savanna in Brazil, Bolivia, Colombia, Peru, and Venezuela sustained high rainfall has leached soluble cations (useful nutrients) from the soil and created acidic to highly acidic soils (pH less than 5.5). At such pH levels, the effective cation exchange capacity (that is, the ability to absorb cations) tends to be saturated with aluminum, and this saturation reaches toxic levels in around 27 percent of LAC. High levels of acidity also reduce exchangeable potassium (in 14 percent of LAC) and enhance phosphorus fixation (in 3.0 percent of LAC). Some areas have been classified simply as acidic (11 percent). Since these specific FCC constraints are generally applied in a mutually exclusive fashion, the results show that up to 55 percent of LAC land is constrained by one or other manifestation of soil acidity**.** Where economically feasible, the management response to this problem has been to apply lime.

The other regionally significant constraint is that of shallow soils (often associated with sloping lands) and gravelly soils, which together account for 13 percent of LAC. Only about 12 percent of all LAC soils are dominantly free of constraints.

In considering the significance of soil constraints (Table 3.3), it is important to recognize that many plants are adapted to tolerate some, not too severe, constraints even though higher yields are likely to be obtained in unconstrained soils. Irrigated paddy-rice production systems create a unique flooded soil environment for the rice plant that overcomes many constraints inherent in the original soils. Many crop improvement programs within LAC are actively seeking to develop germplasm that can produce acceptable yields even with soil constraints like high acidity and aluminum toxicity.

Location of Agriculture in Latin America and the Caribbean

The previous section explored the overall biophysical potential of agriculture in LAC and characterized the spatial variability of key biophysical factors that shape the region's agricultural potential. This section focuses specifically on compiling and interpreting evidence about the actual location of contemporary agriculture in LAC. Unless new technologies, land-use policies, or large-scale migration open up major new areas of agricultural land, the spatial pattern of R&D impacts—in terms

Table 3.3 Land area distribution by dominant soil constraints

Subregion	Soil Fertility Constraints														
	No cons-traints	High P-fixation	Hydro-morphy	Al Toxicity	Acidity	Shallow/ gravelly	Low moisture holding	Basic reaction	Low K-reserve	Low CEC	Natric	Salinity	Vertisol	X-ray amor-phous	Total
								(percentage)							
Andean subregion	1.5	0.4	1.8	8.8	2.6	3.0	0.6	0.6	1.7			0.2	0.2	0.2	21.8
Caribbean	0.2	0.4	0.3	0.7	0.2	0.3	0.1		0.6				0.2		3.2
Mesoamerica	1.9		0.5	0.4	1.7	4.2	0.4	1.0	0.7			0.1	0.7	0.3	12.2
Southern Cone	8.1	2.1	4.1	17.5	6.2	5.1	2.2	2.1	11.2	0.2	1.2	1.9	0.6	0.1	62.8
LAC total	11.7	2.9	6.8	27.4	10.6	12.7	3.2	3.6	14.3	0.2	1.2	2.2	1.6	0.6	100.0

Sources: Calculated by authors from FAO 1995.

Notes: Table shows the breakdown of the complete land surface of LAC. For a complete description of the soil constraint categories see Ahamed et al 2006.

of productivity, natural resources, and rural household welfare—will be principally determined by the current geography of agricultural production.

Remarkably, there has been little systematic recording of the actual location of agriculture, especially in ways that are comparable across countries. While small-scale efforts—such as micro-watershed studies—provide the luxury of observing details of the location, type, and intensity of agriculture, this is much more difficult at the macro level. For most regional studies, we must rely on production statistics reported for individual administrative units, with no clue as to the actual location of production within those units. The availability and resolution of agricultural production statistics in LAC range from the country level to the third-level administrative unit (usually *municipios,* equivalent to counties in the USA). Compiling such detailed information presents difficulties in reconciling differences in definitions and measurement units and other differences among reporting agencies (arising, for example, from different sampling techniques and crop calendars).

At a macro scale, the most consistent indicator of broad land-cover categories is satellite-derived data. Satellite data provide continuous spatial and periodic temporal land-cover imagery. But while satellite-derived data can reduce compatibility problems between conventional land-cover/land-use data sets, there is a (sometimes significant) tradeoff between spatial and temporal completeness, on the one hand, and image resolution and land-cover interpretation reliability on the other.

We proceed with four sections presenting evidence of the location and nature of LAC agriculture that have been integrated into our spatial assessments:

- the overall structure and trends in agricultural land use in LAC, drawing from global, regional, and subregional data sources;
- the delineation of the spatial extent of croplands in LAC based on a reinterpretation of 1 by 1 kilometer satellite-based land-cover imagery;
- the spatial distribution of several major crops—beans, cassava, potatoes, and rice-–as compiled from a variety of census and survey data covering a number of years and a variety of scales; and
- the first (albeit coarse) spatial assessment of the location of areas equipped for irrigation in LAC.

Agricultural Land-Use Trends

Statistics for LAC on actual land-use have only been gathered in a consistent and systematic manner at the national level. FAO compiles annual statistics received from member countries on arable land, permanent crops, permanent pasture, irrigated area, and harvested area. These data provide an overview of aggregate changes in land use since 1961.

Table 3.4 shows the relative levels and trends of agricultural land use for Mesoamerica, the Caribbean, and South America relative to the rest of the Americas and to other regions of the world. In comparing LAC agricultural land use to global trends, a major characteristic is its high proportion of total agricultural land under pasture. Only Oceania (primarily Australia) has a higher share of pasture—some 89 percent of total agricultural land, compared with around 82 percent for both South America and Africa. But contrary to trends in both those regions, pasture has continued to grow significantly in Central America and Brazil in the period 1986–96 (at around 0.5 percent per year against a global average growth rate of about 0.3 percent per year, with pasture lands actually shrinking in both the African and Oceania regions).

Irrigated land has been another growth area for LAC. The global rate of expansion in irrigated area in the 1986–96 period was around 1.6 percent per year, while South America expanded its irrigation capacity by 2.5 percent per year. Mesoamerica and the Caribbean also expanded their irrigated areas, but at about the global average rate. And while annual cropland areas have also grown at higher rates than in all other parts of the world, the substantially larger growth rate in the area of permanent cropland lags significantly behind the area expansion of over 3.0 percent per year in Asia and Oceania. The aggregate figures also indicate that both annual and permanent cropping intensities are decreasing—in the case of annual crops, quite significantly.

Turning to the LAC agricultural land-use trends of Table 3.5, the rate of growth of irrigated areas in Mesoamerica and the Caribbean slowed remarkably after 1976. While it also slowed in South America after 1976, during the 1986–96 period it rebounded to its 1966–76 rate of growth. Pastureland, on the other hand, has grown continuously for the past 30 years in South America, but with steadily declining rates of growth. For Mesoamerica and the Caribbean, the growth of pastureland has steadily accelerated in each decade since 1966. These two subregions also show different trends in growth rates of total agricultural land. While on average the post–1965 growth rates of agricultural land have been slightly more modest in Mesoamerica and the Caribbean than in South America, they increased in each decade in the northern regions. South America's slightly higher rates of growth of agricultural land, however, have been decelerating.

Caution should be exercised in interpreting the relatively low growth rates noted for agricultural land in Mesoamerica/the Caribbean and South America (0.74 percent and 0.39 percent per year, respectively). These are net rates of land-use change at the national level, and a lot of evidence suggests that such rates mask much larger dynamics in the gross switching of land both into and out of agriculture in different locations, in any country, in any given year (Wood, Sebastian, and Scherr 2000). For example, if 100,000 hectares were converted from forest to pasture in one part of a country, while 100,000 hectares of pasture were reforested in another part of the same country, national land-use accounts would show no change, while in reality significant changes would have taken place in both locales.

Table 3.4 Latin American and Caribbean land use and trends in a global context

A. Land use patterns: 1995–97 average

		Agricultural land		Share of agriculture			Annual crop area			Permanent crop area		
Regions	**Total land**	**Area**	**Share of total land**	**Pasture**	**Cropland**	**Irrigated land**	**Share of cropland**	**Share harvested**	**Cropping intensity**	**Share of cropland**	**Share harvested**	**Cropping intensity**
	(thousand hectares)				*(percentage)*				*(index)*	*(percentage)*		*(index)*
Africa	2,963,568	1,085,792	36.6	82.1	18.3	6.2	87.8	73.4	0.84	12.2	10.5	0.86
Asia	3,085,414	1,301,625	42.2	60.9	39.4	33.4	89.0	91.7	1.03	11.0	9.4	0.86
The Americas	3,889,968	1,252,859	32.2	69.4	30.7	10.4	92.7	59.5	0.64	7.3	4.5	0.61
North America	1,872,207	497,714	26.6	53.9	45.1	9.8	99.0	57.1	0.58	1.0	0.8	0.81
United States	915,912	422,976	46.2	56.6	42.3	12.0	98.9	56.5	0.57	1.1	1.0	0.84
Mesoamerica and the Caribbean	264,836	140,673	53.1	69.7	31.0	18.7	86.6	49.0	0.57	13.4	10.8	0.81
South America	1,752,925	614,471	35.1	81.8	18.9	8.5	82.7	68.0	0.82	17.3	9.2	0.53
Brazil	845,651	245,333	29.0	75.7	26.7	4.8	81.7	68.5	0.84	18.3	8.6	0.47
Europe	472,578	215,397	45.6	36.8	62.7	12.5	90.0	61.3	0.68	10.0	9.3	0.93
Oceania	849,137	481,814	56.7	89.3	11.5	5.2	94.7	35.5	0.38	5.3	2.0	0.38
World	13,048,410	4,923,788	37.7	69.4	30.6	17.5	91.3	70.5	0.77	8.7	6.9	0.79

B. Annual Growth Rates: 1986–1996

Regions	Agricultural land	Share of agriculture		Irrigated land	Annual crop area			Permanent crop area		
		Pasture	Cropland		Share of cropland	Share harvested	Cropping intensity	Share of cropland	Share harvested	Cropping intensity
						(percentage per year)				
Africa	0.12	−0.02	0.8	1.65	0.76	2.42	1.65	1.1	1.67	0.57
Asia	0.59	0.7	0.39	1.87	0.1	0.62	0.52	3.06	2.82	−0.23
The Americas	0.19	0.2	0.12	1.14	0	0.15	0.14	1.7	0.86	−0.82
North America	−0.21	−0.08	−0.45	0.9	−0.46	0.21	0.67	0.12	0.78	0.66
United States	−0.23	−0.09	−0.05	0.95	−0.56	0.17	0.73	0.08	0.83	0.76
Mesoamerica and the Caribbean	0.74	0.56	1.05	1.62	0.98	−0.24	−1.21	1.53	1.65	0.12
South America	0.39	0.28	0.97	2.48	0.78	0.15	−0.63	1.94	0.55	−1.37
Brazil	0.79	0.51	2.11	3.72	2.17	−0.61	−2.72	1.82	0.2	−1.60
Europe	−0.56	−0.81	−0.37	0.59	−0.37	−0.87	−0.50	−0.43	−0.88	−0.45
Oceania	−0.27	−0.29	0.61	3.57	0.49	0.62	0.13	3.1	0.61	−2.42
World	0.26	0.28	0.18	1.57	0.03	0.32	0.29	1.88	1.56	−0.32

Sources: Calculated by authors from FAO (2000).

Notes: Irrigated land, annual crop and permanent crop area are expressed as a share of cropland. Cropping intensity is harvested area divided by physical area.

Table 3.5 Land-use trends for Latin America and the Caribbean

Area	1965–1967	Share of agriculture	1975–1977	Share of agriculture	1985–1987	Share of agriculture	1995–1997	Share of agriculture
	(1,000 hectares)	*(percentage)*	*(1,000 hectares)*	*(percentage)*	*(1,000 hectares)*	*(percentage)*	*(1,000 hectares)*	*(percentage)*
Mesoamerica and the Caribbean								
Cropland	33,692	27.2	36,460	28.5	39,291	29.4	43,631	31.0
Annual crops	29,994	24.2	31,925	24.9	34,258	25.6	37,771	26.8
Annual harvested	20,415	16.5	20,629	16.1	21,898	16.4	21,377	15.2
Permanent crops	3,698	3.0	4,535	3.5	5,033	3.8	5,860	4.2
Permanent harvested	2,759	2.2	3,192	2.5	4,010	3.0	4,723	3.4
Permanent pasture	90,269	72.8	91,514	71.5	94,287	70.6	98,045	69.7
Irrigated land	4,041	3.3	5,990	4.7	6,952	5.2	8,165	5.8
Total agriculture	123,960	46.8	127,974	48.3	133,578	50.4	140,673	53.1
Total land	264,849		264,840		264,836		264,836	
South America								
Cropland	76,664	14.9	92,910	16.5	105,494	17.6	116,170	18.9
Annual crops	63,373	12.3	77,936	13.8	88,868	14.9	96,016	15.6
Annual harvested	51,585	10.0	67,972	12.0	77,836	13.0	78,977	12.9
Permanent crops	13,291	2.6	14,974	2.7	16,627	2.8	20,154	3.3
Permanent harvested	7,850	1.5	7,223	1.3	10,171	1.7	10,745	1.7
Permanent pasture	437,758	85.1	471,397	83.5	492,508	82.4	502,348	81.8
Irrigated land	5,007	1.0	6,368	1.1	7,719	1.3	9,865	1.6
Total agriculture	514,422	29.3	564,307	32.2	598,003	34.1	614,471	35.1
Total land	1,752,911		1,752,925		1,752,925		1,752,925	

(continued)

Significant dynamics were observed within each major agricultural land use—for example, in the share and location of individual crop species. As rural communities in LAC have become market economies and grown, factors such as comparative advantage, technical change, specialization, and economies of scale have tended to transform traditional, low external-input, polyculture production systems into higher input, monoculture, or simple rotation systems. Supplementary Figure S3.5 shows the case of two commodities (rice and soybean) illustrating these developments in Brazil.

In the mid-1960s, before the introduction of the new semi-dwarf (irrigated) rice varieties, Brazil relied on vast tracts of the Cerrados to produce its rice in mechanized "upland rice" (un-irrigated) production systems. With the introduction of the new, high-yielding, modern varieties in the mid-to-late 1960s, a distinct transformation began, with rice production expanding considerably into areas that are more favorable for irrigation, predominantly in the south. The upper half of Supplementary Figure S3.5 shows rice production areas in 1975 and 1995 and the difference

Table 3.5 (continued)

Annual growth rate	1966–76	1976–86	1986–96
	(percentage per year)	*(percentage per year)*	*(percentage per year)*
Mesoamerica and the Caribbean			
Cropland	0.79	0.75	1.05
Annual crops	0.63	0.71	0.98
Annual harvested	0.10	0.60	–0.24
Permanent crops	2.06	1.05	1.53
Permanent harvested	1.47	2.31	1.65
Permanent pasture	0.14	0.30	0.56
Irrigated land	4.01	1.50	1.62
Total agriculture	0.32	0.43	0.74
South America			
Cropland	1.94	1.28	0.97
Annual crops	2.09	1.32	0.78
Annual harvested	2.80	1.36	0.15
Permanent crops	1.20	1.05	1.94
Permanent harvested	–0.83	3.48	0.55
Permanent pasture	0.74	0.44	0.28
Irrigated land	2.43	1.94	2.48
Total agriculture	0.93	0.58	0.39

Sources: Calculated by authors based on data from FAO 2000.

Notes: Since FAO does not report total agricultural area and permanent pasture after 1995, averages under 1995¬–97 column for these two items are for the period 1992–94. Accordingly, their growth rates under the 1986–96 column are calculated from 1986¬–92.

between them. In 1975 Brazil was producing about 7.6 million tons of rice on 5.3 million hectares of land, at a yield of around 1.6 tons per hectare. Between 1975 and 1995 the once predominant rice production belt in the Cerrados shrank significantly because upland rice farmers could not compete with the lower production costs of irrigated rice farmers. By 1995 Brazil was producing 11.3 million tons of rice on 4.4 million hectares at an average yield of around 2.6 tons per hectare, chiefly as a consequence of the higher proportion of rice production under irrigated conditions in the south (Sanint and Wood 1998).

Improved soybean varieties and new land-management practices helped create the contemporary farming boom in the Cerrados. Many of the original soybean varieties were sensitive to day length, so they were more suited to conditions in the southern parts of Brazil. Drawing on U.S. know-how and material not sensitive to day-length, Brazilian researchers bred less photosensitive, disease-resistant varieties. Soybeans advanced northwards into the Cerrados region where the crop was often a timely replacement for the shrinking rice systems. The global surge in demand for vegetable oils also fueled the area expansion of soybeans—and by much

more than was the case for rice—since soybeans has not enjoyed an equivalent "Green Revolution" in its yield performance. As the lower part of Supplementary Figure S3.5 illustrates, between 1975 and 1995 the total soybean area more than doubled from 5.1 to 11.7 million hectares, while average yields increased from 1.7 to 2.2 tons per hectare (Pardey et al. 2004).

This example also serves to illustrate one of the potential applications of spatial analysis. Had the data and tools of spatial disaggregation and technology-specific characterization been available, the consequences that changes in rice and soybean technology brought about could well have been anticipated. A clearer *a priori* picture of outcomes would have been valuable not only for the design of appropriate R&D and technology dissemination strategies, but also for the design of rural development plans for the affected areas.

Agricultural Extent and Spatial Intensity

To obtain spatially disaggregated understandings of agriculture there are two prime sources of data: subnational production statistics and land-cover (or land-use) maps. Most national agricultural statistical yearbooks contain data for the first level of geopolitical disaggregation (for example, by state, department, or subregion), although collecting these data is a formidable task when dealing with many countries, especially if the intent is to construct spatially disaggregated time series to assess production trends.[10] National and subnational land-use maps exist for most countries. While many maps depict important subcategories of agriculture—rainfed versus irrigated areas and annual versus permanently cropped areas—they often suffer a number of inconveniences. The maps are frequently outdated or are not available in digital formats that would facilitate their integration with other data and models—they often employ different land-use/land-cover classification schema, even within the same country.

Of increasing availability and usefulness are data from a variety of satellite-based sensors that detect and record the nature of the earth's land cover. For this study, a 1- kilometer resolution global land-cover database was used, which was developed by the EROS Data Center (EDC) of the USGS (EDC 1999). This dataset identifies approximately 200 seasonal land cover regions (SLCRs) per continent (167 for South America and 205 for North America) based on the interpretation of 1 kilometer resolution satellite imagery obtained every 10 days for the period April 1992 to March 1993. Each SLCR has similar floristic and physiographic characteristics, as well as onset, peak, and seasonal duration of vegetative greenness; thus, the SLCRs capture both spatial and seasonal variations in vegetation cover. In the schema used by USGS to categorize each 1 by 1 kilometer (100 hectare) pixel, a pixel is declared to be of a given land-cover type if that land cover is deemed to occupy

10 At even more detailed levels, such as at the *municipio* level, it is usually necessary to rely on periodic agricultural census information, or survey data.

60 percent or more of the pixel area. When the dominant land use is not agriculture, this approach leaves open the possibility that up to 40 percent of a "nonagricultural" pixel could contain agriculture. However, by inspecting the detailed satellite data interpretations underlying the definitions of the SLCRs, it is possible to extract more specific data about the selected land-cover types. In consultation with EDC, this process was adopted, and the satellite land-cover data were reclassified in five levels of agricultural area intensity (Wood, Sebastian, and Scherr 2000):

1. *Greater than 60 percent agriculture.* As originally assigned, agriculture continues to be recognized as the dominant land-cover class.
2. *Between 40 and 60 percent agriculture.* Agriculture is explicitly recognized as part of a vegetation mosaic, for example, cropland/grassland.
3. *Between 30 and 40 percent agriculture.* Agriculture is explicitly recognized as a secondary, associated land cover, for example, forest with cropland.
4. *Between 0 and 30 percent agriculture.* In this instance, agriculture is not explicitly identified but might feasibly occur.
5. *Zero percent agriculture.* In this case, land is taken to be sparse or barren, making agriculture infeasible.

This dataset does not capture year-to-year variations in land cover. For example, the Pampas region of Argentina is characterized by between-year shifts in emphasis from cropping to grazing that cannot be captured in a single year of observation. And, indeed, it is difficult to identify such areas of shifting land use based solely on biophysical data. Although climate may have some effect on the choice of land use in the Pampas, shifts in cultivation are primarily dictated by the relative prices of grain and livestock produce (Hall et al. 1992).

Another shortfall of measuring land cover with coarse resolution satellite data is the difficulty in distinguishing between land-cover types that exhibit similar biophysical and temporal characteristics. For example, managed pasture is difficult to differentiate from natural grassland using satellite data at one-kilometer resolution. Pastures are a key component of agricultural production systems in LAC and should be included in any analysis of agricultural extent. Because of the difficulties of measurement, EDC consistently attempted to include highly managed pasture with agriculture but did not include extensive grazing lands. It is important to recognize this deficiency when comparisons are made between census-based values of agricultural area and those based on satellite data interpretation, particularly in LAC where extensive grazing systems are so widespread.

Supplementary Figure S3.6 shows the agriculture-focused reinterpretation of the USGS land-cover dataset for the Americas. The figure identifies the satellite-interpreted extent of agriculture while also distinguishing among different area intensities of agriculture within that extent. The overall distribution of agricultural

Table 3.6 Land-area distribution by agricultural land-cover class and subregion

Subregion	Agricultural land cover (cropland intensity) class[a]				Outside agriculture	Total area
	>60 percent	40–60 percent	30–40 percent	Total		
			(percentage)			
Andean subregion	0.8	2.1	1.3	4.2	18.8	23.1
Caribbean	0.3	0.1	0.1	0.5	2.5	3.0
Mesoamerica	1.5	0.8	0.1	2.4	9.0	11.4
Southern Cone	5.1	10.3	8.5	24.0	38.5	62.4
Latin America and the Caribbean	7.7	13.3	10.0	31.1	68.8	100.0

Sources: Authors calculations based on global agricultural land cover estimates from Wood, Sebastian, and Scherr 2000.
[a]For areas within the satellite-derived extent of agriculture.

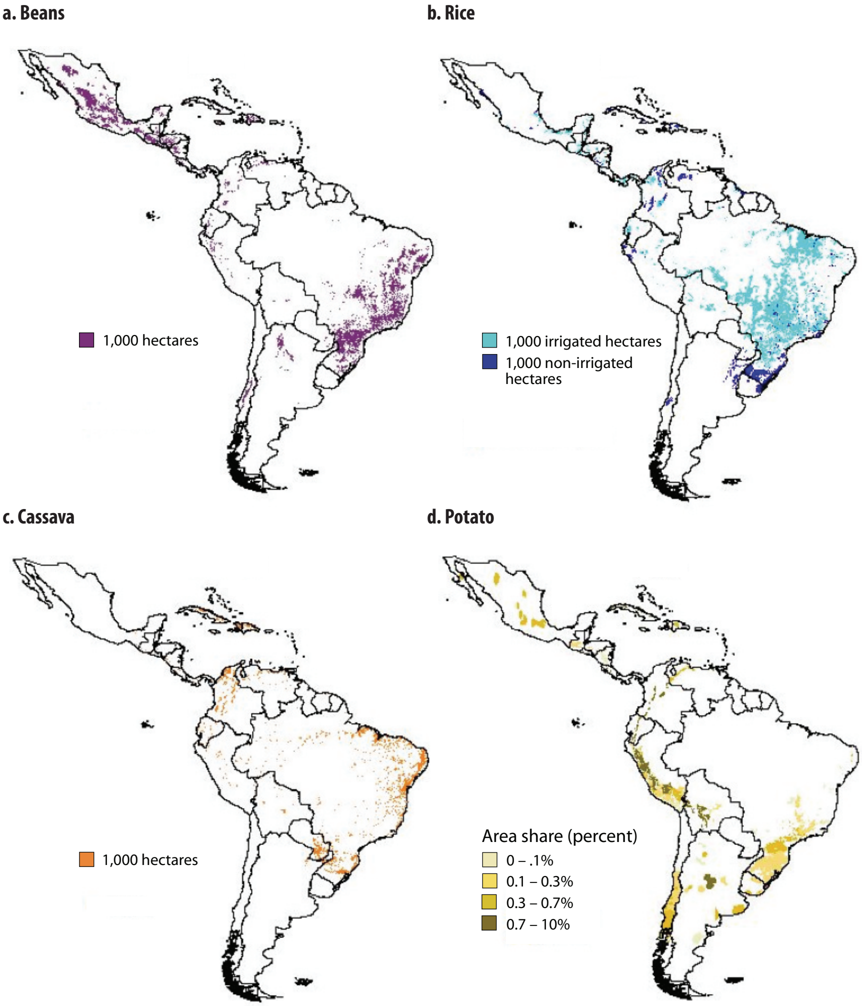
land by agricultural land-cover intensity and subregion is summarized in Table 3.6. Around 31 percent of LAC's area was interpreted as being under agricultural land cover in 1992–93, with roughly one-quarter of that area being intensively cultivated (areas containing more than 60 percent of agricultural land cover account for 7.7 percent of the 31.1 percent of land that is agricultural). The Southern Cone contains approximately 38 percent of the land under agriculture, while the other subregions have between 17 and 21 percent. The Caribbean and Mesoamerica are the most intensively cultivated in terms of the proportion of agricultural land classified as having greater than 60 percent agricultural land cover. Both the Southern Cone and Andean subregions have only around 20 percent of their agricultural land in this higher intensity agricultural land-cover class.

Crop Distribution

Collecting production statistics from increasingly detailed geopolitical units is one (albeit, costly and time-consuming) strategy for gaining an improved understanding of the crop-specific distribution of production. A complementary strategy is to prepare crop distribution maps that synthesize crop statistics, expert knowledge, remote-sensing information, and household census and survey data to make more spatially precise estimates of production areas. Several such maps have been prepared for LAC for beans, rice, cassava (CIAT 1996), and for potatoes (Hijmans 1999) (Figure 3.1).

While existing crop distribution maps are valuable, they have a number of operational difficulties. Because they are costly to update, they are often out-dated (the three CIAT maps used in this study were constructed from data sources spanning 1989 to 1993), and they are very often difficult to interpret and apply analytically. For example, the bean, rice, and cassava maps show points (dots) representing 1,000 hectares of harvested cropland, but that information alone is insufficient to define how to represent the 1,000 hectares spatially. The simplest assumption would be to make a circle of radius 1.78 kilometers around the point (thus delineat-

Figure 3.1 Crop distribution for beans, rice, cassava, potatoes



Sources: Rice, cassava, and bean data are from CIAT (1996); potato data are from Hijmans (1999).

ing a 1,000 hectare circle), but in very few cases would any area be 100 percent occupied by a crop. In making our own crop-specific, spatial allocation of production, we arbitrarily declared that the commodity should ideally be allocated within a 5 kilometer radius (7,850 hectare circle) of the 1,000 hectare reference point.[11]

11 The potato distribution map adopts a different approach that depicts the actual area ratio of potato production to the area of the reporting unit from which the data were derived, implying that this map

A comparison of the improvement in location specificity between the department (state or second-level) and the *municipio* (third-level) data is provided in Supplementary Figure S3.7. Here the left map shows potato production data taken from the IFPRI department-level database, on which has been superimposed the potato distribution data derived from more location specific data sources. The much better spatial definition is clear, as is the weakness of any approach that assumes a uniform distribution of production across or even within departments. The inset map of Brazil shows how the International Potato Center (CIP) distribution data are derived from *municipio* statistics. The shaded production areas are derived from the IFPRI departmental production database, which, in the case of Brazil, contains both state and *municipio* data. There are obviously significant advantages in compiling production statistics at the most detailed level available, but there are also significant costs involved.

The extent to which available crop distribution information corresponds to the satellite-derived interpretation of agricultural land is shown in Supplementary Figure S3.8. This figure is a composite of an enlargement of Supplementary Figure S3.6, centered on Brazil, and the 1,000 hectare points of the distribution maps for beans, cassava, and rice shown in Figure 3.1. Visually and qualitatively, at least, the correspondence seems good, although much more agricultural land is identified by the satellite than is suggested by the reference points for these three crops alone.

Irrigation

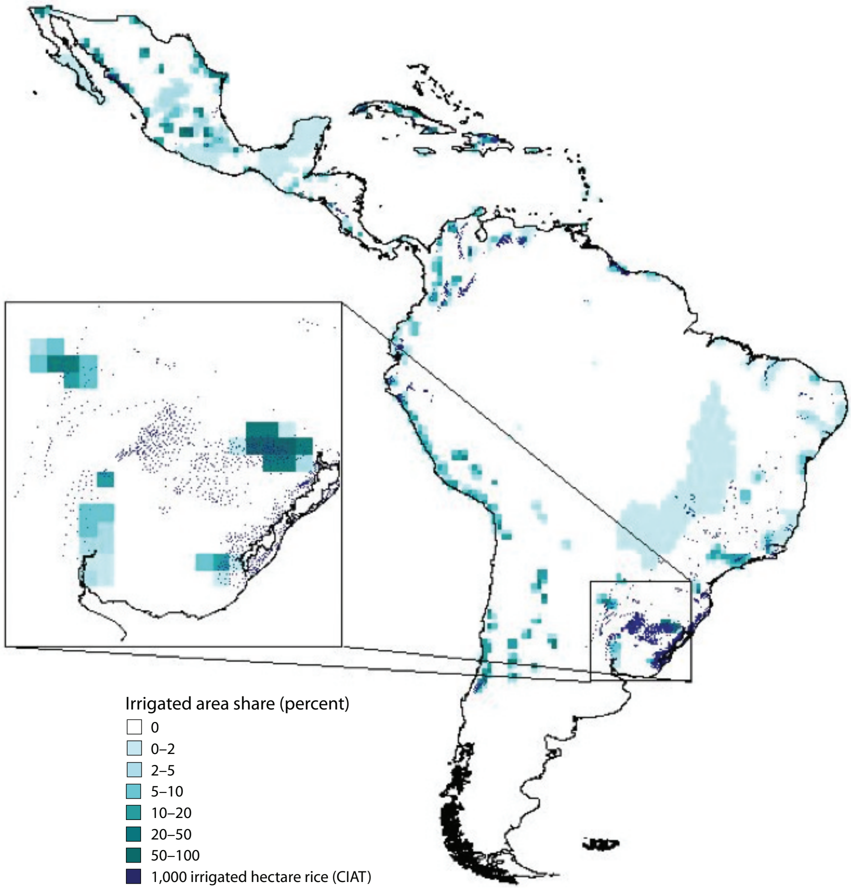
As the land-use statistics earlier indicated, irrigation has doubled in LAC over the past 30 years (1966–96) and now accounts for about 13 percent of arable cropland. There are no reliable estimates of the regional share of production these areas produce, although as much as 40 percent of global crop production has been ascribed to the 16 percent of global cropland that is irrigated (Bruinsma 2003).

The Center for Environmental Systems Research at the University of Kassel, Germany, generated the first digital global map of irrigation, which shows the spatial distribution of irrigated areas within each country. The map is a coarse resolution grid (0.5 by 0.5 degrees), with the cell values representing the area proportion of each spatial mapping unit equipped for irrigation in 1995. The map is based on national and international maps (dating as far back as 1963) showing the outline of primary irrigated areas within countries or drainage basins. Since the majority of the original maps did not provide information on irrigation density within the designated areas, these data were combined with FAO total irrigated area by country to determine the irrigated area and percentages within each mapping unit (Döll and Siebert 1999).

Figure 3.2 shows Döll and Siebert's percentage irrigated area for LAC, together with an overlay of CIAT's irrigated rice points. CIAT's rice distribution map is based on data gathered through expert interviews and on-site examination (CIAT 1992).

was primarily constructed from detailed administrative-unit statistics.

Figure 3.2 Irrigated areas of Latin America and the Caribbean



Sources: Doell and Siebert 1999; CIAT 1996.

Each data point represents 1,000 hectares of irrigated rice. Figure 3.2 suggests that, although much of the irrigation for Latin America is captured in the Kassel data, there are many known irrigation locations that fall outside Kassel's irrigated area. This is possibly due to the re-aggregation techniques that were used to scale the data from the digitized irrigated area units to the 0.5 degree resolution grid, but it is more likely because the source maps used for the Kassel database for Latin America date back to the 1960s and 1970s, and the irrigated areas have grown significantly in the intervening years.

In the following section, we describe how this irrigation area map was integrated with other data to arrive at a prototype rainfed and irrigated agroecological characterization of the agricultural lands of LAC.

Agroecological Characterization of Agriculture in Latin America and the Caribbean

Within the same country, potatoes will be grown in different places from bananas and papaya. Irrigated production will occur in areas that have both significant rainfall deficits during the growing season and access to surface or groundwater sources. Rice grows best in well-watered, heavy texture soils, while millet performs well in much less humid environments with better drained soils. Some maize varieties are well adapted to the radiation and temperature patterns found in lowland tropical areas, while other maize is better adapted to cooler and wetter areas found at higher elevations.

As these examples suggest, being more explicit about the characteristics of geographic zones makes it possible to increase the accuracy with which the impacts of production innovations can be anticipated.[12] We use the term agroecological zones (AEZs) to denote geographical areas within which the potential biophysical impacts of a new technology are expected to be relatively uniform.

Three significant, practical problems in implementing these broad concepts are:

- deciding how to delineate the spatial boundaries of appropriate AEZs;
- establishing what proportion of base-period production is found in each AEZ, with this proportion being a major determinant of the potential scale of impacts; and
- estimating the between AEZ technology spillover potential—that is, the extent to which technologies generated for one AEZ retain their effectiveness when applied in other AEZs.

Delineating Boundaries of Agroecological Zones

The preceding sections have described the biophysical diversity of land in LAC, as well as the spatial extent of rainfed and irrigated agriculture across the region. The agroclimatic schema described and implemented earlier—based on temperature-determined major climates and moisture-determined lengths of growing periods—was designed to assess the *potential* biophysical suitability of land for rainfed agriculture (FAO 1978, 1981). The irrigation map and the satellite-derived map of

12 Other aspects, like infrastructure, have different spatial dimensions that affect spatial patterns of adoption, and so an AEZ need not coincide with spatial patterns of adoption. We do not include this infrastructure dimension in the spatial assessments reported in this volume.

cropland extent provides additional information on the *actual* locations of irrigated and rainfed production. We have combined all these sources of data to create the integrated AEZs presented in this section, which provide the basis for the technology spillover simulations described in Chapter 7. By comparing mapped irrigated areas with those considered by experts to be substantially irrigated, we defined areas more than 15 percent equipped for irrigation as "irrigated" and areas that are 5.0 to 15 percent equipped for irrigation as "mixed-irrigated/rainfed"; we left all areas less than 5.0 percent equipped for irrigation unchanged in their original rainfed classification.

This AEZ characterization for LAC conforms to a generalized schema developed by IFPRI that has been applied to agricultural land globally (Wood, Sebastian and Scherr 2000). This facilitates the task of assessing the potential for technologies to spill across distant national and regional borders—for example, between the United States and LAC in the case of soybean varieties, or between Australia and LAC in the case of wheat—but also across locations within LAC.

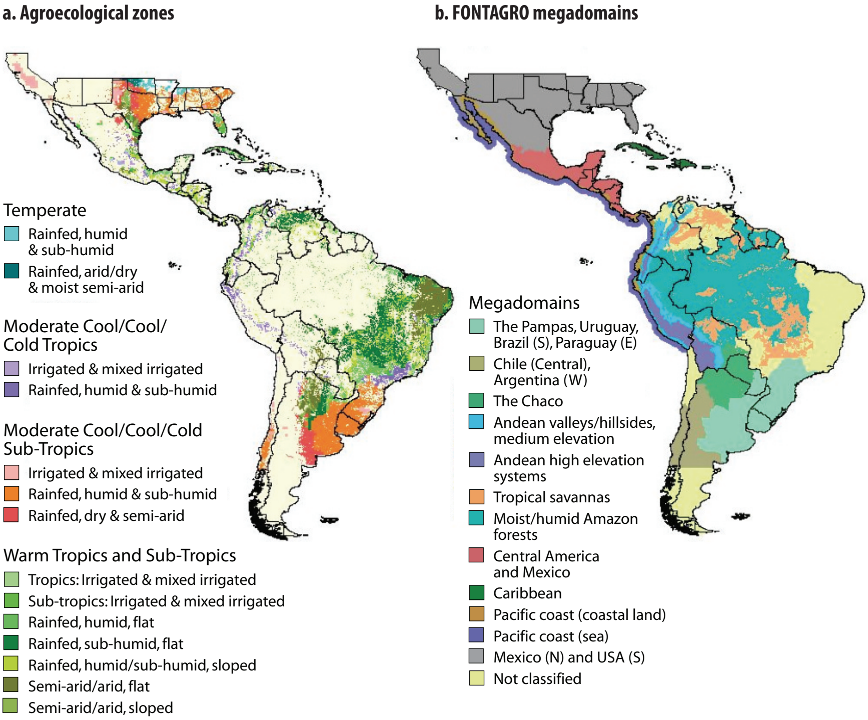
Koeppen (1923), Papadakis (1966), and Holdridge (1967) have specified the use of climatological and ecological measures to define agroecologies in LAC, but the appropriate definition of AEZs depends most importantly on the purposes for which they are to be used. Koeppen and Holdridge defined broad-based vegetation and ecosystem zones; Holdridge's definitions, in particular, are quite widely used in South America. While the Papadakis system was designed specifically for characterizing agricultural lands, its applications and uses have been limited. The Regional Fund for Agricultural Technology (FONTAGRO) divided LAC (and the southern United States) into several "megadomains" that used a mixture of geopolitical and agroecological variables for their definitions (FONTAGRO 1997). FAO (1978) designed a generic set of AEZs for assessing the production potential of rainfed crops, but these have only recently become available in digital formats.

Following a review of agroecosystem classification systems, we adopted a classification that integrates:

- a revised global assessment of the geographical extent and area intensity of agriculture (Wood, Sebastian, and Scherr 2000);
- revised FAO agroecological characterization variables for rainfed agriculture built on recent climate, elevation, and slope data (FAO/IIASA 2000); and
- spatial information on irrigation intensity (Döll and Siebert 1999).

A feature of this classification system is that it identifies existing production areas and distinguishes between rainfed and irrigated areas for the first time in a regional dataset. For some important rainfed zones, flatter and steeper areas are

Figure 3.3 Agroecological zones and megadomains



Sources: Agrocedogical zones are an IFPRI reinterpretation of data from USGS EDC 1998–99, IIAS/FAO 1999, and University of Kassel 1999. FONTAGRO megadomains are from FONTAGRO 1997.

also differentiated.[13] Figure 3.3a maps the resulting AEZ configuration, the country boundaries, and the regional geopolitical groupings adopted in this study.

Apart from including a rich set of attributes that can support characterizations of land at the subnational level, this classification has been applied to the world and, therefore, provides a more general basis for considering both direct and spillover consequences of technical change. This makes it possible to locate areas in (say) the United States, Europe, and Australia that fall within the same AEZ as does a particular area of LAC, making it possible to identify areas from which new technologies could potentially be drawn or, conversely, areas where technologies developed in LAC might be adopted outside the region.

13 And this helps to identify, for example, areas where technologies relying on mechanization would be most appropriate (flatter land), or where soil conservation techniques might have most impact (steeper land).

Allocating Agricultural Areas by AEZ

We were able to determine the area and proportion of agricultural land within each AEZ for each country and subregion of LAC by combining estimates of the location and intensity of agriculture derived from satellite information with an agro-ecological characterization of agricultural land and digitized data on geopolitical boundaries (Supplementary Table S3.6). We estimate that during the 1990s about 32 percent of the total land area in Latin America was used for agriculture, of which 75 percent was located in the Southern Cone, 14 percent in the Andean subregion, 9.0 percent in Mesoamerica, and less than 2.0 percent in the Caribbean. Looking within each subregion, the Andean countries have the smallest share of land in agriculture, about 19 percent, compared with almost 40 percent for the Southern Cone. Looking across LAC as a whole, 70 percent of agriculture lies within the warm tropics and subtropics, and the remaining 30 percent is in the moderately cool to cold tropics and subtropics. There are virtually no crop production areas with temperate climates.

Figure 3.3 illustrates our results and compares them with the megadomains defined by FONTAGRO which are described later in this section. By far the dominant agroecology for LAC's agricultural lands is the flat, rainfed, subhumid, warm subtropics/tropics that occupy some 25 percent of the region's agricultural land (AEZ 43). Much of the agricultural land in the Brazilian Cerrados, Venezuela, northern Argentina, and the savannahs of Bolivia is so classified. The rainfed, cool/cold subtropics (AEZ 31) are the next most extensive area, accounting for some 16 percent of LAC's agricultural land. This zone occurs almost exclusively in the Southern Cone countries, including southern Brazil, Uruguay, the Argentine Pampas, and central Chile.

While AEZs 31 and 43 constitute about half of the agricultural area in the Southern Cone, AEZs 21 and 43 jointly account for about half of the agricultural area in the Andean subregion. The agricultural land in Mesoamerica is agroecologically diverse, although the rainfed, sloping, warm subtropics and tropics (AEZ 44) more popularly known as the "well-watered hillsides" account for about 30 percent of the agricultural land.

Supplementary Table S3.7 is an expanded form of Table 3.6, showing how the agricultural land-cover classes are broken down by AEZ within each LAC subregion. Furthermore, the table quantifies those additional areas from the irrigation map that lay outside the satellite-derived estimate of agricultural extent. This means that the total agricultural extent represented in Figure 3.3a is greater than that of Supplementary Figure S3.6. The additional area is most significant in Mesoamerica, where the agricultural extent is almost 17 percent larger, allowing for irrigated areas not detected by satellite interpretation. In other subregions the differences are much less significant. The importance of well-watered hillside agriculture in Mesoamerica is also apparent. About 40 percent of the highest area intensity agriculture occurs in the AEZ classifying tropical, rainfed, humid/subhumid sloping land. On the other hand, in the Southern Cone around 76 percent of area intensive agriculture is in the tropical, rainfed, humid/ subhumid flat lands.

An alternative spatial aggregation is presented in Table 3.7 that shows the AEZ characterization of agricultural lands within each country and subregion. The upper half of the table shows agricultural extent in absolute area, while the bottom half shows the share of each country's land area in each AEZ class (as well as the share outside the agricultural extent). Differences among the agroecological configurations of each country can have significant impacts on the potential for technology transfer and spillover between countries.

Since both the AEZ characterization and the satellite-data interpretation are global in their coverage, it was possible to extend the mapping beyond LAC into the United States. This extension reveals some interesting patterns in AEZ distribution. For example, the rainfed humid and subhumid, moderately cool subtropics span key production zones in southern Brazil, Uruguay, and the Pampas of Argentina, as well as east Texas and other locations in the southern United States.

FONTAGRO Megadomains

Figure 3.3b shows the megadomains designed for FONTAGRO's first medium-term plan (FONTAGRO 1997). The domains were developed to support the cross-country requirements of FONTAGRO's research funding practices. Indeed, this megadomain perspective must be part of the proposal applications submitted to FONTAGRO's regional competitive research program. There were several criteria by which the domains were identified; some were agroecological, as in the case of the Chaco, the High Andes, and Tropical Savannas, while others were more socioeconomic, such as the Pacific Coast (coastal strip). There are still others that had a geopolitical motivation, such as the North Mexico/southern U.S. megadomain.

To better appreciate the extent to which the megadomains accord with an agroecological approach, we have overlaid the AEZ and megadomain maps. Table 3.8 summarizes the results and shows that a significant portion of LAC (25 percent) is not classified according to the FONTAGRO schema. This omission was a deliberate attempt to exclude areas, such as northeast Brazil, having conditions that are essentially unique to a single country. Thus, while such areas may be important from a national investment perspective, few economies of scope or scale are likely to be gained from a regional investment approach. About 62 percent of Megadomain 1, about half of Megadomain 2, and just over one-third of Megadomain 13 falls within AEZ 31—the rainfed humid and subhumid cool tropics. Fifty-five percent of the Chaco is located in the semi-arid/arid, warm, subtropics/tropics, and about the same proportion of Megadomain 4, the valley and hillsides of the mid-altitude Andes, is found in the cool tropics. A dominant share of Megadomain 6, tropical savannas, is located in potentially good land for agriculture—flat, warm, and subhumid—but since there are significant soil constraints in the tropical savannas, crop-based and improved pasture systems in these areas rely heavily on liming or support relatively extensive, medium- to low-grade grazing.

Table 3.7 Agricultural land by country and agroecological zone

Subregion/country	Area per agroecological zone within the extent of agriculture[a]												Area outside agriculture	Total land area
	20	21	30	31	32	40	41	42	43	44	45	46		
	(millions of hectares)													
Andean subregion	2.4	23.7	0.4	0	0	1.4	1.9	12.7	22.4	13.5	6.3	1.4	370.4	456.5
Bolivia		2.8						1.5	4.1	0.5	4.3	0.1	94.6	108.0
Colombia	0.8	6.3				1.1	1.5	6.4	1.9	5.0			89.3	112.3
Ecuador		2.6					0.3	0.5	0.5	0.9	1.4	0.9	16.6	23.6
Peru	1.6	9.9	0.4				0.1	1.7		0.9	0.3	0.2	108.0	123.1
Venezuela		2.0				0.3	0.1	2.6	15.9	6.2	0.3	0.2	62.0	89.5
Caribbean	0.3	0.2	0	0	0	2.0	1.2	3.2	2.2	2.2	0	0	47.9	59.3
Bahamas, the													0.1	0.1
Cuba						1.7	0.4	0.2	1.7	0.5			2.8	7.2
Dominican Republic	0.3	0.1				0.3	0.1			0.3			2.6	3.7
Haiti						0.1	0.2			0.5			0.9	1.8
Caribbean, other		0.1					0.5	2.9	0.5	0.9			41.6	46.5
Mesoamerica	3.5	9.1	1.6	0.2	2.9	2.7	3.8	5.7	3.5	15.8	5.3	1.3	169.7	225.0
Costa Rica	0.1	0.1				0.4			0.1	0.5			2.7	3.9
El Salvador						0.2			0.1	0.8			0.4	1.5
Guatemala		1.2					0.2	0.3	0.1	1.4			6.8	10.1
Honduras		0.5					0.1	0.3	0.1	2.9			7.2	11.0
Mexico	3.4	7.1	1.6	0.2	2.9	1.9	3.6	4.3	2.7	6.6	5.3	1.3	140.9	181.6
Nicaragua		0.1				0.2		0.6	0.3	2.2			7.7	11.1
Panama								0.1	0.2	1.3			4.0	5.7
Southern Cone	0.9	17.5	7.1	100.1	23.5	0.5	4.3	46.8	130.7	60.2	73.5	7.6	765.0	1,237.5
Argentina	0.6	0.3	1.9	46.4	22.7		0.9	4.6	11.0	0.8	17.5	6.3	161.5	274.6
Brazil	0.1	15.8	2.5	29.8		0.5	3.2	39.9	119.4	57.0	52.9	1.2	519.6	842.0
Chile	0.2		2.7	7.4	0.8								52.9	63.9
Paraguay		1.3		0.1			0.2	2.3	0.2	2.4	3.0		30.4	39.9
Uruguay				16.4									0.7	17.1
LAC total	7.3	50.5	9.1	100.3	26.4	8.6	11.5	65.6	160.1	92.2	85.1	10.3	1,352.9	1,979.9

(continued)

Table 3.7 (continued)

Subregion/country	Area per agroecological zone within the extent of agriculture[a]												Area outside agriculture	Total land area
	20	21	30	31	32	40	41	42	43	44	45	46		
									(percentage)					
Andean subregion	0.5	5.2	0.1	0	0	0.3	0.4	2.8	4.9	3.0	1.4	0.3	81.1	100.0
Bolivia		2.6						1.4	3.8	0.4	4.0	0.1	87.6	100.0
Colombia	0.7	5.6				0.9	1.3	5.7	1.7	4.5			79.5	100.0
Ecuador		11.1					1.2	2.0	2.1	3.9	5.8	3.8	70.1	100.0
Peru	1.3	8.1	0.4				0.1	1.4		0.7	0.2	0.2	87.7	100.0
Venezuela		2.2				0.3	0.1	2.9	17.8	6.9	0.4	0.2	69.3	100.0
Caribbean	0.4	0.3	0	0	0	3.4	2.0	5.4	3.7	3.8	0	0	80.9	100.0
Bahamas, the									30.7				69.3	100.0
Cuba		0.3				23.1	5.2	2.6	23.0	7.6			38.2	100.0
Dominican Republic	7.2	1.8				7.5	3.5	0.4	0.9	8.6			70.1	100.0
Haiti		0.5				4.1	13.1	0.9	0.9	29.4			51.1	100.0
Caribbean, other		0.2					1.0	6.3	1.0	1.9			89.5	100.0
Mesoamerica	1.5	4.0	0.7	0.1	1.3	1.2	1.7	2.5	1.6	7.0	2.3	0.6	75.4	100.0
Costa Rica	1.9	1.9				10.9		1.1	3.2	13.9			67.2	100.0
El Salvador						14.7			3.8	55.4			26.1	100.0
Guatemala		12.3					1.6	2.9	1.1	14.4			67.8	100.0
Honduras		4.7					0.8	2.7	0.8	26.0			65.0	100.0
Mexico	1.9	3.9	0.9	0.1	1.6	1.0	2.0	2.4	1.5	3.6	2.9	0.7	77.6	100.0
Nicaragua		1.0				1.8		5.8	2.3	19.6			69.3	100.0
Panama		0.7						2.1	4.0	22.7			70.5	100.0
Southern Cone	0.1	1.4	0.6	8.1	1.9	0	0.4	3.8	10.6	4.9	5.9	0.6	61.8	100.0
Argentina	0.2	0.1	0.7	16.9	8.3		0.3	1.7	4.0	0.3	6.4	2.3	58.8	100.0
Brazil		1.9	0.3	3.5		0.1	0.4	4.7	14.2	6.8	6.3	0.1	61.7	100.0
Chile	0.3		4.2	11.6	1.2								82.7	100.0
Paraguay		3.3		0.4			0.6	5.7	0.5	5.9	7.5		76.1	100.0
Uruguay				96.1									3.9	100.0
LAC Total	1.1	8.1	1.5	16.0	4.2	1.1	1.8	10.9	25.4	14.7	13.6	1.6		100.0

Sources: Calculated by authors.

[a]See Table 4.6 for a complete listing of AEZ definitions.

Table 3.8 Land area distribution by agroecological zone and megadomain

	Megadomains[a]													
Agroecological zones	1	2	3	4	5	6	8	9	10	11	12	13	14	Total
	(percentage)													
Temperate														
10 Irrigated and mixed irrigated/rainfed												0.5		2.5
11 Rainfed, humid and subhumid, flat												0.9		14.0
12 Rainfed, humid and subhumid, sloping												0.9		10.7
13 Rainfed, arid/dry and moist semi-arid												0.4		2.9
Moderately cool/cool/cold tropics														
20 Irrigated and mixed irrigated/rainfed			0.1	0.2	0.1			0.4				0.1		0.9
21 Rainfed, humid and subhumid	1.1		0.2	1.7	1.0			0.8		0.1		0.4	1.3	6.8
Moderate cool/cool/cold subtropics														
30 Irrigated and mixed irrigated/ rainfed	0.4	0.4	0.1	0.1						0.1		2.5	0.1	3.6
31 Rainfed, humid and subhumid	12.4	1.0	0.1									6.3	0.1	20.3
32 Rainfed, dry and semi-arid	2.5	0.5	0.1									2.3		5.6
Warm tropics and subtropics														
40 Tropics, irrigated and mixed irrigated/ rainfed				0.1				0.2	0.3	0.1		0.1	0.2	1.0
41 Subtropics, irrigated and mixed irrigated/ rainfed	0.2		0.1	0.1		0.1		0.1	0.1	0.1		0.6	0.4	1.8
42 Rainfed, humid, flat	1.9		0.3			1.2	2.0	0.7		0.2		0.6	2.6	9.7
43 Rainfed, sub-humid, flat	1.2		0.7			8.1	2.6	0.3	0.2	0.2		0.1	8.1	21.4
44 Rainfed, humid/subhumid, sloping	0.6		0.1	0.6	0.1	2.5	1.4	1.8	0.2	0.4		0.1	4.7	12.4
45 Semi-arid/arid flat	0.3	0.1	2.8	0.1			0.1	0.3		0.2		1.2	7.1	12.3
46 Semi-arid/arid, sloping	0.2		0.6	0.1				0.1		0.1		0.9	0.2	2.2
LAC Total	20.8	2.0	5.1	3.0	1.3	11.9	6.2	4.7	0.9	1.5		18.0	24.7	100.0

Sources: Calculated by authors.

Notes: FONTAGRO (www.fontagro.org) Megadomains are defined as follows:

1	Pampas, Uruguay, Brazil (S), Paraguay (E)	5	Sistemas Andinos Altos	10	Caribe
2	Chile (Centro), Argentina (O)	6	Sabanas Tropicales	11/12	Coste Pacifico
3	Chaco	8	Bosques Húmedos Amazónicos	13	Mexico (N) y EEUU (S)
4	Valles/Laderas Andinos Medio Altos	9	Centro América y México (Sur)	14	No Classification

Summary

LAC is agroecologically diverse and, with the exception of Sub-Saharan Africa, one of the few regions of the world where there remains significant potential for area expansion of agriculture. We have developed a regionally consistent schema to characterize the cultivated lands of LAC, allowing for both a visual and an analytical comparison of the conditions under which cultivation takes place. This spatial framework provides a powerful means of exploring multilateral and regional approaches to the design and implementation of agricultural research. Improved understanding of the similarity of production environments within and among LAC countries reveals opportunities for institutional and investment synergies that can exploit potential economies of scope and scale in the generation and testing of new technologies. The same framework can also be useful in identifying areas for the broader scale dissemination of a wide range of successful agricultural innovations from one part of LAC to another. We utilize this spatial framework in Chapter 7 of this volume when assessing the prospective local and spillover payoffs to research-induced productivity gains in LAC agriculture.

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Chapter 4

Agricultural Productivity

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A thorough understanding of the pattern and sources of agricultural productivity growth throughout LAC is critical for assessing the role of agricultural R&D. Productivity measures are of intrinsic interest as well. For example, how well has LAC agriculture performed, especially in terms of productivity levels and rates of growth? How variable was the performance among countries, crops, and different measures of productivity? What are the sources of the differences in observed productivity performance, and, especially, what is the role played by investments in R&D and technical change? These are among the central questions addressed in this chapter. We begin by examining the available evidence on trends in multi-factor productivity (MFP) and also provide new regional estimates of aggregate land and labor productivity patterns.

Agricultural performance is especially sensitive to agroecological aspects. However, with few exceptions, the available productivity evidence for LAC is based on country-level data, and so the explanations available for the observed changes in productivity are correspondingly coarse. To delve deeper, we also examine productivity at finer levels of spatial aggregation, namely, using state (second-) and *municipio* (third-level) aggregates. At these spatial scales of resolution there are insufficient data to estimate MFP indexes, so the analysis is performed using partial productivity measures, specifically output per unit of land input (yields) on a commodity basis. The interpretation of this evidence, stratified according to the AEZs described in the previous chapter, leads to additional insights into agriculture's performance. To enable the re-aggregation of national and subnational production data into AEZs, a novel method of spatially distributing tabular crop production systems was developed and applied. The last sections of the chapter also examine soil degradation and primary soil-nutrient balances in LAC as key determinants of the observed productivity of land.

These data point in the same direction, indicating that the levels of and changes in partial productivity are quite specific to particular, often rather narrowly delineated, agricultural areas. In many instances, crop productivity for LAC overall has risen at appreciable rates but often as a consequence of large productivity gains in just a few places throughout the region. In the Caribbean, for example, land productivity declines are shown for all countries—from 0.7 percent per year in Jamaica to 3.2 percent per year in Cuba. One view is that this sort of technical regression could be a consequence of protective agricultural policies that reduced competitive pressures to adopt new technology. It could also reflect a supply-side problem—lack of suitable, locally relevant technologies available for adoption.

We found that yield growth has favored areas where yields were already high and that less remarkable (even retrogressive) performance is evident in areas where yields were initially low. It seems LAC agriculture is becoming increasingly bifurcated and that land productivity gaps are widening. A partial explanation for these productivity patterns stems from the hitherto poorly measured spatial differences in agroecological attributes, especially soil-nutrient and other soil-quality considerations. We present new evidence on these agroecological features as a basis for understanding the roles that natural resource endowments play in shaping productivity performances and potentials.

Measuring Productivity

While the notions of productivity and changes in productivity seem straightforward and intuitive, developing meaningful measures of productivity or identifying the productivity consequences of investments in agricultural R&D is often problematic.[1] A clear understanding of the conceptual issues and inherent data problems involved is central to any attempt to estimate and correctly interpret productivity measures. The underlying concepts of productivity growth and its measurement in the context of primary agricultural production were broached by Schultz (1956) and Griliches (1961 and 1963).[2] Many of the measurement methods and problems are further discussed by Alston, Norton, and Pardey (1998). In the sections to follow we draw on these discussions, highlighting those aspects most pertinent to productivity growth and its measurement in LAC agriculture.

1 Parts of this and the following subsection draw heavily from Alston and Pardey (1996, Chapter 4).

2 Studies of U.S. productivity patterns formed the bulk of the early empirical work in agriculture, beginning with the estimates of national trends in MFP by Barton and Cooper (1948), which was extended to include 1866 to 1957 by Loomis and Barton (1961) and Kendrick (1961). The USDA published a Laspeyres productivity index (with coverage of the 10 USDA subregions) up until 1990, including estimates back to 1870, but a number of studies (for example, Diewert 1976) have shown that a chain-linked index specifically an approximation of a *Divisia* index is to be preferred. Hence, the types of index number formulation have changed. For instance, Ball (1985) provided Törnqvist–Theil indexes (recently extended and updated by Ahearn et al. (1998), and recent studies, such as Ball et al. (1997) and Acquaye, Alston, and Pardey (2003), have used Fisher Ideal indexes.

Partial-Factor Productivity

A conventional productivity index is a measure of the quantity of outputs divided by a measure of the quantity of inputs. The most widely used productivity measures express a single output per unit of a *particular* input such as land or labor. These partial-factor productivity (PFP) indexes divide a quantity index of total output (Q) by an index of the quantity of a particular input, or input aggregate, X_i: that is, $PFP_i = Q/X_i$. Changes in PFP may arise from changes in technology—changes in the relationship between measured inputs and outputs—or changes in the use of other (unmeasured) inputs. Thus an increase in yields (that is, land productivity) could simply reflect an increased use of fertilizer, while an increase in labor productivity may be due to increased use of machinery and other capital items. PFP indexes cannot, by themselves, distinguish between the effects of changes in the state of technology and changes in the input mix induced by shifts in relative prices, and so alternative productivity measures are commonly constructed.[3]

Total- and Multi-Factor Productivity

A more meaningful measure of changes in productivity attributable to R&D–induced changes in technology is given when ideal index number procedures are used so that *all* inputs are properly accounted for and index number problems are minimized.[4] A total-factor productivity (TFP) index includes an index of all N inputs used in production, X^N: $TFP = MFP_N = Q/X^N$. This type of index is comprehensive in that all of the relevant outputs are included in the output quantity index, Q, and all the relevant inputs are included in the input quantity, X^N. In practice the available data make it impossible to get a truly comprehensive accounting of all the inputs used in production, so a TFP index is really a conceptual construct rather than a practical reality. Instead, what are usually reported are MFP indexes that account for a subset, M of the N inputs, and divide the output index by the input index, X^M: that is, $MFP_M = Q/X^M$. Since some inputs are omitted from this index of input quantities (that is, X^M versus X^N), the MFP index is only an approximation of the TFP index.[5] Fewer inputs are omitted in the MFP index than in the PFP measure, but this only changes the degree of the problem of interpreting productivity measures where some inputs are omitted—it does not eliminate the problem of omitted inputs or omitted outputs.

Measures of MFP growth may be greater or less than the TFP growth being approximated, depending on what has been left out and how the left-out vari-

3 For example, if the price of purchased inputs such as fertilizer fell relative to land, farmers would lower their costs of production by substituting fertilizer for land, thereby raising land productivity even in the absence of any research-induced changes in technology.

4 The term "index number problem" refers to a situation where quantity changes resulting from relative price changes are not properly distinguished from other types of changes. This problem is discussed in detail in relation to productivity measurement in Alston, Norton and Pardey (1998).

5 It is also difficult to get a comprehensive accounting of all the outputs from agriculture. The available data may mis-measure changes in output quality or fail to reflect the changes in nonmarketed (for example, environmental) outputs from agriculture.

ables have changed over time. Typical TFP growth measures fail to fully account for changes in the quality of inputs (especially improvements in seed, fertilizer, machinery, schooling of workers [human capital], and deteriorations in the quality of land and water); inputs represented by infrastructure (for example, road, rail, and irrigations systems and telecommunications); and other rural public goods (for example, agricultural R&D or education investments); they also leave out certain types of outputs (such as environmental outputs).

MFP growth reflects both the changes in the quantity of the included output attributable to all the inputs that were omitted and any measurement problems arising from indexing procedures. If the aim is to measure the contribution of public agricultural R&D, it would be desirable to leave nothing else that matters out of the index. Otherwise, the productivity growth due to R&D will be confounded with productivity growth due to other omitted variables. On the other hand, if the objective is to measure the productivity effects of private as well as public investments in R&D or education, it would be inappropriate to "remove" the effects of private R&D and investments in education by including them in the index of inputs. In other words, different MFP indexes may be appropriate for different purposes, and in using indexes it is important to be clear about what is left out of the input index (hence, what is included in the set of things that account for growth in measured productivity).

Multi-Factor Productivity in Latin America and the Caribbean

The literature on agricultural MFP developments in LAC is comparatively sparse (Table 4.1). The first known study on agricultural productivity for Latin America using MFP indexes is by Hertford (1971), who reports an average rate of productivity growth for Mexico of 0.4 percent per year for the 1940–65 period. The next study, according to Trueblood (1996) was by Arnade (1992). Since then, a small number of studies have been published that report MFP indexes. But they differ in terms of their data sources, the span of outputs and inputs included, the aggregation procedures used, and their cross-sectional and time coverage, making it difficult to compare them.[6]

One group of studies assessed productivity developments as part of a comprehensive global assessment of productivity trends. A second group of studies reported aggregate agricultural productivity estimates for selected LAC countries, while a third group analyzed MFP developments for specific crops and subregions.

In the first group, Trueblood (1996), Arnade (1998), and Fulginiti and Perrin (1998) computed Malmquist indexes to estimate MFP for a comparatively large number of countries, including 17 countries in the case of Arnade, 22 countries for

6 Pardey, Roseboom, and Craig (1999) describe the difficulties of comparing different productivity estimates in more detail.

Table 4.1 Estimates of productivity growth in Latin American agriculture

Study		Orientation			Estimation procedure		Productivity estimates	
Authors	Year	Country	Commodity	Period	Indicators[a]	Method[b]	Rate of growth	Notes
							(percent per year)	
Hertford	1971	Mexico	Agriculture	1940–65	TFP		2.0	Change in aggregate input index formed as the sum of the compound growth rate of each input weighted by corresponding input elasticities taken from fitted Cobb-Douglas production functions.
Trueblood	1996	Argentina	Agriculture	1962–90	Malmquist	DEA	–3.46	This study estimated MFP growth for a total of 177 countries, of which 86 were developing countries, 31 developed countries, and 22 Latin American countries. MFP declined in 77 of the 86 developing countries.
		Bolivia	Agriculture	1962–90	Malmquist	DEA	–0.93	
		Brazil	Agriculture	1962–90	Malmquist	DEA	–1.76	
		Chile	Agriculture	1962–90	Malmquist	DEA	0.64	
		Colombia	Agriculture	1962–90	Malmquist	DEA	–5.61	
		Costa Rica	Agriculture	1962–90	Malmquist	DEA	2.00	
		Cuba	Agriculture	1962–90	Malmquist	DEA	–0.96	
		Dominican Republic	Agriculture	1962–90	Malmquist	DEA	–3.14	
		Ecuador	Agriculture	1962–90	Malmquist	DEA	–2.52	
		El Salvador	Agriculture	1962–90	Malmquist	DEA	–0.23	
		Guatemala	Agriculture	1962–90	Malmquist	DEA	–2.34	
		Haiti	Agriculture	1962–90	Malmquist	DEA	–1.62	
		Honduras	Agriculture	1962–90	Malmquist	DEA	–1.64	
		Jamaica	Agriculture	1962–90	Malmquist	DEA	0.12	
		Mexico	Agriculture	1962–90	Malmquist	DEA	–2.21	
		Nicaragua	Agriculture	1962–90	Malmquist	DEA	–4.41	
		Panama	Agriculture	1962–90	Malmquist	DEA	–1.91	
		Paraguay	Agriculture	1962–90	Malmquist	DEA	–2.17	
		Peru	Agriculture	1962–90	Malmquist	DEA	–0.48	
		Trinidad Tobago	Agriculture	1962–90	Malmquist	DEA	0.06	
		Uruguay	Agriculture	1962–90	Malmquist	DEA	0.06	
		Venezuela	Agriculture	1962–90	Malmquist	DEA	–0.69	

(continued)

Table 4.1 (continued)

Study		Orientation			Estimation procedure		Productivity estimates	
Authors	Year	Country	Commodity	Period	Indicators[a]	Method[b]	Rate of growth	Notes
							(percent per year)	
Arnade	1998	Argentina	Agriculture	1961–93	Malmquist	DEA	–1.85	This study estimated MFP growth for a total of 70 countries, of which 42 were developing countries, 28 developed countries, and 17 Latin American countries. MFP declined in 29 of the 72 developing countries.
		Bolivia	Agriculture	1961–93	Malmquist	DEA	4.68	
		Brazil	Agriculture	1961–93	Malmquist	DEA	–2.05	
		Chile	Agriculture	1961–93	Malmquist	DEA	1.25	
		Colombia	Agriculture	1961–93	Malmquist	DEA	1.82	
		Costa Rica	Agriculture	1961–93	Malmquist	DEA	3.32	
		Dominican Republic	Agriculture	1961–93	Malmquist	DEA	–1.15	
		Ecuador	Agriculture	1961–93	Malmquist	DEA	–0.99	
		El Salvador	Agriculture	1961–93	Malmquist	DEA	–0.75	
		Guatemala	Agriculture	1961–93	Malmquist	DEA	–0.46	
		Honduras	Agriculture	1961–93	Malmquist	DEA	–0.42	
		Mexico	Agriculture	1961–93	Malmquist	DEA	1.16	
		Nicaragua	Agriculture	1961–93	Malmquist	DEA	–2.01	
		Paraguay	Agriculture	1961–93	Malmquist	DEA	0.24	
		Peru	Agriculture	1961–93	Malmquist	DEA	0.62	
		Uruguay	Agriculture	1961–93	Malmquist	DEA	–1.30	
		Venezuela	Agriculture	1961–93	Malmquist	DEA	0.19	
Fulginiti and Perrin	1998	Argentina	Agriculture	1961–85	Malmquist	DEA	–4.80	This study estimated MFP growth for a total of 18 developing countries, of which 5 were Latin American countries.
		Brazil	Agriculture	1961–85	Malmquist	DEA	–0.50	
		Chile	Agriculture	1961–85	Malmquist	DEA	1.10	
		Colombia	Agriculture	1961–85	Malmquist	DEA	0.00	
		Dominican Republic	Agriculture	1961–85	Malmquist	DEA	1.00	
		Argentina	Agriculture	1961–85	TFP	OLS	–0.60	Coefficients of production function are used to estimate TFP.
		Brazil	Agriculture	1961–85	TFP	OLS	2.70	
		Chile	Agriculture	1961–85	TFP	OLS	0.80	

							(percent per year)
		Colombia	Agriculture	1961–85	TFP	OLS	1.50
		Dominican Republic	Agriculture	1961–85	TFP	OLS	1.10
Hutchinson and Langham	1999	Cuba	Agriculture	1961–90	Malmquist	DEA	−3.20
		Dominican	Agriculture	1961–90	Malmquist	DEA	−1.50
		Guyana	Agriculture	1961–90	Malmquist	DEA	−0.80
		Jamaica	Agriculture	1961–90	Malmquist	DEA	−0.70
		Suriname	Agriculture	1961–90	Malmquist	DEA	−1.80
		Trinidad and Tobago	Agriculture	1961–90	Malmquist	DEA	−0.80
Fernandez-Cornejo and Shumway	1997	Mexico	Agriculture	1960–90	Tornqvist		2.79
		Mexico	Agriculture	1960–90	Tornqvist		4.53
		Mexico	Agriculture	1960–90	Tornqvist		3.25
		Mexico	Agriculture	1960–90	Tornqvist		0.62
		Mexico	Agriculture	1960–90	Land productivity		3.64
		Mexico	Agriculture	1960–70	Land productivity		5.47
		Mexico	Agriculture	1970–80	Land productivity		4.71
		Mexico	Agriculture	1980–90	Land productivity		0.82
		Mexico	Agriculture	1960–90	Labor productivity		4.34
		Mexico	Agriculture	1960–70	Labor productivity		7.43
		Mexico	Agriculture	1970–80	Labor productivity		3.51
		Mexico	Agriculture	1980–90	Labor productivity		2.16
Arnade	1992	Brazil	Crop	1968–87	TFP	Cost function	1.20
		Brazil	Crop	1968–79	TFP	Cost function	−0.07
		Brazil	Crop	1980–83	TFP	Cost function	4.50

(continued)

Table 4.1 (continued)

Study		Orientation			Estimation procedure		Productivity estimates	
Authors	Year	Country	Commodity	Period	Indicators[a]	Method[b]	Rate of growth	Notes
							(percent per year)	
		Brazil	Crop	1984–87	TFP	Cost function	0.20	
		Brazil	Crop	1968–87	Labor productivity		5.30	
		Brazil	Crop	1968–87	Land productivity		2.80	
Jansse and de Londono	1994	Southern Colombia	Bean	1975–89	TFP			Average increase in TFP from 1975 to 1989 is 54 percent.
Bravo-Utera and Pinheiro	1997	Dominican Republic (Dajabon)	Crop	1988	TE	Stochastic Production Function	70.0	Substantial gain in increasing output or decreasing cost can be attained at the given technology.
			Crop	1988	AE		44.0	
			Crop	1988	EE		31.0	
Bravo-Ureta and Evenson	1994	Eastern Paraguay	Cotton	1986–87	TE	Stochastic Production Function	58.2	Inefficiencies found in both cotton and cassava production.
			Cotton	1986–87	AE		70.1	
			Cotton	1986–87	EE		40.7	
			Cassava	1986–87	TE		58.7	
			Cassava	1986–87	AE		88.9	
			Cassava	1986–87	EE		53.3	

Sources: Compiled by authors.

Notes: See chapter references for bibliometric details of table entries.

aTFP indicates total factor productivity; TE - technical efficiency; AE - allocative efficiency; EE - economic efficiency; DEA - data envelopment analysis; and OLS, ordinary least squares.

Trueblood, and 5 countries for Fulginiti and Perrin. Their results are qualitatively similar but differ substantially in important details. They tell us that since the early 1960s MFP in agriculture grew for most developed countries, but a large number of the less developed countries—maybe a majority—lost ground. Among developing countries studied by Arnade (1998), MFP dropped in 69 percent of the countries and Trueblood reported declines in 90 percent since the 1960s. Similarly, Fulginiti and Perrin (1998) reported that between 1961 and 1985 MFP receded in half of the 18 developing countries they studied.

MFP trends in LAC mirrored these global results. Arnade (1998) reported that MFP declined in 53 percent of the LAC countries he studied in the 1961–97 period; according to Trueblood (1996), MFP fell in 77 percent of his sample countries over the 1962–90 period; and Fulginiti and Perrin (1998) estimated that 40 percent of their smaller sample of five LAC countries experienced declines in MFP during the 1961–85 period.

Country-by-country comparisons of the estimates in Table 4.1 reveal puzzling anomalies. The Arnade and Trueblood studies are the most directly (but not exactly) comparable in terms of methodology and period coverage. According to Arnade's estimates, MFP performance in Brazil and Nicaragua were the most dismal of the countries in his sample, declining by more than 2 percent per year between 1961 and 1993. Both countries did poorly according to Trueblood's estimates, but in his case MFP declined by 1.8 percent per year in Brazil from 1962–90 (close to the 2.1 percent contraction reported by Arnade) and by 4.4 percent in Nicaragua (substantially more than Arnade's 2.0 percent loss in productivity). Both studies were also consistent in the direction of growth but substantially different in the magnitude of MFP reported for Chile and Costa Rica (MFP increasing), and for the Dominican Republic, Ecuador, El Salvador, Guatemala, and Honduras (MFP declining). In contrast, Arnade and Trueblood reported MFP growth moving in the opposite direction for Bolivia, Colombia, Paraguay, Peru, Uruguay, and Venezuela. For instance, Arnade reports a 4.7 percent increase per year in Bolivian MFP and a 1.16 percent increase per year in Mexico, whereas Trueblood had Bolivia's and Mexico's MFPs declining by 0.93 and 2.2 percent per year, respectively.[7]

Hutchinson and Langham (1999) more recently estimated agricultural productivity developments for the Caribbean. Malmquist indexes of MFP were computed for six countries for the 1961–91 period. They showed productivity declining in all six countries studied, ranging from a 0.7 percent yearly decline in MFP in Jamaica, to a decline of 3.2 percent per year in Cuba over the period of study.

There is a common perception that the process of technical change "discriminates" against smaller agricultural producers. Notwithstanding Sumner's (1991) comments that defining smallness in agriculture is problematic, Janssen and de

7 Using Tornqvist indexes, Fernandez-Cornejo and Shumway (1997), found that Mexico's MFP grew by 2.8 percent per year from 1960 to 1990, but they report an unstable and generally declining rate of productivity improvement. Their estimates suggest that Mexican agricultural productivity grew by 4.5 percent per year during the 1960s, 3.3 percent per year during the 1970s, and only 0.6 percent in the 1980s.

Londoño (1994) analyzed the impact of the modernization of small-scale bean and maize production in the predominately bean growing areas of Huila and Nariño in southern Colombia. Data were gathered from surveys conducted in 1975 (124 farmers) and 1989 (141 farmers). The authors found that between 1975 and 1989, TFP at the farm level increased by an average of 54 percent, or (equivalently) at 3.8 percent per year, a very large figure when compared with such estimates for other regions of the world.

Others have studied the concept of economic efficiency, often characterized as one of two types—technical efficiency, which relates to maximizing output for a given amount of inputs, and allocative efficiency, which minimizes the costs of producing a given amount of output (Yotopoulos and Lau 1973). Inefficiencies are deemed to exist when a country or firm deviates from the minimum cost input ratios, or falls inside the output maximizing production frontier. Using a stochastic production frontier approach, Bravo-Utera and Pinheiro (1997) compared the efficiency of 60 farmers surveyed in 1988 in the Dajabon region, a principal agricultural area in the Dominican Republic. They estimated that technical efficiency indexes ranged from 42 to 85 percent, with an average of 70 percent, meaning that, if the average farmer in the sample were to achieve the same level of technical efficiency as his most efficient counterpart, then the average farmer would realize an 18 percent saving in the unit cost of production (18 = [1 – 70/85]*100). In an earlier study, Bravo-Ureta and Evenson (1994) used the same approach to investigate the efficiency of 87 cotton and 101 cassava producers in eastern Paraguay, using data for 1986–87. For nearly two-thirds of the cotton producers and two-fifths of the cassava producers sampled, the economic efficiency indexes were below 50 percent. The main conclusion drawn was that productivity improvements (perhaps, through increased economic efficiency) could be an important source of future output growth, given the state of technology.

Accounting for MFP Growth

Identifying the principal sources of productivity growth is important for the design of strategic policies targeted to food security. Table 4.2 summarizes the measured sources of productivity growth in Latin American agriculture. The studies vary widely in approach and variables.

According to Arnade (1998), Trueblood (1996), and Fuginiti and Perrin (1998), the productivity losses they found in LAC agriculture stemmed from technical regression rather than efficiency losses.[8] Arnade (1998) and Fulginiti and Perrin (1998) reported that all of the countries exhibiting decreases in MFP also experienced technical regression. Trueblood (1996) asserted that technical regression was the cause of the contraction in productivity in 11 of the 17 countries for which he reported declines in MFP. Arnade (1998) speculated that technical regression in LAC

8 Technological regression in these instances refers to a trend of declining output for a given total cost of production.

Table 4.2 Published sources of productivity growth in Latin American agriculture

Study		Orientation			Source of productivity		
Authors	Year	Country	Coverage	Period	Method	Explanatory variables	Comments
Trueblood	1996	22 LAC countries	Agriculture	1962–90	Malmquist Decomposition	Efficiency and Technical change	The sources of MFP decline for the 17 LAC countries were decline in efficiency for 6 countries, technical regression for 3 countries, and both loss in efficiency and technical regression for 8 countries.
Arnade	1998	17 LAC countries	Agriculture	1961–93	Malmquist Decomposition	Efficiency and Technical change	The source of MFP decline for the 9 LAC countries was technical regression.
Fulginiti and Perrin	1998	5 LAC countries	Agriculture	1961–85	Malmquist Decomposition	Efficiency and Technical change	The source of MFP decline for the 2 LAC countries was technical regression.
Fernandez-Cornejo and Shumway	1997	Mexico	Agriculture	1940–90	Cointegration	R&D expenditures, U.S. agricultural TFP (proxy for international transfer of technology)	A 1-percent increase in R&D increases TFP by 0.13 percent, and a 1- percent increase in U.S. TFP increases Mexican TFP by 1.1 percent.
Hutchinson and Langham	1999	6 Caribbean countries	Agriculture	1961–90	Malmquist Decomposition	Efficiency and Technical change	Technical change was the source of MFP decline in the 6 countries of study.
Arnade	1992	Brazil	Crop	1968–87 1968–79 1980–83 1984–87	Estimates from cost function	Technical effect, scale effect, and Efficiency effect	In all subperiods, scale effect is the source of productivity. Efficiency effect increase during the 1980–83 period but decline afterwards. This decline in efficiency is concomitant with subsidies removal policy from the Brazilian government.
Thiesenhusen and Melmed-Sanjak	1990	Brazil		1970 and 1980	OLS	Farm size, region	Inverse relationship between farm size and land productivity, as small farmer tend to use input more intensively.

(continued)

Table 4.2 (continued)

Study		Orientation			Source of productivity		
Authors	**Year**	**Country**	**Coverage**	**Period**	**Method**	**Explanatory variables**	**Comments**
Janssen and Ruiz de Londono	1994	Southern Colombia	Bean	1975 1979	OLS (production function)	Bean plant density, maize plant density, rotation, fertilizer uses, cost of sanitary control, and region dummy	All explanatory variables have a positive impact on bean yield except maize density. Coefficients from regression use to dissect yield increase into variables representing allocative efficiency, technical efficiency, and technical change. Allocative efficiency (proxied with increased bean seed density, reduced maize plant density, increased investments for sanitary control and fertilizer use) explained half of the bean yield increase between 1975 and 1989. Technical efficiency (proxied by improved planting methods and increased frequency of rotations) explained one-third of bean yield improvement, and technical change (proxied by seed treatment) explained the remaining 20 percent.
Jonakin	1997	Nicaragua	Maize	1986–87	OLS	Tractor, labor, fertilizer, seed, zone, organizational characteristics of cooperative (that is, membership, social class, kinship, cooperative age, instability, family plot size, work-based payment, sanctions).	Institutional management and membership factors contribute to explain the difference in maize yield across cooperatives. Cooperative age, social class, and membership are significant and positively related to yield. Kinship (the degree of family ties) has a significant but negative impact on yield. These four variables capture some internal structural and membership characteristics of cooperatives. Work-based payment (rewards based on work contribution), used as a proxy for management factor, was found to have a significant and positive impact on yield.

Sources: Compiled by authors.

Notes: See chapter references for bibliometric details of table entries. OLS indicates ordinary least squares.

could be a consequence of protective agriculture policies that reduced competitive pressures to adopt new technology.

The decomposition of Malmquist productivity indexes into efficiency change and technical change ostensibly provides some insights into the sources of MFP growth, but the approach has its difficulties. It does not lend itself readily to discerning the fundamental determinants of productivity growth, nor does it permit statistical tests of hypotheses regarding these determinants. Econometric methods address these shortcomings, seeking to identify sources of productivity growth, such as investments in infrastructure, R&D, and changes in the quality of conventional inputs like labor, capital, and land.

Research results in productivity gains through improved genetic material, machinery, farm chemicals, agricultural management practices, and the like. Using cointegration procedures on Mexican data for the period 1940–90, Fernandez-Cornejo and Shumway (1997) found a positive and significant relationship between estimated TFP, agricultural research, and the international availability of technology (proxied by an index of U.S. agriculture productivity). According to their estimates, a 1 percent increase in local research investment increases TFP by 0.13 percent, while a 1 percent increase in U.S. TFP was associated with a 1.1 percent increase in agricultural productivity in Mexico, presumably reflecting the effects of technology spillover.

Arnade (1992) attributed productivity growth in the Brazilian crop sector to changes in the scale of production, technical change, and efficiency change. His results suggest that economies of scale were the most significant factor, accounting for the 1.2 percent measured growth in Brazilian agricultural productivity for the 1968–87 period. Related to the concept of scale economies is the relationship between farm size and productivity. Thiesenhusen and Melmed-Sanjak (1990), among numerous other authors writing on LAC, observed an inverse relationship between farm size and land productivity in Brazil during the 1970–80 period.

The Janssen and de Londoño (1994) study, referenced earlier, also analyzed the sources of yield improvement in small-scale bean production in southern Colombia. They found that allocative efficiency—represented by an increase in the planting density of bean seeds, reduced maize plant density, and increased investments for phytosanitary control and fertilizer use—had the largest effect on bean yields, accounting for roughly half of the average bean yield increase observed between 1975 and 1989. Technical efficiency—represented somewhat arbitrarily, perhaps, by improved planting methods and the increased frequency of rotations—explained one-third of the gains in bean yields, and technical change (proxied by seed treatments) the remaining 20 percent.

Jonakin's 1995 study sought to shed some light on the impact of different property regimes and management structures on agricultural productivity in Nicaragua. Farm-level data were obtained by surveying corn producers in 1986 and 1987, and coffee producers in 1987 and 1988. These corn and coffee producers involved a heterogeneous group that included collectively managed cooperatives, household

Table 4.3 Agricultural land and labor productivity developments, 1961–2001

	1961	1971	1981	1991	2001	Growth rate
		(1989–91 international dollars)				(percent)
Labor productivity						
Mexico	1,077.9	1,538.2	1,997.5	2,120.3	2,844.0	1.99
Mesoamerica excluding Mexico	828.0	1,130.9	1,281.7	1,341.5	1,506.1	1.20
Mesoamerica	1,002.2	1,406.0	1,778.0	1,872.8	2,381.5	1.78
Caribbean	1,026.3	1,178.9	1,391.5	1,428.7	1,435.2	0.77
Andean countries	1,061.6	1,305.1	1,518.7	1,767.9	2,189.9	1.67
Brazil	1,215.7	1,481.0	2,119.6	3,213.9	5,512.7	3.94
Southern Cone excluding Brazil	5,490.6	6,686.2	8,499.1	8,879.8	11,082.5	1.55
Southern Cone	1,969.8	2,254.8	3,035.2	4,212.6	6,658.8	3.11
Latin America and the Caribbean	1,463.2	1,761.1	2,261.0	2,765.8	3,842.7	2.35
Asia	277.9	329.5	382.5	480.6	643.3	2.11
Sub-Saharan Africa excluding South Africa	312.3	348.3	329.4	360.0	393.7	0.38
China	188.8	248.5	288.8	397.1	647.8	2.87
South Asia	305.7	319.7	349.4	436.3	492.8	1.49
East and Southeast Asia excluding China	309.1	372.8	480.8	550.3	664.9	1.97
Developing countries	336.0	393.2	451.3	548.2	714.3	1.86
Transitional markets	1,721.9	2,885.1	3,494.6	4,316.8	4,207.7	1.97
United States	18,754.7	30,060.7	37,177.4	41,371.8	59,912.9	2.59
Western Europe	3,950.0	7,062.4	10,617.1	15,891.5	23,252.3	4.39
Japan	757.4	1,379.2	2,596.2	3,801.8	5,935.8	5.23
Australia and New Zealand	22,026.5	31,832.3	34,663.4	37,393.5	49,879.1	1.50
Developed countries	3,055.5	5,137.8	7,088.0	9,125.7	12,037.1	3.26
World	702.2	831.8	901.9	971.4	1,111.5	1.01

farms, and "capitalist enterprises." However, Jonakin found no statistical evidence of a relationship between differences in tenancy/property regimes and TFP.

Land and Labor Productivity Patterns

Worldwide, agricultural land and labor productivity have increased steadily since 1961.[9] Notably, the growth in labor productivity in developed countries (3.3 percent

9 Both these partial productivity ratios are constructed using measures of gross agricultural output (that is, crop and livestock output) based on the national production quantities reported in FAO (2004). To generate measures of aggregate output, 190 output quantities (including 160 crop and 30 livestock items) were weighted by their respective 1989–91 international agricultural prices taken from FAO (1997). The general measurement issues involved are discussed in Craig, Pardey, and Roseboom (1991) and the references therein. The land productivity measure is a ratio of gross output to the total hectares used in agriculture, whether irrigated or non-irrigated cropland, pastureland, or rangeland. Labor productivity measures gross output relative to the economically active agricultural population, be they male or female. Given the available data, land and labor quality differences are ignored, as are the effects of part-time farming (labor is a head count of those economically engaged in agriculture rather than an estimate of

Table 4.3 (continued)

Land productivity						
Mexico	76.5	114.7	176.9	193.5	250.8	2.74
Mesoamerica excluding Mexico	177.1	254.1	283.0	293.5	363.3	1.37
Mesoamerica	89.1	133.9	192.9	209.7	269.0	2.48
Caribbean	381.8	410.3	472.4	468.2	510.5	0.63
Andean countries	62.7	81.7	102.8	126.4	161.7	2.28
Brazil	114.7	123.6	166.6	203.9	287.4	2.48
Southern Cone excluding Brazil	82.0	93.3	119.4	135.1	168.2	1.73
Southern Cone	95.9	108.1	143.8	171.4	231.3	2.25
Latin America and the Caribbean	93.2	112.4	149.1	173.8	228.0	2.21
Asia	164.5	212.8	270.0	354.2	483.8	2.73
Sub-Saharan Africa excluding South Africa	32.5	42.5	48.4	61.9	79.0	2.10
China	146.1	205.6	249.3	358.9	591.4	3.30
South Asia	303.0	346.5	416.6	557.7	728.9	2.45
East and Southeast Asia excluding China	122.7	161.1	243.3	312.9	385.4	3.19
Developing countries	98.2	126.4	163.8	215.0	293.7	2.79
Transitional markets	209.7	278.2	297.3	324.6	246.5	0.34
United States	261.6	344.6	404.9	438.3	534.4	1.69
Western Europe	819.9	1,022.2	1,201.4	1,363.9	1,462.6	1.44
Japan	1,292.3	2,401.0	3,229.1	3,882.0	4,246.6	2.88
Australia and New Zealand	29.4	39.0	42.9	52.7	69.4	1.82
Developed countries	218.3	280.5	317.3	352.0	357.5	1.17
World	144.9	184.2	220.8	262.3	315.1	1.90

Sources: Compiled by authors from FAO 2004.

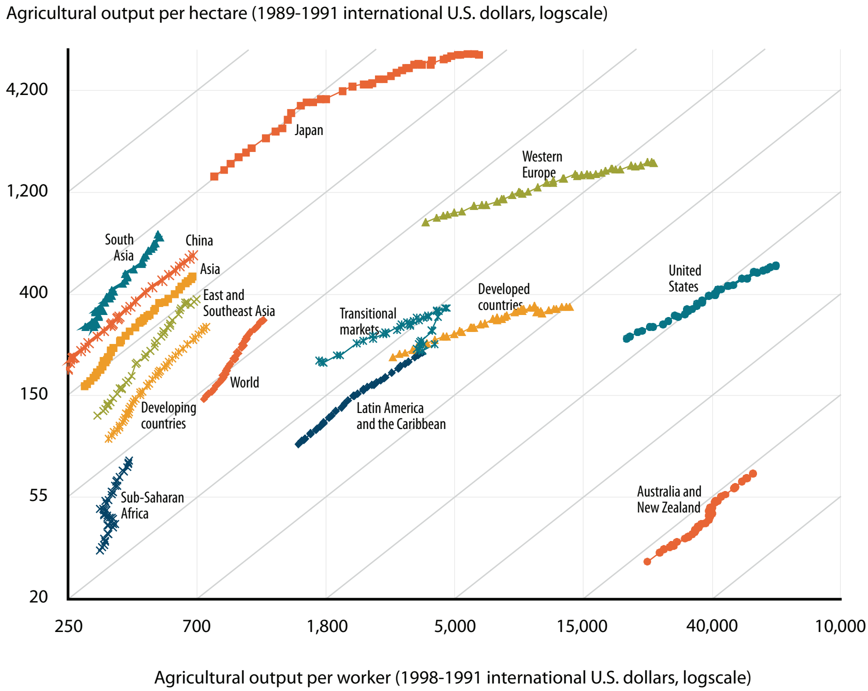
Notes: See Appendix Tables 4A.1 and 4A.2 for land and labor productivity measures for countries in Latin America and the Caribbean. Compound growth rates obtained from logarithmic regression estimates.

per year from 1961–2001) has outpaced labor productivity gains in the developing world (1.9 percent) (Table 4.3). Conversely, land productivity has grown faster in developing as opposed to developed countries (2.8 versus 1.2 percent). In 2001, output per agricultural worker in LAC was US$3,843 (1989–91 international dollars), and output per hectare of agricultural land was US$228.

For LAC as a whole, labor productivity grew slightly faster than land productivity after 1960, consistent with the (very slowly) rising land–labor ratios for the region. Moreover, there was a general tendency for land productivity to grow more rapidly throughout the rest of the developing world than land productivity in LAC, while labor productivity rose more rapidly in LAC than in the developing countries generally. To further clarify LAC land and labor productivity trends and to better place them in a global context, we used the graphical technique of Hayami and Ruttan (1985). In Figure 4.1 we plot logged ratios of agricultural output per hectare

hours worked in agriculture). Our land-in-use construct takes some account of multiple cropping by using harvested area rather than arable land as the estimate of cropped area (to which we add pastureland as a measure of grazed areas to get total land used in agriculture).

Figure 4.1 A global perspective on land and labor productivity in agriculture, 1961–2001



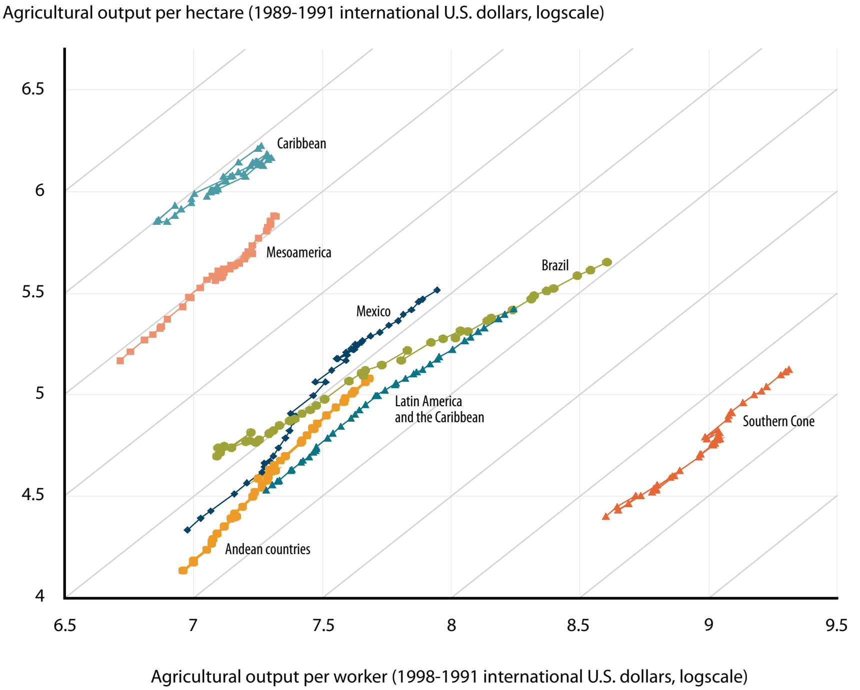
Sources: Developed by the authors from FAO 2004.

and output per worker for 11 regions and 3 countries of the world (representing 231 countries) for each of the years 1961 to 2001.

All the productivity paths move in a northeasterly direction starting in 1961 and ending in 2001, indicating increasing productivity. A longer productivity locus means a greater *percentage* change in productivity. China and the East and Southeast Asia region experienced the fastest rate of growth of land productivity (3.3 and 3.19 percent per year, respectively); the transition markets of east and central Europe experienced the slowest (0.34 percent). With a rapid exodus of labor from agriculture, Japan's labor productivity grew the fastest (5.23 percent per year), and Africa's the slowest (0.38 percent).

The diagonal lines in Figure 4.1 indicate constant factor ratios. When a region's productivity locus is flatter than these diagonal lines (for example, Japan in more recent decades), it indicates an increase in the number of agricultural hectares per agricultural worker in that country as we move from left to right: in Japan's case from 0.59 hectares per worker in 1961 to 1.4 in 2001 (see Table 2.10). Land–labor ratios in Australia and New Zealand have changed little, whereas they have risen by some 25

Figure 4.2 Land and labor productivity in Latin America and the Caribbean, 1961–2001



Sources: Developed by the authors from FAO 2004.

percent in North America. They also rose, albeit very slowly, in LAC, consistent with the region's labor productivity growing slightly faster than its land productivity, as noted above. Africa has become much more labor intensive, so land–labor ratios have declined. In 1961 the region had 10 hectares per agricultural worker, but by 2001 the land–labor ratio had nearly halved to 5 hectares per worker.

The regionwide productivity trends mask significant spatial differences in both the levels and rates of change in labor productivity throughout Latin America. The Southern Cone consistently produced more output per agricultural worker than any other subregion in Latin America ($6,659 per worker in 2001, denominated in 1989–91 international prices) and had the fastest growing labor productivity ratio: 3.11 percent per year since 1961 (Figure 4.2). In contrast, the Caribbean had the lowest level ($1,435 in 2001) and rate of growth (0.77 percent per year) of labor productivity.

Nicaragua was one of the few Latin American countries in our sample in which labor productivity declined after 1961. El Salvador and Guatemala, two additional countries plagued by civil strife, also experienced negligible labor productivity

growth in agriculture, as did Peru, whose overall economy has performed erratically in recent decades. Output per worker grew fastest in Martinique (4.54 percent per year), and exceeded 3.0 percent per year in Brazil, Costa Rica, Barbados, Puerto Rico, Guadeloupe, and Montserrat.

There are also marked spatial differences in land productivity throughout Latin America (Figure 4.2). In 2001, agricultural output per hectare averaged just US$49 (1989–91 international dollars) in the Cayman Islands and US$53 in Bolivia, compared with US$2,504 per hectare in Barbados. Notwithstanding the lackluster improvement in land productivity in the Caribbean since 1961, the subregion still ranked first in terms of value of agricultural output per hectare in LAC in 2001 (specifically, $511 per hectare). Furthermore, all top-ranked countries, in terms of agricultural output per hectare, were from the Caribbean. These Caribbean countries share some common characteristics. Other than Puerto Rico, agricultural land accounted for less than half the total land area, and most of the agricultural land was arable and permanently cropped rather than pastureland and grassland. In addition, Caribbean countries had similar patterns of production, involving mainly chicken meat, sugarcane, bananas, milk, and beef (see Chapter 2).

Spatial Assessments of Crop Yields

The location specificity of much agriculture (and agricultural R&D) means that the changing location and spatial structure of agriculture can have an important bearing on broader patterns of output and productivity growth. The most readily available agricultural production data (used above) are compiled by FAO. These data report agricultural production, harvested area, and yields on a national basis, thus glossing over many of the economically important location attributes of agricultural production. However, a much richer appreciation of the spatial distribution of production can be developed using data from second- or third-level administrative units.

The Data

We gathered subnational production data for 21 countries in LAC for the period 1975–95 for 13 major commodities: maize, rice, wheat, cassava, potatoes, beans, soybeans, sorghum, bananas, coffee, beef and veal, and milk. Although the data series excludes sugarcane, it represents the primary annual and perennial crop commodities produced. Setting aside crops with anomalous subnational data, we focused on maize, wheat, rice, cassava, sorghum, potatoes, beans and soybeans. These eight crops made up over two-thirds of the harvested crop area in LAC in 1993–95. To address the remaining data gaps in some of these subnational series, we devised various spatial and temporal interpolation routines. To ensure consistency between disaggregated national data and the national totals compiled by FAO, we recalibrated the subnational series so that their respective sums equaled

Table 4.4 Level of disaggregation of subnational production database

Region	Number of countries	Reporting level
South America	3	Country
	9	Department
	1	Municipio
Central America	2	Country
	6	Department
Caribbean	22	Country

the corresponding FAO national totals. Table 4.4 summarizes the level of detail of the production data.

Spatial Yield Patterns

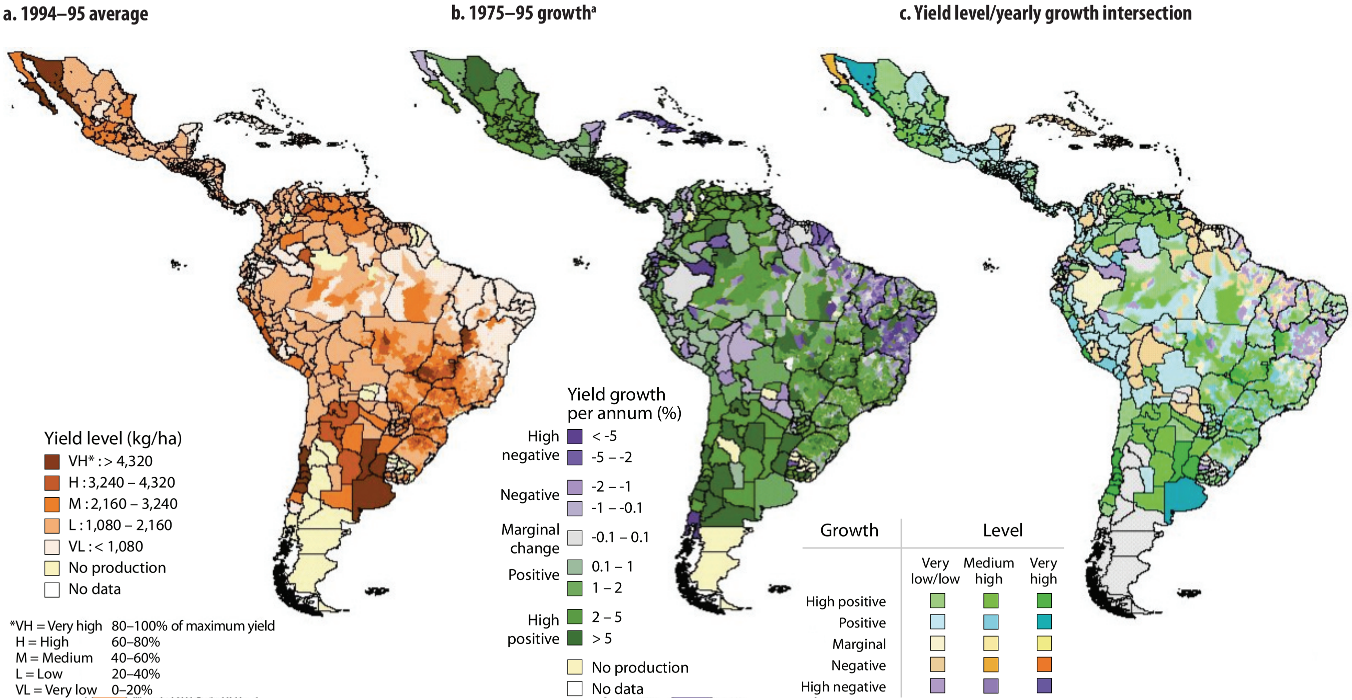
From a technology design perspective, we are interested not only in the spatial distribution of production, but also of yield, as well as in observing spatial patterns in yield trends. Figure 4.3 shows the spatial distribution of yields and yield trends for maize.[10] Maize yields are comparatively high in the Buenos Aires, Entre Rios, and Santa Fe provinces of Argentina, in parts of the Cerrados of Brazil, and in Baja California Sur and Sonora in Mexico. Very low yields are observed in northeast Brazil, parts of Ecuador and Bolivia, and isolated parts of the Amazon Basin. Mapping yield growth rates reveals a generally positive picture of yield trends, but it is apparent that negative yield growth rates often occur in those regions where yields are already low. This is a discouraging picture. In practically all areas with higher yields, growth rates are positive, indicating a widening gap between the best and the worst yield levels.

Others way of depicting yield variation are shown in Figures 4.4 and 4.5, which summarize the distribution of yields and yield growth rates, respectively, by harvested area (Supplementary Figures S4.2 and S4.3 show the equivalent yield distributions according to production).

In Figure 4.4, the harvested area of each yield class devoted to crops in Brazil is denoted by the dark shading; the white shading indicates harvested area throughout the rest of the region. There is a clear bi-modal pattern in rice yields—a clustering of harvested area in the 0.8 to 2.0 tons per hectare range (mostly in Brazil), reflecting rice production under rainfed conditions. A second, somewhat less sharply defined clustering in the 3.2 to 5.6 tons per hectare range is most likely irrigated rice. About 5.0 million hectares of wheat (61 percent of the LAC total) fall within the 1.9 to 2.2 tons per hectare range. Virtually all of this wheat is located in the Pam-

10 Corresponding maps for all other commodities, subject to detailed analysis in Chapter 7, can be found in Supplementary Figure 4.1.

Figure 4.3 Latin American and Caribbean yield and yield trend patterns: Maize

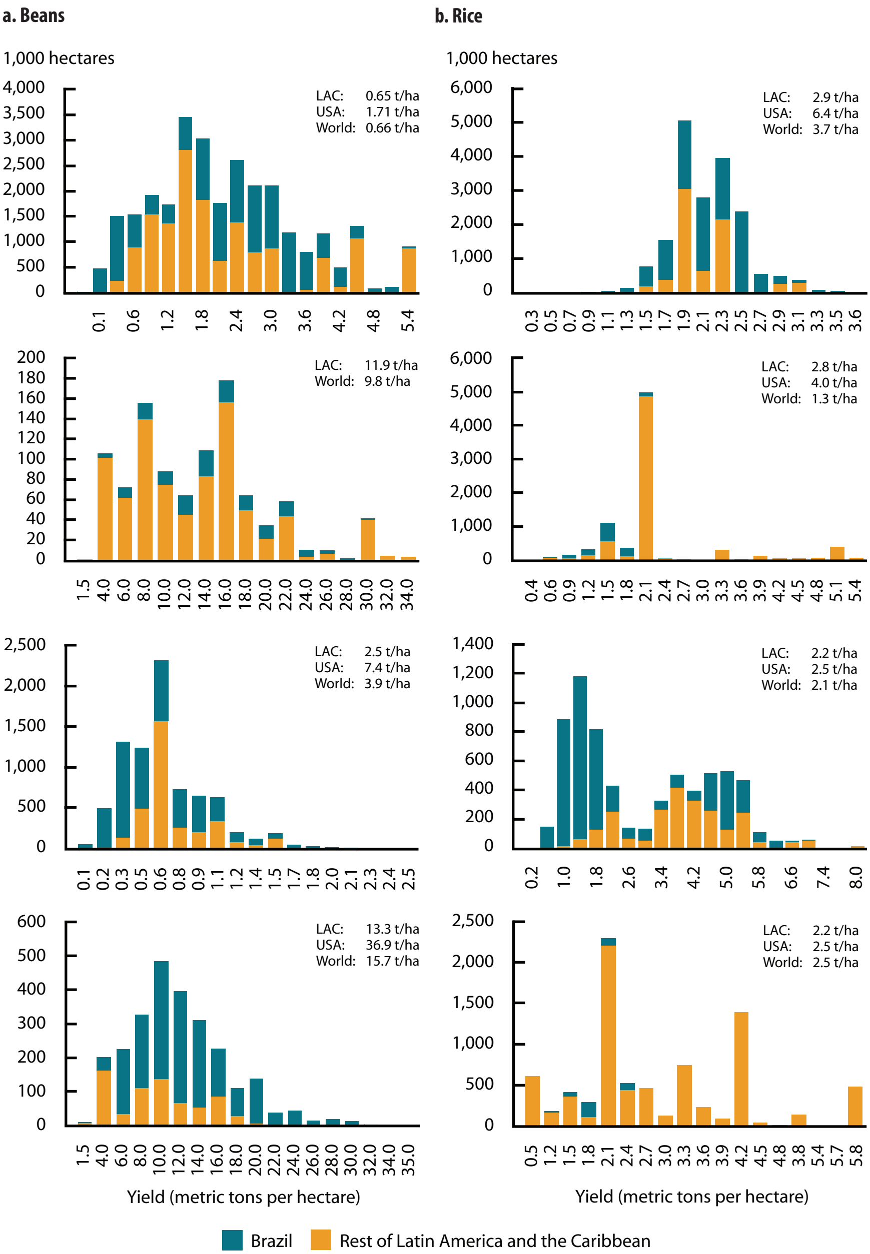


Sources: Calculated by authors.

Notes: Very high yield levels (VH) constitute 80–100 percent of maximum yield potential; high levels (H) constitute 60–80 percent; medium levels (M) constitute 40–60 percent; low levels (L) constitute 20–40 percent; and very low levels (VL) constitute 0–20 percent.

[a]Growth rates can appear in departments for which no 1994–95 production was recorded.

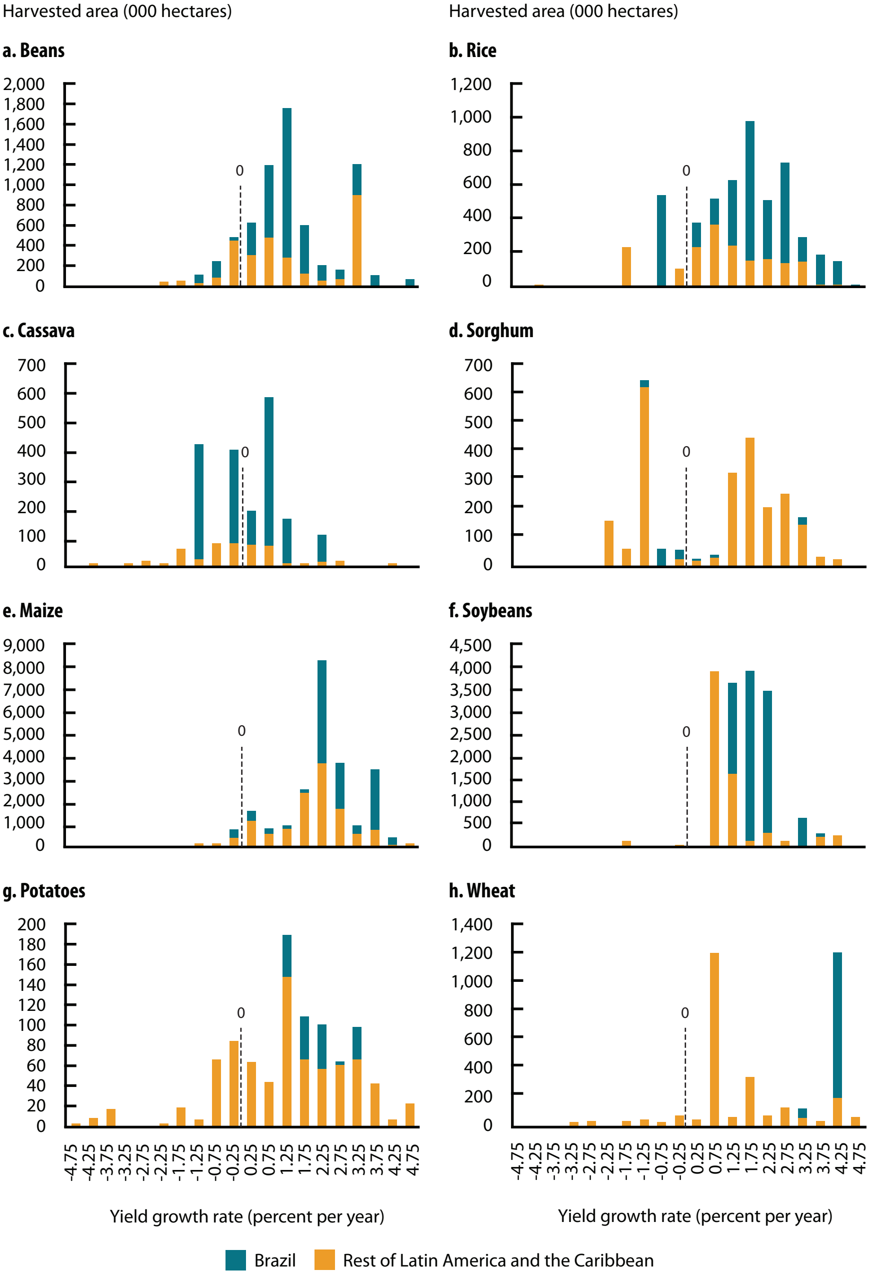
Figure 4.4 Latin American and Caribbean crop-yield distributions by harvested area



Sources: Chan-Kang, Pardey, and Wood 2000.

Notes: Data are 1993–95 averages.

Figure 4.5 Latin American and Caribbean crop-yield growth distributions by harvested area



Sources: Chan Kang, Pardey, and Wood 2000.

Notes: Yield growth rates are annual averages for the period 1975–95.

pas of Argentina, a fairly homogeneous region favoring wheat production in terms of agroecological conditions, infrastructure, and other important productivity and market determinants.

The spatial pattern of maize yields is the antithesis of that seen for wheat, since there is much more significant spatial disparity. A wide variety of micro-regions are producing at quite different levels of yield from a very broad range of germplasm. In Brazil, for example, the production of maize ranges from predominantly smallholder systems growing open pollinated varieties in the dryer northeastern part of the country to the larger scale commercial producers planting hybrid varieties in the Cerrados and much of the rest of the country. The broad adaptability of maize germplasm would appear to permit farmers to produce more competitively in a wider variety of agroecologies than is the case for wheat. Consistent with these observations are the greater difficulties faced in improving the maize crop in LAC—since there are so many different kinds of AEZs and technologies—compared with the wheat crop.

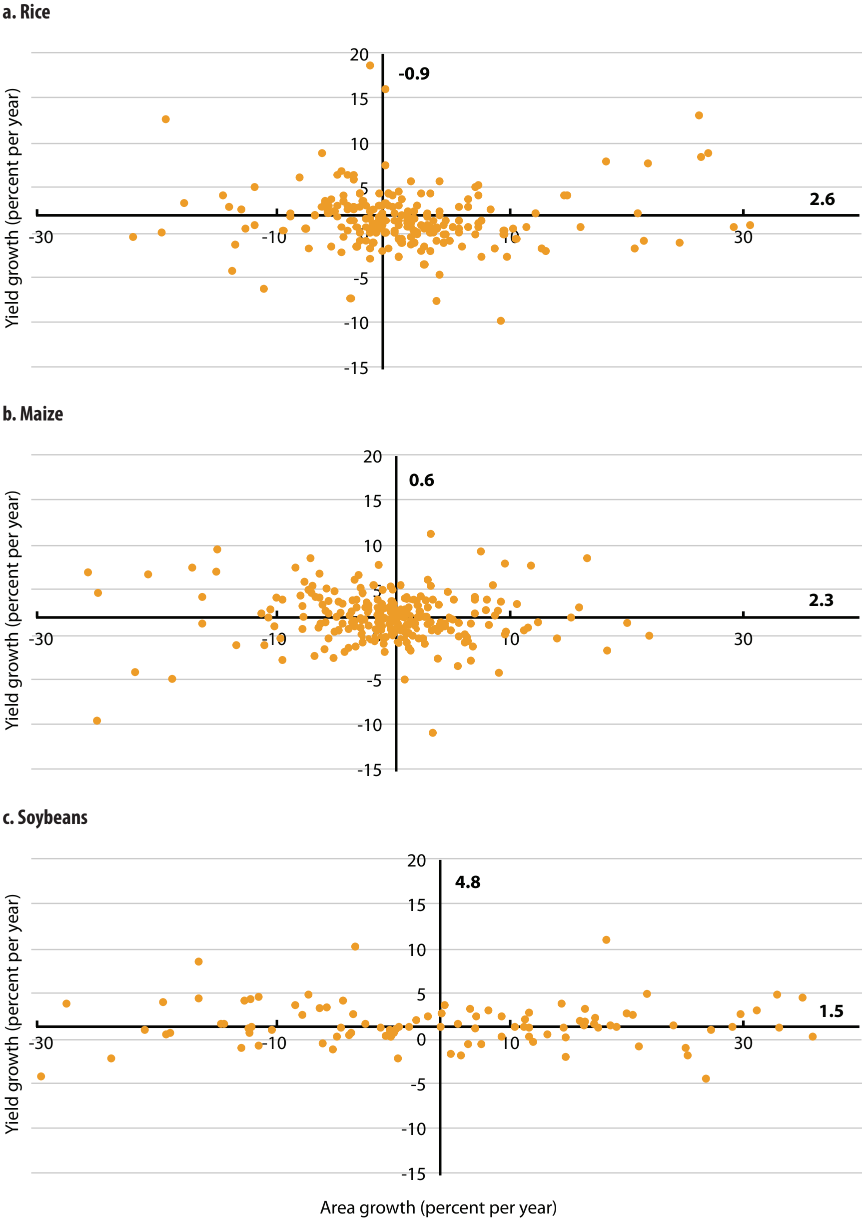
Figure 4.4 also provides regional average yields, and the corresponding world and U.S. averages. Notably, average LAC yields in 1993–95 were above world yields only in the cases of cassava, sorghum, and soybeans, although LAC's soybean yields were just 5.0 percent higher. Supplementary Figure S4.2 shows the amounts of yearly production output by yield class. The most dramatic difference between Figure 4.4 and Supplementary Figure S4.2 is for rice, reflecting the proportionately greater output from the higher yielding irrigated, compared with rainfed, rice systems.

Figure 4.5 and Supplementary Figure S4.3 present the distribution of yield *growth* by harvested area and crop production respectively. Denominating the frequency distribution in terms of yield changes rather than levels produces more tightly clustered distributions that are more normal in shape. Moreover, land productivity (yield) growth, appears to occur where most of the production is located. This is consistent with the notion that the public and private supply of improved technologies (including improved crop varieties and other purchased inputs) is influenced by the size of the market.

Finally, much information can also be gleaned about agricultural production systems by analyzing simultaneous changes in area and yield growth rates. Again, taking rice, maize, and soybeans, it is possible to see emerging patterns simply by plotting yield and area growth rates for each department or state over the period 1975–95 (Figure 4.6).

The data reveal significant spatial and crop-specific variability in the evolution of production in LAC. Increases in soybean output, for example, are driven mainly by increases in harvested area, with comparatively small improvements in crop yields (a mean of 1.5 percent per year across all departments in the 1975–95 period). Cereals show a much greater reliance on yield increases as a source of output growth, with yields growing by between 2.3 and 2.6 percent per year for rice and wheat. Area harvested expanded by only 0.6 percent per year or less, implying a continuous intensification of the rice and maize production systems. The figure

Figure 4.6 Latin American and Caribbean yield and area growth rates, 1975–95



Sources: IFPRI (1999).

also shows that, despite the significant aggregate increases in production that took place over the 20-year period (50 percent for rice and 96 percent for maize), there are many areas where production decreased. One reason for this can be understood based on the situation in Brazil, which underwent significant shifts in the location of production, and a more rapid development of improved irrigated, versus rainfed, rice varieties.

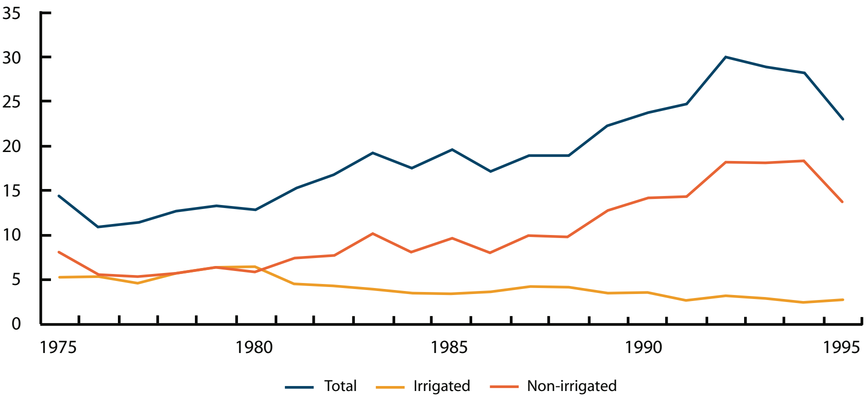
Crop Yield Divergence

There are a number of good reasons to expect crop yields to converge over time and space: growth in yield potential is likely to exhibit diminishing returns; the share of crop varieties sown to high-yielding varieties (HYVs) tends to increase over time, the barriers to the free flow of knowledge and information tend to diminish, and investments in institutions that facilitate the international and interregional flows of agricultural technologies continue to be made. However, an analysis of LAC yield data for rice, maize, and soybeans suggests such convergence has not occurred. On the contrary, evidence indicates a divergence in crop yields across the region (Wood, You, and Zhang 2004).

Yield Divergence Hypotheses

The data we assembled for this study was used to assess three hypotheses concerning yields throughout LAC. First, have crop yields throughout the region tended to converge as a consequence of local market and research-related developments? There are a number of developments that are likely to have structural implications for the pattern of crop yields throughout LAC. The development of improved crop breeds and crop management technologies over the past several decades has been heavily targeted to more-favored production systems. Taking rice as an example, of the estimated 275 new varieties released in LAC over the three decades 1965–95, about 90 percent were intended for use under irrigated conditions (Sanint and Wood 1998) that tend to reduce yield variability (Hazell 1989). Modern varieties have predominantly been better suited to areas having sufficient rainfall or irrigation facilities, and fewer terrain and soil constraints. In rainfed, especially upland, areas lower input, lower yielding traditional varieties still predominate. Irrigation expansion in LAC over the past 40 years has produced a broader spectrum of irrigated and rainfed production domains, often existing in close proximity (Sanint and Wood 1998). At the same time, there is abundant evidence of the expansion of rainfed production into less productive areas, particularly in the hillsides of Central America and the Andean subregion, and a general decline in the fallow periods and consequently in the fertility of soils associated with many low-input, rainfed systems (Pender and Scherr 1999). On balance, we suspect these factors may have tended to cause a divergence in yields over time. Rice yield data at the district (*municipio*) level in Brazil were used to test this hypothesis.

Figure 4.7 Spatial variability in rice yields in Brazil



Sources: Wood, You, and Zhang (2004).

Since yields of rainfed crops are strongly linked to weather conditions (Walker 1989), a second hypothesis is that changes in rainfall patterns during the period 1975–1998 have exacerbated yield divergence across LAC. Either a downward trend in yearly rainfall totals or an increase in rainfall variability could plausibly be associated with the type of crop yield divergence observed.

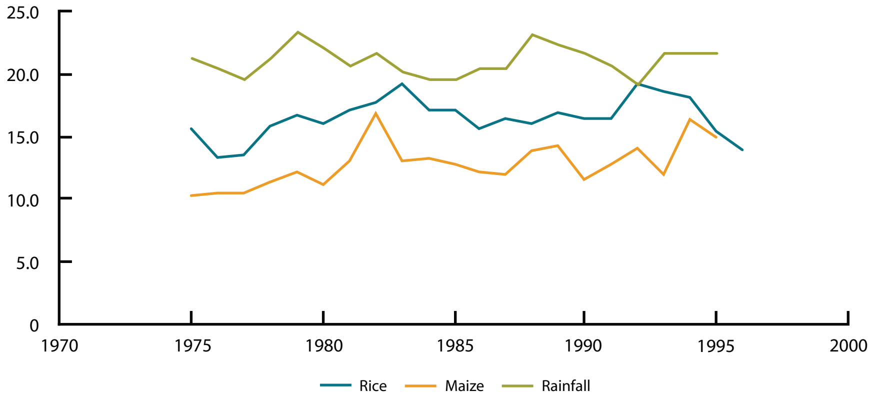
Third, was the hypothesis that technology transfers across national borders are less effective than those within a country due to weak institutional arrangements and lack of domestic research capacity to adapt new ("spillin") technologies. This may magnify divergence of yields among countries. To test this hypothesis, total yield variation was decomposed into *between-country* and *within-country* sources. If the between-country variation is large this might signal continuing scope for improvement in regional (multi-country) technology intervention strategies and mechanisms, such as those fostered by IICA, the Procis (as mentioned in Chapter 1, subregional research and technology development systems), FONTAGRO, and the CGIAR.

Results

Within Brazilian rice systems, yields in irrigated areas increased from 3.5 to 4.8 tons per hectare over the period 1975–95, while in rainfed areas yields reached only 1.7 tons per hectare by 1995. An entropy index of irrigated yield dispersion declined from 5.3 to 2.7, while it increased from 8.0 to 13.7 in rainfed areas (Figure 4.7).[11] Moreover, the yield spread between irrigated and rainfed areas has widened. The share of total variation explained by variation between irrigated and rainfed area

11 See Wood, You, and Zhang (2004) for a complete specification of the entropy index. Larger values indicate greater variability.

Figure 4.8 Spatial variability in rainfall and rice and maize yields in Latin America and the Caribbean



Sources: Wood, You, and Zhang 2004.

yields increased from 46 to 54 percent. The findings seem to support the hypothesis that productivity gains in more favorable production environments have widened the productivity gap with less-favored regions.

To test the second hypothesis, gridded monthly rainfall data (New, Hulme, and Jones 2000) were used to generate annual rainfall series for the subnational geopolitical regions (departments) in LAC from 1975–95. Figure 4.8 plots regional variability in annual rainfall and the yields of rice and maize for the whole period. First, of note, is that rainfall is more variable than yield, and that aggregate rice yields (including both irrigated and rainfed production) are more variable than maize yields. Second, there is a small but statistically significant downward trend in the amount of annual rainfall (a slope of –1.40 mm per year, with a *t*-value of –4.47, controlling for fixed effects across departments). Third, in the case of maize, the association of yield with rainfall variability appears much stronger (correlation coefficient 0.18), and maize yield variability appears to have increased over time. The finding of a downward trend in LAC annual rainfall over the 1975–95 period corroborates findings of other studies, and supports the hypothesis that changing weather patterns may have contributed to increasing yield divergence, since drier conditions are associated with lower yields in rainfed systems.

The third hypothesis tested was that there may be obstacles to the flow of knowledge and technology among countries. Agricultural production technologies generated in one country often spillover to other countries with similar agroecological conditions if regional or local capacity to adapt and disseminate the technologies is available. However, the capacities of national research and extension systems differ widely among countries (see Chapter 6). Many countries lack sufficient research capacity to adapt modern crop varieties to local needs, and many national

agricultural R&D systems are experiencing increasingly tighter budgets (Alston, Craig, and Roseboom 1998; Pardey, Alston, and Piggott 2006). Therefore, the ability to modify and adapt new technologies can differ significantly among countries and may constitute significant barriers to country-to-country knowledge spillovers.

To capture the between-country variation in yield, a decomposition method was applied to quantify the relative contributions to overall spatial inequality in yields *between* and *within* countries (Wood, You, and Zhang 2004). As shown in the last three columns of Table 4.5, the between-country variation in rice yields accounts for a large share of total variation, but the share generally declined throughout the 1965–95 period. For maize, the between-country contribution has been lower but more variable. Between-country variation in soybean yields has consistently accounted for more than half of the total variation in yields for that crop. The results suggest there is still significant scope for improving the flow of information about new technologies, as well as the flow of the technologies themselves, among LAC countries.

Summary

It appears that the technological factors leading to yield convergence over time have been more than offset by a number of larger, yield-diverging effects. The growing difference in yield between irrigated and rainfed areas appears to play a significant role in accounting for increasingly diverse yields, particularly in the case of rice. Although irrigation may be effective in reducing yield variability in those areas where irrigation replaces rainfed production, it has lead to greater yield disparities across locations because a significant share of LAC production remains in rainfed and mixed rainfed/irrigated farming systems. With evidence on the higher potential payoffs to investment in marginal lands, there is now much debate about the growth, as well as the equity consequences, of such biases (Fan, Hazell, and Thorat 1999). The spatial variation in yield for soybeans is much smaller than that for rice and maize, largely because soybeans are typically grown throughout LAC by larger scale, farm enterprises, where external inputs such as water and fertilizer are used to increase and stabilize yields. It seems that technology spillovers among commercially oriented systems may be more prevalent than those among smallholder systems. Therefore, in addition to developing technologies more appropriate to the needs of farmers in less-favored production environments, fostering improved technology diffusion among small-scale farmers also appears to merit greater attention.

Overall, these results should be of concern to those, often smaller, countries where yield growth rates appear to be falling behind LAC yield-growth leaders (for example, many parts of Argentina, Brazil and Mexico). They also send a message to the international, regional, and subregional agricultural R&D community that there remains much to be done to accelerate the flow of improved technologies across the region, especially those targeted to smallholders in less-favored areas. A

Table 4.5 Spatial yield variability in Latin America and the Caribbean: Maize, rice, and soybeans, 1975–95

	Total variation (Generalized entropy index)			Between-country/total variation (Polarization index)		
Year	Rice	Maize	Soybeans	Rice	Maize	Soybeans
					(percentage)	
1975	15.6	10.3	4.0	44.8	29.7	65.7
1976	13.3	10.4	3.5	46.3	25.2	60.0
1977	13.5	10.6	2.9	45.0	26.8	52.2
1978	15.8	11.3	2.8	49.1	35.5	53.0
1979	16.7	12.3	3.3	52.5	43.7	60.3
1980	16.0	11.2	3.9	51.0	29.4	66.3
1981	16.9	12.9	3.2	50.1	26.3	59.5
1982	17.7	16.8	2.8	46.9	17.5	62.1
1983	19.1	13.1	2.1	43.3	21.9	59.1
1984	17.1	13.2	2.3	42.8	21.1	67.5
1985	17.1	12.9	2.2	39.2	26.1	64.7
1986	15.5	12.2	2.4	38.6	33.4	68.4
1987	16.4	12.0	2.1	37.0	29.1	60.4
1988	15.9	13.8	2.8	36.5	26.6	58.7
1989	16.7	14.3	2.7	33.2	21.4	54.3
1990	16.3	11.6	2.3	29.9	24.3	69.0
1991	16.4	12.8	1.9	25.7	20.7	70.2
1992	19.0	14.1	2.0	23.4	26.8	80.5
1993	18.5	12.0	2.3	19.7	35.8	65.4
1994	18.1	16.3	1.9	23.0	24.1	64.4
1995	15.3	14.9	2.4	25.8	25.8	57.2
1996	13.8	14.1	2.9	29.4	27.3	53.8
1997	14.3	14.9	3.9	28.2	28.7	55.4
1998	14.2	15.6	4.0	30.3	35.4	55.6

Sources: Wood, You, and Zhang 2004.

Notes: See Wood et al. (2004) for a definition of the generalized entropy index. The polarization index is the ratio of between-country variation relative to total variation for the three major crops. The entropy measures for rice and maize are weighted by planted area. Due to a significant number of missing values for area data, we assume equal weights in calculating the yield variation in soybeans.

largely unmet challenge for R&D is to develop cost-effective strategies to improve the profitability and competitiveness of agriculture in less favored (non-irrigated) areas, where the majority of LAC's farmers, rural population, and a disproportionate share of its rural poor are to be found.

Locating Crop Production

The yield patterns analyzed to this point are based on tabulations of production data by statistical reporting units—that is, geopolitical units, be they national or, as

emphasized in the previous subsection, subnational. Often these spatial units encompass many different types of agroecological conditions and, consequently, important variation in the distribution and yield of specific crops. While satellite data do help assess the location of agricultural versus nonagricultural land, additional information can be used to make more precise assessments of the spatial distribution of individual crops. In particular, we know that different crops have distinct agroecological requirements (that is, they are better adapted to some agroecological zones than others), especially in the case of production under rainfed conditions. Thus, the temperature and rainfall regimes most appropriate for sugarcane are unsuitable for potatoes. Similarly, heavy clay soils may be unsuited for the production of maize and many vegetables, but they are ideal for irrigated rice production. We have developed an approach that draws on tabular data on crop production, satellite assessments of croplands, and our knowledge of the agroecological requirements of crops to gain much richer insights into the spatial distribution of crops.

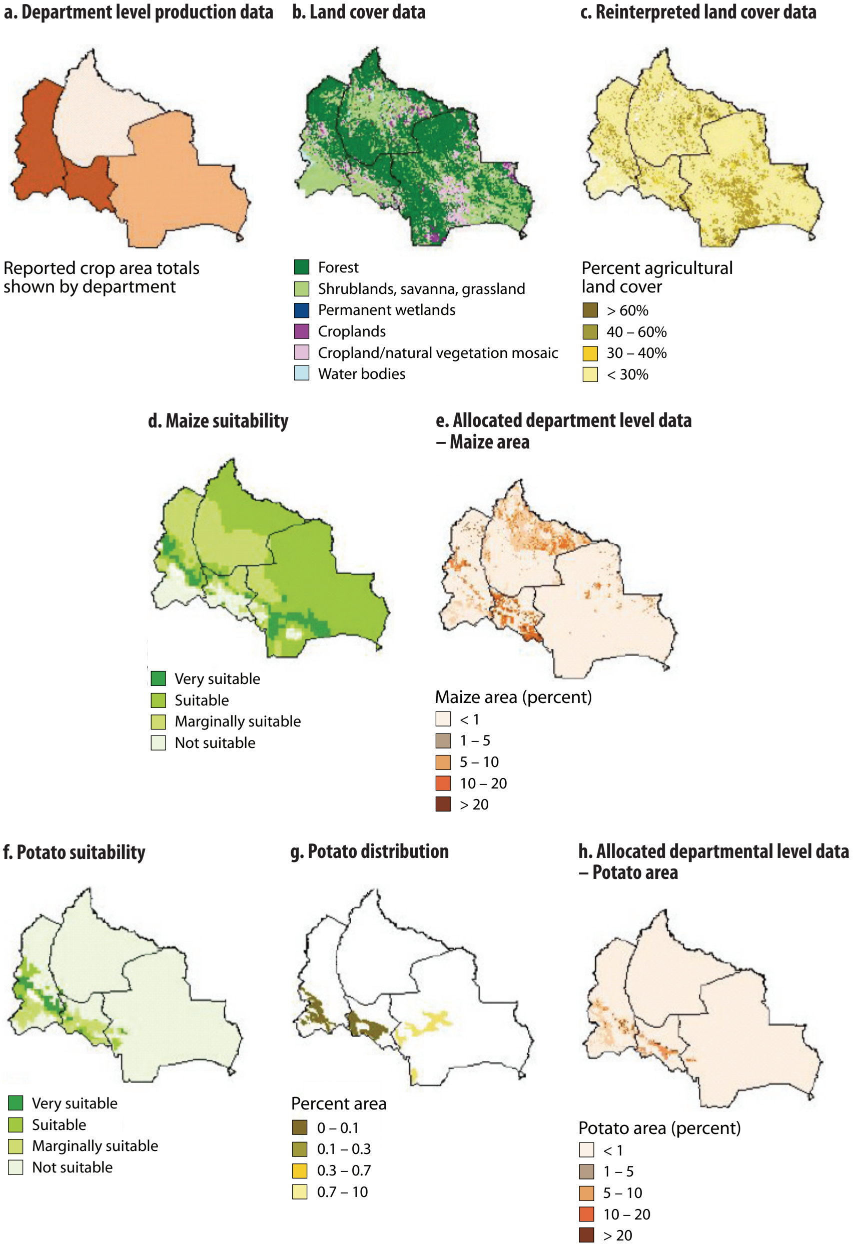
Consider the smallest geopolitical unit for which agricultural statistics on production, harvested area, and yield by crop are available. Depicting those statistics in map format necessitates the assumption that production is spatially uniform across that geopolitical unit (Figure 4.9a), which is inappropriate for some purposes. A much more refined spatial assessment of production can be gained by assuming crops are only grown within those areas interpreted as cropland using satellite data; for example, we can eliminate the forest, savanna, and urban areas from our consideration of the location of agriculture (Figure 4.9b).[12]

We then assessed the spatial intensity of crop production within the agricultural extent—that is, what share of every square kilometer cell, or pixel, of the satellite-derived data is dedicated to crop production. Following this reinterpretation, we arrive at the estimation of agricultural extent shown in Figure 4.9c. This still leaves several difficulties, the most significant of which is: Where does each specific crop fit within these agricultural areas? To answer this question, we applied our spatial model of production allocation, which uses agricultural extent, subnational production statistics, crop-specific suitability maps (see Chapter 3), and crop distribution maps where they are available. Other data elements used in the allocation include cropping intensities (to convert statistical data on harvested areas to physical crop area), the regional distribution of crop yields, and crop prices. The approach ensures that within each department (the smallest geopolitical unit in this instance):

- the total area and production allocated to each crop within each geopolitical reporting unit accords with the statistical data available for that reporting unit;
- any existing knowledge on actual crop location is incorporated to guide the area allocation process;

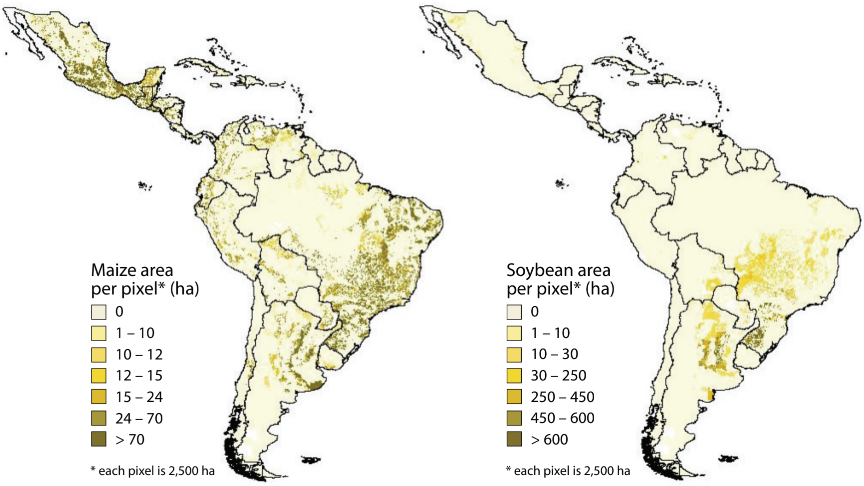
12 There are some issues related to the accuracy of satellite data interpretation for some agricultural land cover types. Such problems, however, are decreasing with time as spatial resolution, sampling frequency, and interpretation accuracy are improved and innovative, low-cost, ground-truthing techniques are developed.

Figure 4.9 Crop area allocation: Map-based overview



Sources: Figure 4.9a data are from IFPRI 1999; Figure 4.9b data are from EDC 1999; Figure 4.9c data are an IFPRI reinterpretation of 4.9b; for Figures 4.9d and 4.9f, FAO 1981 crop suitability rules were applied to CIAT 1996 climate data; 4.9g data are from CIP 1999.

Figure 4.10 Spatial allocation of crop production: Maize and soybeans



Sources: Compiled by authors.

- the areas allocated across all crops conform to the spatial pattern of area intensity of agriculture, as derived from the satellite data; and
- areas are allocated among crops according to their potential gross revenue (as estimated from the agroclimatic suitability surfaces and national crop price data for the given year).

A linear program was used to allocate area simultaneously among all crops so as to maximize revenue from the overall spatial configuration of production subject to a set of constraints (You and Wood 2006). Some examples of crop-specific allocations are shown in Figure 4.9e–h for maize and potatoes, respectively, where the potato allocation included additional information about actual crop distribution. The intent is not to try to match the real world, pixel by pixel, but rather to derive a better informed spatial allocation of production. Such a “plausible” allocation of production can then be related in more meaningful ways to other statistics, such as inputs of labor, seeds, fertilizers, pesticides, and irrigation water.

Figure 4.10 shows the result of applying this approach to assessing the distribution of maize and soybeans across LAC. Results for additional crops are presented in Supplementary Figure S4.3. The allocations were performed separately for each of the 297 national or first-level (state or department) spatial units for which tabular statistical data were available. Within each statistical unit, all crop areas were simultaneously allocated to ensure, among other things, that areas were not dou-

ble-counted. Multiple crops were allowed to occupy the same area on a proportionate-share basis.

Crop Areas by Agroecological Zone

The spatial allocation maps were combined with the regional AEZ map to estimate the area and production share of each commodity in each AEZ in LAC. These maps were then combined with the country boundary file to reveal crop area by country and by AEZ (Table 4.6). In Chapter 7 this information is used as a basis for exploring the likely economic payoff of targeting R&D investments by country versus targeting technology development to AEZs that span multiple countries.

The upper part of Table 4.6 shows the share of harvested area in each agroecological zone for each crop throughout LAC, while the lower half shows the equivalent distribution of production. A comparison of the two halves of the table illustrates the variation in productivity levels among AEZs. For example, AEZ 45, the semi-arid tropics, contains over 27 percent of the harvested area of beans in LAC (primarily in northeast Brazil) but provides only around 19 percent of LAC production. By contrast, AEZ 31, the moderately cool, humid/subhumid subtropics, contains 14 percent of the area but contributes 20 percent of the production. Similarly for rice, AEZ 43, the tropical, flat, humid/subhumid AEZ (primarily, in this case, the Cerrados of Brazil), contains over 30 percent of LAC's harvested rice area that is rainfed but only 17 percent of its production, while the irrigated areas of AEZ 31 contain about 22 percent of the area and about 34 percent of the production. Given prevailing varietal and technological options, we see that some commodities are strongly preferred in a few AEZs—for example, three-quarters of the potato production comes from just AEZs 21 and 31. Naturally if new varieties or other new technologies were to become available, the spatial distribution of commodities could well be different.

Agroecological Specificity

One of the hypotheses underlying the importance of disaggregating production by agroecologies is that commodities and technologies are often best suited to a few specific environments. Figure 4.11 illustrates the extent to which agroecological specificity is, in fact, observed. If there were no productivity bias, we would expect the proportionate area of each commodity found in each AEZ to be about the same as the area shares of each AEZ in agricultural land in LAC. For example, AEZ 31 occupies 16 percent of LAC, and we would expect to find 16 percent of the area of each crop in that AEZ, absent any agroecological bias. Figure 4.11 shows the ratio of both area and production of each commodity in each AEZ relative to the area share of that AEZ in LAC. Without bias, the ratio would be 1. If the ratio is 2, the commodity is twice as concentrated in that AEZ than uniform area shares would indicate. We see clearly here, for example, that potatoes in AEZ 21, rice in AEZ 30, and

Table 4.6 Harvested area and production by agroecological zone

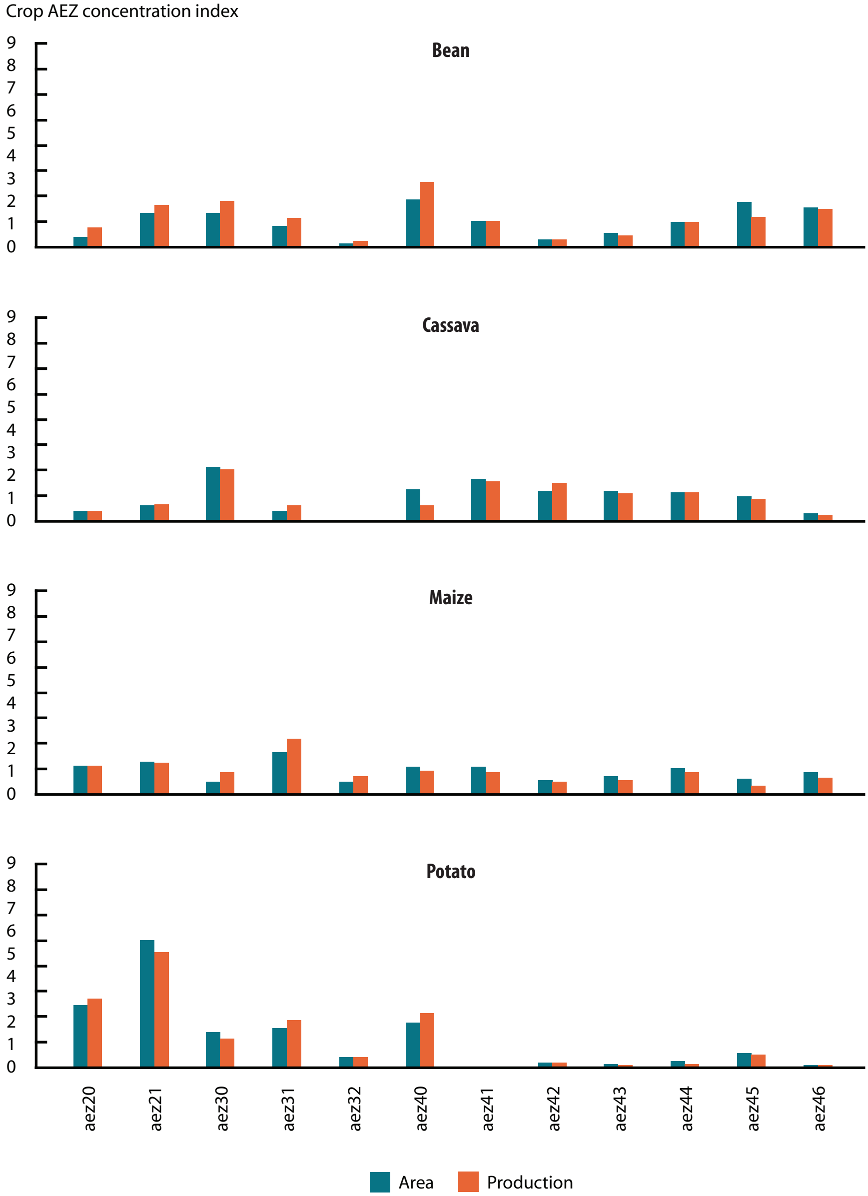
Agroecological zone	Beans	Cassava	Maize	Potatoes	Rice	Sorghum	Soybeans	Wheat
					(percentage)			
Harvested area								
Aez20	0.6	0.5	1.4	3.2	0.6	1.5	0.0	1.4
Aez21	12.5	5.0	11.2	46.0	7.1	11.0	2.3	3.7
Aez30	2.2	3.4	0.7	2.4	7.7	0.1	1.1	1.2
Aez31	14.0	6.9	29.4	28.7	21.8	18.2	39.9	59.5
Aez32	0.7	0.0	2.1	2.0	0.0	12.8	5.1	28.7
Aez40	2.3	1.5	1.2	2.1	2.0	1.9	0.1	0.1
Aez41	2.2	3.3	2.1	0.0	1.9	6.1	0.8	0.1
Aez42	3.8	14.2	6.9	1.7	7.6	2.4	5.1	2.0
Aez43	15.4	32.3	18.2	1.7	30.5	18.7	28.6	0.5
Aez44	16.2	18.3	16.0	3.6	14.2	6.9	8.0	0.9
Aez45	27.3	14.2	9.4	8.7	5.4	18.2	6.9	1.3
Aez46	2.9	0.5	1.4	0.1	1.4	2.3	2.2	0.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Crop production								
Aez20	0.9	0.5	1.4	3.5	0.9	2.1	0.0	2.6
Aez21	15.4	5.7	10.5	41.4	7.5	8.7	2.6	2.9
Aez30	2.9	3.3	1.4	1.8	11.7	0.1	1.0	1.3
Aez31	20.2	10.0	38.0	34.0	34.2	22.6	38.1	57.9
Aez32	1.2	0.0	3.3	2.0	0.0	15.1	5.8	30.1
Aez40	3.1	0.7	1.1	2.5	1.9	1.5	0.1	0.2
Aez41	2.2	3.1	1.8	0.0	2.4	4.6	0.9	0.2
Aez42	3.7	17.8	5.6	1.8	6.8	1.7	5.4	1.9
Aez43	12.6	28.5	16.3	1.7	16.8	20.4	30.0	0.4
Aez44	16.2	17.7	14.0	3.3	11.5	4.0	7.6	0.6
Aez45	18.7	12.5	5.4	7.9	4.8	16.1	6.2	1.1
Aez46	2.9	0.4	1.3	0.1	1.5	3.0	2.3	0.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Sources: Calculated by authors.

Notes: Data refer to average of 1995-97 period. Agroecological zones are delineated as follows:

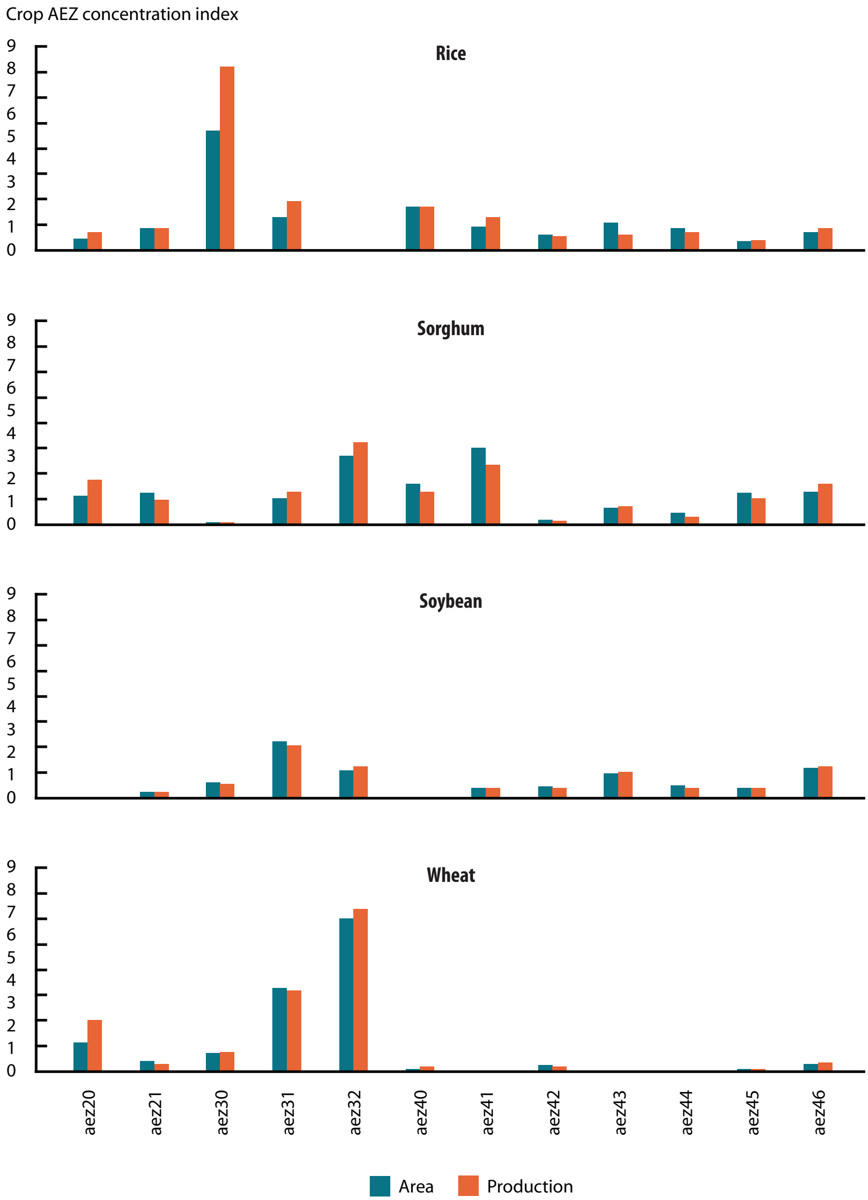
AEZ 20 Moderately cool/cool/cold tropics; irrigated and mixed irrigated/rainfed
AEZ 21 Moderately cool/cool/cold tropics; rainfed, humid and subhumid
AEZ 30 Moderately cool/cool/cold subtropics; irrigated and mixed irrigated/rainfed
AEZ 31 Moderately cool/cool/cold subtropics; rainfed, humid and subhumid
AEZ 32 Moderately cool/cool/cold subtropics; rainfed, dry and semi-arid
AEZ 40 Warm tropics; irrigated and mixed irrigated/rainfed
AEZ 41 Warm subtropics; irrigated and mixed irrigated/rainfed
AEZ 42 Warm tropics and subtropics; rainfed, humid, flat
AEZ 43 Warm tropics and subtropics; rainfed, subhumid, flat
AEZ 44 Warm tropics and subtropics; rainfed, humid/subhumid, sloping
AEZ 45 Warm tropics and subtropics; semi-arid/arid flat
AEZ 46 Warm tropics and subtropics; semi-arid/arid, sloping

Figure 4.11 Crop concentration by agroecological zone



(continued)

Figure 4.11 (continued)



Sources: Compiled by authors.

Notes: The figures show the shares of harvested area and production, for each commodity in each AEZ in LAC, relative to the area share of each AEZ in LAC agricultural land.

wheat in AEZ 32 are six to eight times more concentrated in those AEZs. Likewise, ratios that are less than 1 suggest an unfavorable set of agroecological conditions for production.

Soil Degradation

In 1990 the results of a global assessment of human-induced soil degradation, GLASOD, were published (Oldeman et al. 1991). GLASOD was the first and, so far, the only attempt to comprehensively assess the extent of soil degradation worldwide by synthesizing available information with expert consultations. The study assessed different types of degradation—water and wind erosion, as well as physical and chemical degradation—and examined the degree and extent of degradation for each. In the final printed map, the measures for the degree and extent of degradation were combined into "severity" classes. The GLASOD soil degradation severity results have been widely used, often in ways that go well beyond the purposes envisaged and recommended by the authors.

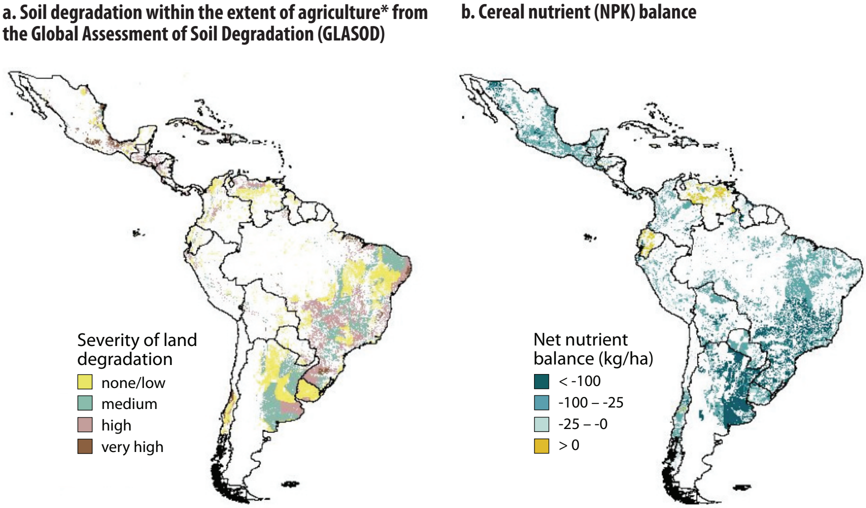
Degradation assessment is difficult and controversial for several reasons. It is hard to establish what would have been the situation without human intervention, there are extreme measurement and valuation problems, and it is not always easy to plausibly link causes and effects. While caution is called for in interpreting the GLASOD findings, they are indicative of the relative incidence of soil constraints on a regional scale. We have combined the GLASOD and agricultural extent maps to illustrate the incidence of soil degradation within LAC croplands (Figure 4.12a).

Soil Nutrient Balances

Production intensification to raise yield levels is achieved in various ways—shortening fallow periods, increasing planting densities, adopting crop varieties that are more efficient at extracting soil nutrients, and so on. As intensification pressures increase throughout LAC, there is a real threat of soil-nutrient mining if management practices are inappropriate. Conversely, in highly capitalized systems, nutrients are often applied excessively, and residual nutrients are leached into surface and groundwater, although this does not yet appear to be a regionally significant problem in LAC. While such leaching problems are most often associated with nitrogenous fertilizers and nitrate pollution, an increasing problem in some high-input production systems is that soils have become saturated with phosphorus; as a result, phosphorus leaching to surface- and groundwater bodies is becoming much more prevalent.

The International Fertilizer Development Center (IFDC) has undertaken a country- and crop-specific study of gross nutrient balances in LAC (Henao 1999). The analysis brings together data on national inorganic fertilizer consumption, crop-specific fertilizer application, organic fertilizer application, and crop-residue recy-

Figure 4.12 Soil degradation and cereal nutrient balance



Sources: ISRIC and UNEP 1990.

cling, as well as nutrient-extraction rates. The gross nutrient balance for each crop was computed for two periods, 1983–85 and 1993–95, as an average yearly difference between the sum of the nutrient inputs and the sum of the nutrient outputs.

In the analysis, nutrient inputs correspond to:

- mineral fertilizers applied as kilograms of nitrogen (N), phosphorus (P_2O_5), and potassium (K_20) per hectare (together referred to as NPK);
- organic fertilizers applied as manure or animal residue expressed as kilograms of NPK per hectare;
- nitrogen, phosphorus, and potassium from crop residues, corresponding to the amount of residues left on the soil after harvest and estimated as kilograms of NPK per hectare; and
- nitrogen fixation by soybeans and pulse crops, expressed in kilograms of NPK per hectare.

Nutrient outputs correspond to:

- nutrient uptake in grain or main crop products in kilograms of NPK per hectare; and
- nutrient uptake in the main crop residues in kilograms of NPK per hectare (depending on the crop and country, some proportion of this extraction was assigned for recycling (see nutrient inputs).

The results of this analysis (summarized for the major crops in Table 4.7) indicate a significantly negative nutrient balance for most crops and cropping systems throughout LAC. At face value, this points to a general tendency throughout the region of declining soil fertility. In many locations, and for many crops, observed production increases must thus be due to a combination of area expansion, improved varieties, and other factors that mask (or offset) the decline in soil fertility. Argentina, Belize, Bolivia, El Salvador, Guyana, Honduras, Paraguay, and Peru show no positive balance for any crop (although the nutrient balance may be positive for some crops within the "other" category). Brazil, Colombia, Costa Rica, Jamaica, Nicaragua, Trinidad and Tobago, and Uruguay have a positive balance for only one crop, usually beans or potatoes. Beans and potatoes in general have the most favorable set of nutrient balances. However, the two largest negative balances of over 200 kilograms per hectare per year are for potatoes in El Salvador and Nicaragua, where the areas involved are small.

Argentina has large negative balances across all crops, implying that the agricultural systems there are not sustainable in the long-term without increased attention to soil nutrient status. While significantly larger fertilizer applications might stem the problem, the rise in production costs could adversely affect the country's competitive position and increase undesirable environmental externalities. Notably, Venezuela has several positive balances. It is almost certain that this reflects the low cost of fuel for nitrogenous fertilizer production.

One interesting counterpoint is the estimation of large positive nutrient balances associated with potato production in Costa Rica and Ecuador. Assuming these results do not reflect data or modeling errors, they call for vigilance against the possibility of local water pollution and eutrophication.[13]

For illustrative purposes, an aggregate balance was constructed for just the major cereals: wheat, rice, maize, and sorghum (Figure 4.12b). The individual cereal nutrient balances were weighted by the proportion of area allocated to each cereal to arrive at an overall nutrient balance for cereals for each map pixel. The final yearly nutrient balances (averaged over the years 1993–95) are predominantly negative in LAC, with only Ecuador and Venezuela exhibiting positive values in the mid-1990s. In both countries the positive nutrient balance for cereals lies in the estimated positive balance for maize—23 kilograms per hectare in Ecuador and about 8 kilograms per hectare in Venezuela (Table 4.7). It is remarkable that the only other country with a positive nutrient balance for maize is a Caribbean state, Jamaica. The major areas of significantly negative nutrient balances in cereal production are found in the Buenos Aires province of Argentina, as well as in other parts of Argentina, and in the Brazilian Cerrados.

The gross nutrient-balance calculation holds promise as a useful indicator of the pressures on soil fertility. We have used these results further in the construc-

13 Eutrophication refers to waterways that are rich in dissolved nutrients but often seasonally deficient in oxygen.

Table 4.7 Estimated gross nutrient balances in Latin America and the Caribbean

Country	Period	Gross nutrient balance by crop								
		Wheat	Rice	Maize	Sorghum	Potatoes	Cassava	Beans	Soybeans	Other
					(kilograms per hectare)					
Argentina	1983–85	−131.7	−142.3	−176.9	−170.9				143.3	−137.7
	1993–95	−100.7	−135.3	−200.9	−190.8				114.9	−172.9
Belize	1983–85		−122	−76.1				−18.6		−65.8
	1993–95		−92.9	−62.1				−2.7		−34.9
Bolivia	1983–85	−52.8	−70.3	−103.5		−72.7	−75.0	0	−106.9	−82.6
	1993–95	−72.4	−94.5	−130.9		−69.8	−74.4	0	−186.6	−89
Brazil	1983–85	−45.6	−42.2	−66.2	−62.4	−134.1	−52.1	5.8	−76.5	−40.6
	1993–95	−38.8	−69.2	−99.9	−59.3	−17.5	−34.2	7.6	−83.4	−2.2
Chile	1983–85	−0.4	−78.2	−54.8		−60.2		−33.4		−28.6
	1993–95	−27.8	8.5	−110.4		−64.8		49.5		−26.5
Colombia	1983–85	−157.4	−156.2	−62.7	−67.7	−56.0	−60.9	−62.0	−123.7	−45.4
	1993–95	−199.0	−34.4	−70.8	−9.1	20.9	−66.1	−78.7	−133.2	−9.7
Costa Rica	1983–85		−48.2	−55.7		175.6	−36.7	−28.8		−14.3
	1993–95		−35.3	−44.3		179.7	−141.4	−23.8		30.4
Dominican Republic	1983–85		−221	−70.8	−119.7	−41.5	−18.7	−10.7		−32.8
	1993–95		−138.1	−18.2	−85.4	46.7	−18.1	39.3		13.0
Ecuador	1983–85	−85.8	−77.3	3.2	−215.8	27	−77.7	−41.2	−103.4	−48.4
	1993–95	−58.3	−102.5	23.3	−74.1	116.6	−24.9	−44.8	−110.2	−39.8
El Salvador	1983–85		−213.8	−79.2	−66.8	−172.2	−115.1	−20.3	−139.1	−78.2
	1993–95		−242	−40.1	−80.7	−237.7	−153.0	−17.3	−238.1	−18.4
Guatemala	1983–85	−128.9	−134.7	−63.8	−109.0	3.3	−21.4	−11.5		−77.7

	1993–95	−74.8	−75.8	−39.8	−75.5	7.0	−21.5	101.7		−53.7
Guyana	1983–85		−170.6	−51.1						−55.9
	1993–95		−201.2	−42.3						−48.1
Honduras	1983–85	−58.3	−96.7	−74.6	−35.1	−128.9	−56.8	−26.5		−50.6
	1993–95	−61.4	−79.5	−62.9	−32.1	−57.1	−57.5	−22.7		−3.9
Jamaica	1983–85		−124.5	−36.2		−106.9	−63.6	−73.1		−11.3
	1993–95		−103.9	20.6		−80.4	−95.9	−85.9		9.9
Mexico	1983–85	−200.3	−89.3	−9.4	−124.3	10.1	−119.3	20.5	−87.6	−13.6
	1993–95	−200.4	−162.7	−50	−118.1	−122.7	−67.6	2.1	−88.1	−6.8
Nicaragua	1983–85		−141	32.1	−79.7	−156.4	−89.0	−10.5	−63.3	−50.2
	1993–95		−179.6	−36.6	−92.2	−226.4	−87.1	−20.9	−135.5	−27.8
Panama	1983–85		−67.9	−31.7	−41.2	−13.1	−34.1	3.5		−37.1
	1993–95		−38	−15.7	−87	83.3	−23.0	−9.1		−4.3
Paraguay	1983–85	−80.6	−77.1	−83.8	−66	−137.2		−59.4	−71.1	−124
	1993–95	−125.4	−96.8	−107.4	−73.4	−127.4		−55.1	−179.8	−125.1
Peru	1983–85	−58.1	−108.5	−90	−98.4	−65.8	−87.8	−57.9	−123.4	−89.6
	1993–95	−36.7	−99.4	−34.6	−156.4	−18.1	−65.7	−42.2	−61.5	−57.7
Trinidad and Tobago	1983–85		−28.6	−76.8			−92.8			−3.1
	1993–95		−133.6	−143.8			−84.5			17.7
Uruguay	1983–85		−122.7	−32.7	−77.2	3.9			−59.8	−15.9
	1993–95		−95.7	−21.0	−89.0	−21.1			−35.4	−1.5
Venezuela	1983–85		−49.1	40.3	9.1	−90.4	−28.9	33.5		−8.9
	1993–95		−45.8	8.8	−5.6	−145.4	6.7	38.8		22.7

Sources: Computed by authors from Henao 2000.

tion of a pilot composite indicator of "hot spots" for Latin America (Figure 4.13c). Our calculations, above, revealed that long-term trends in cereal yields were positive in Argentina, Chile, much of the southern parts of Brazil, Uruguay, Venezuela, and much of Mexico. Cereal yields were stagnant or declining in northeast Brazil, Paraguay, most parts of the Andean countries, and in many Caribbean countries. Superimposing the data in Figures 4.13a and 4.13b reveal the spatial concordance between different classes of yield trends and nutrient balances. Hot spots were identified as areas where yields are decreasing, and the nutrient deficit is greater than 25 kilograms per hectare per year, or where yields are stable, but the nutrient deficit is greater than 100 kilograms per hectare per year. Bright spots were identified as having stable or increasing yields, with positive or only marginally negative nutrient balances (0 to –25 kilograms per hectare per year).[14]

Under some circumstances a farmer's economically optimum strategy may be to run down and, perhaps, exhaust the soil's inherent fertility (that is, produce as long as possible without adding fertilizer) before investing in chemical fertilizer applications. The mapped index we have created simply draws attention to ongoing biophysical degradation of the agricultural ecosystem as the inherent stock of soil fertility is depleted. At some time the land must either be abandoned or left fallow to restore its fertility, or—to maintain current output levels—additional production costs must be incurred to add fertilizer and trace elements and restore soil structure.[15]

Summary

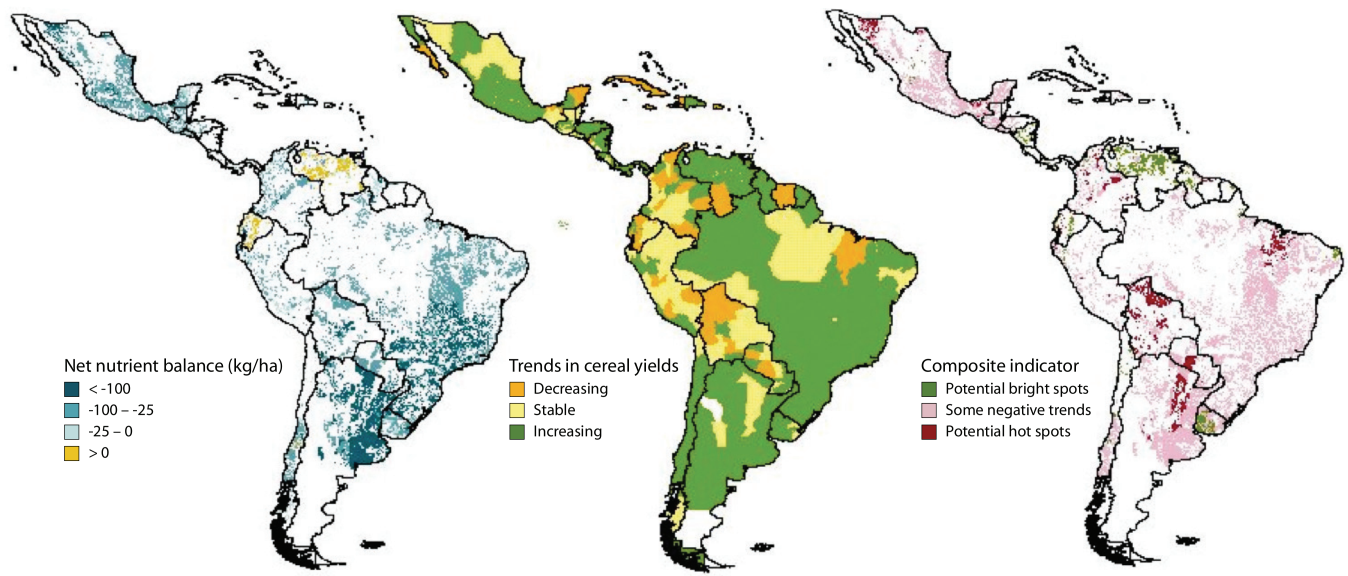
While the overall picture of growth in agricultural productivity in LAC is mixed, some important patterns and trends have emerged. The first is that there are significant geographic differences in the levels of productivity. This fact alone is not newsworthy. There are very large differences in economic strength, as well as in the strength and capacities of the agricultural research and development sectors both among and within the subregions of Mesoamerica, the Caribbean, and South America (see Chapter 6). But more worrying and newsworthy is the finding that productivity gaps appear to be growing, both among countries and between more and less advantaged regions within countries (for example, northeast Brazil versus southern Brazil). We have seen three specific features of these productivity trends. The first, most clearly seen in Brazil has been the expansion and relocation of agriculture over the years. This phenomenon has been driven in part by expanded market opportunities—for example, rapidly expanding domestic and international demand for soybean products—and expansion of the agricultural frontier through re-settlement where land resources permit. Also responsible is the intensification

14 These categories are arbitrary and would ideally be based on values that have economic significance in terms of changes in production costs and product prices.

15 Less-intensive production systems could also be introduced, but these might reduce profit levels.

Figure 4.13 Soil nutrient balance hot spots

a. Cereal nutrient (NPK) balance **b. Cereal yield trends** **c. Potent hot spots / bright spots**



Sources: Wood, Sebastian, and Scherr 2000.

of production, for example, through increased irrigation and fertilizer use, coupled with an emphasis on technologies best suited to such favorable intensification conditions. Third, however, are the apparent changes in the climate and soil resources underpinning agriculture.

We have seen some limited evidence of recent declines in rainfall totals, and stronger evidence of underlying degradation of the soil resource base as nutrients have been removed without adequate replenishment. The previous chapter revealed that many soils in LAC have intrinsic constraints for agricultural production, but it appears that long-term nutrient depletion is further exacerbating this problem. Clearly there are areas, such as the hillside and mountain-based systems of Mesoamerica and the Andean subregion, where intensification practices have not been conducive to long-term productivity growth. The promising overall trend, however, is that negative soil nutrient balances do not appear to be getting worse over time—in fact, they were significantly less negative in recent years than in the mid-1980s in most countries.

In the following chapters we examine some of the policy and R&D investment trends that appear to be fuelling the growing bifurcation in productivity trends in the region, as well as undertake analyses that, given the appropriate institutional mechanisms, suggest how more broad-scale growth in agricultural productivity might be achieved across the region.

Appendix Table 4A.1 Land productivity in Latin America and the Caribbean, 1961–2001

Rank	Countries	1961	1971	1981	1991	2001	Growth rate
		(1989–91 international dollars per hectare)					*(percent)*
1	Barbados	1,316	1,385	1,814	2,342	2,504	1.75
2	Martinique	1,595	1,712	1,610	1,755	2,468	0.70
3	Bahamas, The	1,935	2,725	2,477	2,019	2,174	0.36
4	Montserrat	1,033	1,445	1,674	2,008	2,110	1.86
5	Trinidad and Tobago	1,153	1,233	1,032	1,070	1,808	0.20
6	St. Lucia	1,989	2,197	2,117	1,202	1,273	–1.97
7	Guadeloupe	1,146	1,212	1,003	1,055	1,171	–0.31
8	Grenada	736	964	1,432	964	1,093	0.52
9	Puerto Rico	687	705	753	901	1,081	1.09
10	Dominica	1,547	1,586	1,736	1,143	975	–1.34
11	Jamaica	516	648	675	780	972	1.36
12	Antigua and Barbuda	766	807	1,452	931	908	0.19
13	St. Vincent and the Grenadines	1,629	1,567	1,232	933	886	–1.64
14	Suriname	704	908	830	946	848	0.16
15	Belize	332	443	505	501	838	2.03
16	St. Kitts and Nevis	900	1,146	1,294	705	817	–0.18
17	French Guiana	699	570	590	688	768	0.03
18	Costa Rica	259	339	314	427	560	1.83
19	Cuba	459	453	579	523	554	0.44
20	El Salvador	352	439	486	477	497	0.61
21	Guatemala	248	335	448	366	472	0.99
22	Ecuador	338	363	297	333	464	0.26
23	Dominican Republic	247	303	358	406	462	1.59
24	Honduras	166	274	332	345	439	2.15
25	Virgin Islands	421	314	314	352	432	0.70
26	Haiti	295	340	384	361	392	0.47
27	Chile	163	168	185	248	346	2.02
28	Panama	186	280	294	294	308	1.20
29	Brazil	115	124	167	204	287	2.48
30	Mexico	76	115	177	193	251	2.74
31	Venezuela	66	101	142	156	212	2.58
32	Colombia	79	93	130	170	182	2.43
33	Argentina	78	89	117	132	163	1.75
34	Peru	53	74	78	92	150	2.11
35	Uruguay	102	112	132	135	146	1.19
36	Guyana	116	134	120	95	145	0.06
37	British Virgin Islands	106	89	110	119	127	0.99
38	Nicaragua	72	119	107	94	124	0.02
39	Paraguay	46	56	76	90	113	2.16
40	Bolivia	16	22	30	38	53	2.94
41	Cayman Islands	0	100	106	45	49	–2.73
	Latin America and the Caribbean total	93	112	149	174	228	2.21

Sources: Compiled by the authors from FAO 2004.

Notes: Countries are ranked according to 2001 productivity levels. Compound growth rates obtained from logarithmic regression estimates.

Appendix Table 4A.2 Labor productivity in Latin America and the Caribbean, 1961–2001

Rank	Countries	1961	1971	1981	1991	2001	Growth rate
		(1989–91 international dollars per worker)					*(percent)*
1	Argentina	7,545	9,630	13,588	14,244	18,722	2.04
2	Martinique	1,675	2,216	3,645	5,390	11,367	4.62
3	Uruguay	7,042	7,937	10,003	9,970	10,982	1.42
4	Puerto Rico	2,543	3,229	5,729	6,930	9,548	3.30
5	Guadeloupe	1,748	2,368	2,456	4,786	9,419	3.98
6	Barbados	1,453	2,368	3,651	4,849	6,306	3.49
7	Brazil	1,216	1,481	2,120	3,214	5,513	3.94
8	Venezuela	1,411	2,225	3,563	3,640	5,343	2.95
9	Chile	2,337	2,946	3,239	3,741	5,004	1.73
10	Costa Rica	1,425	2,391	2,677	3,831	4,833	3.01
11	Belize	1,460	2,050	2,783	3,084	4,539	2.84
12	Bahamas, The	783	2,578	3,894	2,492	4,286	3.00
13	Paraguay	1,813	2,067	2,548	3,440	3,877	2.04
14	Guyana	2,175	2,458	2,540	2,253	3,732	1.14
15	Cuba	2,033	2,373	2,986	3,182	3,202	0.96
16	Ecuador	1,341	1,475	1,678	2,026	2,853	1.71
17	Montserrat	651	832	1,039	2,656	2,852	4.83
18	Mexico	1,078	1,538	1,998	2,120	2,844	1.99
19	Dominica	1,178	1,506	1,847	2,865	2,670	2.43
20	Suriname	1,287	2,145	3,680	3,326	2,377	1.52
21	Dominican Republic	1,082	1,244	1,572	1,860	2,334	2.06
22	Colombia	1,063	1,288	1,526	2,058	2,238	1.99
23	Panama	1,277	1,887	2,347	2,144	2,232	1.31
24	Trinidad and Tobago	1,619	1,971	2,039	1,797	2,208	0.09
25	St. Lucia	1,644	1,912	1,783	2,497	2,001	0.44
26	Grenada	704	1,222	1,644	1,567	1,921	1.96
27	Nicaragua	992	1,692	1,482	1,304	1,796	–0.01
28	St. Vincent and the Grenadines	1,257	1,303	1,437	1,837	1,532	1.05
29	Jamaica	898	1,209	989	1,194	1,530	0.90
30	Peru	945	1,111	1,016	986	1,493	0.58
31	Netherlands Antilles	4,017	6,513	2,298	1,339	1,415	–3.79
32	Honduras	700	1,002	1,113	1,202	1,369	1.57
33	French Guiana	651	597	546	1,228	1,323	2.94
34	St. Kitts and Nevis	890	919	1,294	1,075	1,323	1.03
35	Bolivia	611	741	932	1,049	1,252	1.77
36	Guatemala	612	772	974	940	1,014	0.96
37	El Salvador	787	830	970	998	1,008	0.62
38	Antigua and Barbuda	540	601	659	842	722	1.49
39	British Virgin Islands	423	223	276	301	321	0.47
40	Haiti	263	312	345	300	280	0.02
41	Virgin Islands	603	257	218	162	180	–2.41
	Latin America and Caribbean total	1,463	1,761	2,261	2,766	3,843	2.35

Sources: Compiled by the authors from FAO 2004.

Notes: Countries ranked according to 2001 productivity levels. Compound growth rates obtained from logarithmic regression estimates.

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Chapter 5

Policy and Institutional Environments

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Governments intervene in agricultural economies in all sorts of ways and for all sorts of reasons. The myriad policy, institutional, and regulatory mechanisms deployed by governments have direct and substantive consequences for the conduct of agricultural R&D, just as the economic consequences of the research (and the technical changes arising from it) are affected by government actions as well.[1] And aside from these research-mediated affects, public policies and institutional changes also have substantive consequences for food and agriculture sectors. In this chapter we review the evolution of the LAC policies that we consider had the most bearing on agriculture and agricultural R&D throughout the region, both as a basis for more completely understanding the recent historical developments documented in the previous chapters and for improving our forecasts of the future consequences of current R&D investments.

The early 1980s debt crisis, and the poor economic performance thereafter, triggered a process of structural reforms in most LAC countries. These reforms radically altered the macroeconomic framework and many of the sector-specific polices that affect agriculture. For example, agriculture was directly affected by trade liberalization reforms through the elimination of nontariff barriers, along with reductions in the range and levels of tariffs and the elimination of many export taxes. This process often paralleled the entry of many LAC countries to the General Agreement on Tariffs and Trade (GATT) and, subsequently, the World Trade Organization (WTO).

Financial and monetary reforms affected agriculture by reducing or removing interest- or exchange-rate controls, eliminating special exchange rate regimes, and reforming bank regulations (in particular those lending practices that singled out agriculture or were targeted to specific subsectors or specific agricultural products).

1 For example, Alston, Edwards, and Freebairn (1988) analyzed the effects of market distortions on the size and distribution of the benefits from research.

Some taxes on agriculture were eliminated, while new ones were introduced. Regionwide reductions in public expenditures led to the elimination or scaling back of many government agricultural programs that entailed (sometimes substantial) government outlays, such as price support schemes, commodity storage policies, input subsidies, and so on.

To review and assess policies affecting commodity markets, a comprehensive classification scheme is useful. One suggested by Roberts and Trapido (1991) is used here, which involves three main policy categories. The first category includes "economywide policies," that is, polices that affect all goods and services, such as macroeconomic policies, monetary policies, fiscal policies, financial policies, and trade policies.[2] In reviewing trade policies, we divided them into two subcategories: global trade agreements and specific trade policies, like tariff reductions. The second category comprises "sector-specific policies," which include policies directed to the agricultural sector or to a group of commodities within the sector. These policies encompass parastatal organizations that intervene in the production, domestic marketing, and foreign trade of agricultural goods; sector-specific credit policies; policies dealing with production inputs (fertilizers, machinery, and irrigation investments, and investments in research and extension); and special exchange rates for the agricultural sector. The third category, "commodity-specific policies," chiefly comprises policies that affect the prices received by producers (for example, commodity support prices, public storage, stabilization schemes, and policies affecting border prices) and policies that directly affect the prices paid by consumers for agricultural products (for example, value-added tax [VAT], as well as regional and international commodity agreements).

While this classification scheme is helpful, it can cause some confusion, especially when policies can be included in more than one category. Exchange rate policies are a case in point because they affect both the flows of capital (an economywide policy in our scheme of things), as well as the international movements of goods and services (a trade policy with sector-specific consequences).

In this chapter we first consider economywide policies and then move on to sector-specific policies. We opted to divide the review of economywide policies into two subsections: a pre-reform period beginning in the 1940s and extending through to the late 1970s, and a reform/postreform period covering the 1980s to the late-1990s. A section dealing with more contemporary developments in the early 2000 period concludes the chapter. Public policies aimed directly at agricultural research most logically lie within the realm of sector-specific policies, but their central importance to LAC agriculture and the subject matter of this volume led them to be set aside here and discussed in some detail in the chapter that follows.

2 We opted to exclude labor market policies from this review, judging their impacts on agriculture to be secondary relative to the policies we did review. See IADB (1996a, 1996b) for a survey of these policies.

Economywide Policies

Pre-Reform Period (1940s to late 1970s)

The prevailing policy practice in LAC during this so-called pre-reform period was one of widespread adherence to a package of import-substitution strategies that began in earnest during the 1940s.[3] This strategy entailed a policy environment favoring and seeking to foster "infant industries" in the industrial sector over agriculture (which in prior years was taken as one of the leading sectors when strategies based on the export of primary goods were seen as an effective means of stimulating economic development).[4] Macroeconomic policies were directed toward attaining that objective, with the protection typically taking the form of high import tariffs for domestically produced industrial products combined with overvalued exchange rates aimed at reducing the costs of foreign inputs and capital goods for use by newly emerging infant sectors.

To reduce labor costs, governments controlled consumer prices, especially those for food, while ostensibly seeking to also stimulate the supply of agricultural goods. Achieving these inherently conflicting objectives required direct intervention in agricultural output and input markets. Through time, the scope and magnitude of intervention increased, placing increasing pressure on government budgets. Because the domestic tax base was poor and undermined by numerous tax exemptions, tax revenues were often generated by indirect taxes that were easier to collect. Export commodities were a prime target for taxation, especially in small countries (such as those in Central America) that lacked effective tax administration systems but could more readily tax the export of agricultural commodities with little consequences for the price of their products in world markets.

Because governments were typically starved of domestic sources of revenue, the import-substitution strategies usually manifested themselves in the form of increased foreign debt. In a few cases, however, where domestic capital markets had developed to some degree (for example, in Argentina, Brazil, and Mexico), domestic debt was also used to finance these programs. Various LAC countries entered into a number of trade agreements during the 1960s, including the Central American Common Market (1960), the Andean Pact (1969), and the Caribbean Common Market (1973). These tended to reinforce the import substitution strategy through high tariffs on trade with countries that were not parties to the agreements.

3 Import-substitution strategies came in to being as a "process" over time (rather than a specific policy package introduced at a moment in time), gaining ground as manufacturing sectors emerged and as state policies and processes became increasingly interventionist. Elements of the strategy began prior to the 1930s, becoming more pervasive as the Great Depression took hold. See Thorp (1998) for an account of these developments.

4 The primary export strategy, which was the prevailing policy perspective throughout LAC prior to the shift toward import-substitution, sought to increase exports of raw materials (products like minerals or agricultural products with a low value-added component).

The pattern of policies just described was different among countries depending on their size and resource diversity. For example, governments in small countries, such as those in Central America, were more dependent on taxing primary export goods than were the comparatively large South American countries with a larger and more diverse tax base. During the 1950s and 1960s, LAC countries pursuing import-substitution policies grew at rates only slightly below those of East Asian countries (Edwards 1995). But by the 1970s, the gains from these import-substitution policies were exhausted, and a period of chronic external and fiscal imbalances began. The domestic policy adjustments that would typically follow from these trade and budgetary imbalances were muted as increased foreign debt was financed with the comparatively cheap credit available at that time.

The Oil Crisis in 1973–74 also affected the region, but in different ways, depending on a country's reliance on oil imports. Countries like Brazil, faced with the problem of increasing fuel costs, took steps to substitute alcohol for oil as a source of energy. Others, such as Mexico and Venezuela, had unexpected increases in export revenues.

As foreign debt continued to accumulate and international interest rates suddenly spiked, debt service loads for all the indebted economies of the region increased substantially in the early 1980s. And, unlike the Oil Crisis, the so-called Debt Crisis that peaked in 1982 had a similar effect on all the countries in the region, forcing them all to increase exports to secure enough foreign currency to meet their debt repayments. The typical policy response was to devalue the exchange rate to stimulate exports, while at the same time endeavoring to restrict imports.

Devaluation of the exchange rate affected prices of all tradable goods in the economy, thereby unleashing inflationary pressures. The years of import-substitution policies left a legacy of oversized public sectors with inflexible fiscal expenditure structures. Inefficient tax systems were also prevalent throughout LAC. These problems made public deficits recurrent sources of imbalance for the economies of the region. Eventually, growth through foreign debt financing was no longer possible, and most countries financed their mounting fiscal deficits by issuing money (so-called seigniorage revenue).

Not surprisingly, economic reforms began to be adopted by many Latin American countries in the mid-1980s.[5] The extent of the reforms depended mostly on the degree of economic difficulty being experienced. Table 5.1 presents a summary of macroeconomic indicators by country, at the time the reforms got under way for most LAC countries beginning in the late 1970s. Table 5.2 indicates the sequence of subsequent structural reforms followed by each of the countries. The timing of the reforms differed across countries, and some are still undergoing reforms.

5 A notable exception is Chile, which embarked on its reform processes in 1975.

Table 5.1 Summary of macroeconomic indicators by country

	Average Growth Rate	Average Rate of Inflation	Average Devaluation	Public Sector[b]			Balance of Payments				Debt indicators[c]	
				Total Revenue	Total Expenditure	Result	Trade Balance	Curr.Acc. Balance	Capital Balance	Result	Service paid	Stock
		(percentage)[a]			*(percent of GDP)*			*(US$ Million)*			*(percent of XGS)*	*(percent of GNP)*
Argentina												
1987-89[d]	-1.7	666.7	1,549.6	23.2	25.0	-1.8	3,656.0	-2,370.7	-2,713.3	-5,084.0	36.2	92.9
Bolivia												
1983-85	-2.0	1,610.0	1,741.1	2.4	16.5	-14.1	244.0	-202.0	-16.5	-218.5	49.5	176.6
Brazil												
1988-90	-0.2	1,393.7	1,103.3	26.3	39.6	-13.3	15,342.3	445.0	-9,295.0	-8,850.0	22.2	28.1
Chile												
1972-73	-3.4	228.2	400.0	16.9	26.3	-9.4	-167.0	-457.7	415.4	-42.3	10.6	27.5
Colombia												
1987-89	4.3	25.7	25.3	10.4	11.6	-1.2	1,389.7	-27.0	370.0	343.0	46.1	45.2
Costa Rica												
1987-89	4.6	18.1	13.3	15.9	18.8	-2.9	-158.3	-386.6	-110.9	-497.5	17.7	93.3
Dominican Republic												
1989-91	-0.1	52.8	27.7	14.5	12.9	1.6	-1,056.1	-254.7	94.7	-160.1	11.6	56.2
Ecuador												
1989-91	2.8	57.1	51.4	16.8	15.0	1.8	771.3	-594.3	-431.3	-1,025.7	32.2	112.8
El Salvador												
1989-91	2.7	18.6	17.0	13.0	14.6	-1.6	-677.6	-281.0	203.8	-77.1	17.8	41.8

(continued)

Table 5.1 Summary of macroeconomic indicators by country

	Average Growth Rate	Average Rate of Inflation	Average Devaluation	Public Sector[b]			Balance of Payments				Debt indicators[c]	
				Total Revenue	Total Expenditure	Result	Trade Balance	Curr.Acc. Balance	Capital Balance	Result	Service paid	Stock
		(percentage)[a]			(percent of GDP)			(US$ Million)			(percent of XGS)	(percent of GNP)
Guatemala												
1990-92	3.8	27.4	22.9	9.6	10.0	-0.4	-567.9	-374.2	78.2	-296.0	24.0	26.7
Honduras												
1989-91	2.5	22.0	38.4	17.6	22.1	-4.4	-42.7	-193.4	-85.9	-279.3	29.1	121.9
Mexico												
1984-86	0.8	69.4	72.1	16.5	25.8	-9.3	8,868.0	1,202.0	-1,555.7	-353.7	54.2	82.9
Nicaragua												
1988-90	-5.1	8,001.8	3,399.5	21.1	36.9	-15.8	-316.2	-460.8	-68.6	-529.4	3.9	1,081.0
Panama												
1988-90	-2.3	0.5	0.0	16.1	17.9	-1.8	-41.6	347.2	-973.9	-626.7	5.8	145.3
Paraguay												
1990-92	4.4	25.5	12.4	12.6	11.9	0.8	-617.1	-365.8	541.4	175.6	35.8	25.3
Peru												
1988-90	-8.1	2,630.2	2,136.3	7.8	12.4	-4.6	503.7	-1,257.7	-1,449.3	-2,707.0	10.6	63.1
Uruguay												
1988-90	0.7	83.8	72.9	16.7	18.5	-1.8	393.7	113.8	-57.8	56.1	40.8	55.0
Venezuela												
1988-90	1.5	49.8	47.9	20.1	23.2	-3.1	4,845.7	1,543.7	-3,066.7	-1,523.0	23.2	70.4

Sources: Compiled by authors using data from International Financial Statistics, IMF; World Debt Tables, World Bank; Economic and Social Progress in Latin America, IDB.

[a]Yearly rates.

[b]Yearly average for the period.

[c]Corresponds to the last year of the period. XGS indicates exports of goods and services; GNP indicates gross national product.

[d]Public-sector data exclude provincial governments.

Table 5.2 Timing of reforms

	1985 (or before)	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Stabilization	Argentina (1978 and 1985); Bolivia, Chile (1975 and 1985); Costa Rica, Peru, Uruguay (1978)	Brazil, Dom. Rep.	Guatemala	Mexico	Venezuela	Dom.Rep., Peru	Argentina, Colombia, Guatemala, Nicaragua, Uruguay	Ecuador, Honduras		Brazil		
Trade Liberalization	Argentina (1978), Chile (1975 and 1985), Mexico, Uruguay (1978)	Bolivia, Costa Rica		Guatemala	Argentina, Paraguay, El Salvador, Venezuela	Brazil, Dom. Rep., Ecuador, Honduras, Peru	Colombia, Nicaragua, Uruguay				Panama	
Tax Reform					Argentina	Nicaragua, Peru	El Salvador	Ecuador, Guatemala, Honduras, Paraguay, Venezuela	Bolivia			
Financial Reform	Argentina(1978) Chile(1975), Uruguay(1974 and 1985)	Mexico		Costa Rica, Brazil, Paraguay	Chile, Venezuela	Bolivia, Colombia, El Salvador, Nicaragua, Peru	Dom.Rep., Honduras, Guatemala	Argentina	Ecuador			
Privatization	Chile (1974-78)			Chile (1988)		Argentina	Venezuela	Mexico	Nicaragua	Chile, Peru	Bolivia	
Labor Reform	Chile (1979)					Colombia, Guatemala	Argentina, Peru			Panama		
Pension Reform	Chile (1981)								Peru	Argentina, Colombia		Uruguay, Mexico

Sources: IADB 1996a, 1996b.

Table 5.3 Monetary policies adopted since the late 1990s

Policy	Countries
No monetary policy	Panama
Restrictive policy	Argentina, Bolivia, Brazil, Chile, Ecuador, El Salvador, Mexico, Nicaragua, Peru, Uruguay, and Venezuela
Active	Dominican Republic, Guatemala, Honduras, and Paraguay

Sources: Compiled by authors from IMF (1993,1994, 1995a–f, 1996c–f,1997b–e, 1998a–d) and IADB (1996a, 1996b).

Reform/Post-Reform Period (Early 1980s to Late 1990s)

Despite their different features and varying timeframes, the structural reforms were implemented by all Latin American countries ostensibly with the aim of improving efficiency, spurring economic growth, increasing income, and improving the welfare of the population (IADB 1996a, 1996b). To analyze the current state of the economywide policies, we have divided these policies into five categories. The reform of the financial system (encompassing the reform of the banking sector and other financial institutions) can be subdivided into two categories: the first, called monetary policy, is related to Central Bank policies to control the money supply, while the second, financial policy, is related to the structure of the financial sector, interest rates, and exchange rate policy. A third category, fiscal policy, encompasses changes in the structure of the public sector (for example, the tax structure, expenditure controls, and privatization); the fourth, trade policy, relates to trade-liberalization policies, and the fifth involves trade agreements. Appendix Table 5A.1 summarizes the main events relating to these economywide policies by country.

Monetary policy reforms. Most countries are now pursuing tighter monetary policies, but there are some differences among them. Table 5.3 presents an overview of the policies followed by each country, classifying countries according to whether their central banks applied monetary policy to finance public-sector deficits. As shown in the table, most of the countries are currently following restrictive monetary policies. Only Panama and Argentina had special arrangements that acted as a real restraint on the implementation of monetary policies. Panama lacks a central bank and its domestic currency (the Balboa) is tied to the U.S. dollar. In Argentina, monetary policy was made through the exchange of dollar-denominated bonds for foreign currency, subject to limits and strict regulations.

The countries classified as having restrictive monetary policies have reformed their central banks to differing degrees, but generally they maintain tight monetary policies via targeting such macroeconomic variables as the inflation rate, the interest rate, and the exchange rate. The bottom group of countries in Table 5.4 includes those countries that are still experiencing fiscal problems, and where the central banks are still the principal source of finance to meet budget shortfalls. For example, Paraguay's central bank is still dealing with the effects of a substantial quasi-fiscal deficit that stems from the 1995 and 1997 financial crises that befell that country.

Table 5.4 Status of policies in the financial sector, 1998

Country	Interest rate situation	Exchange rate system	Targeted funds existence
Argentina	Free	Fixed	Some remains
Bolivia	Free	Crawling peg	Some remains
Brazil	Free	Sliding band	Some remains
Chile	Free	Sliding band	Few
Colombia	Free	Sliding band	Few
Costa Rica	Free	Crawling peg	Some remains
Dominican Republic	Free	Flexible	Some remains
Ecuador	Free	Sliding band	Has not decreased
El Salvador	Free	Flexible	Some remains
Guatemala	Free	Flexible	Some remains
Honduras	Free	Crawling peg	Some remains
Mexico	Free	Flexible	Some remains
Nicaragua	Free	Crawling peg	Few
Panama	Free	Fixed	Has not decreased
Paraguay	Free	Flexible	Most remains
Peru	Free	Flexible	Some remains
Uruguay	Free	Sliding band	Eliminated
Venezuela	Free	Sliding band	Some remains

Sources: Compiled by authors from IMF (1993,1994, 1995a–f, 1996c–f,1997b–e, 1998a–d) and IADB (1996a, 1996b).

Other countries in this category are still in the process of reforming their financial systems.

The economic shocks that reverberated throughout the developing world following the Russian financial crisis of 1998 induced capital flights from many countries in LAC. Economic recessions followed, which for many countries in the region persisted until early 2000, and for some countries much longer (for example, Argentina). The Mexican economy, for example, experienced a significant jump in interest rates and a depreciation of its nominal exchange rate. Brazil increased short-term interest rates and initially defended its currency against devaluation, although it later abandoned this policy after failing to prop up the country's currency. Argentina's interest rates increased steadily, and in February 2002 the government terminated its "convertibility law," which had pegged the Argentinean peso to the U.S. dollar since 1990.

Financial sector reforms. During the import substitution period, governments intervened pervasively in domestic financial markets through the provision of targeted credit, the creation and management of public development banks, interest rate controls, controls on foreign currency, and banking reserve requirements (IADB 1996a, 1996b). Structural reforms resulted in most of these interventions being phased out and the financial sector moving to a more market-oriented system (with government largely restricting itself to a regulatory role). Table 5.4 summarizes the state of financial-sector reforms, on a country-by-country basis.

All the countries have eliminated interest rate controls. Although some countries maintained a system of differential exchange rates, a more unified exchange rate regime was also evident in countries throughout the region. Some governments still set the rate of currency exchange (rather than leaving it to market forces); however, the rates are now actively monitored and adjusted to avoid large swings in their real values.

Targeted public funding (wherein monies are earmarked by the government to finance specific activities, such as a fund to finance crop production) is still a policy feature in some Latin American countries. Many such funds, including those for agriculture, have been eliminated, however, except in Paraguay where the National Development Bank has a program to provide short-term loans to finance the production of soybeans, wheat, cotton, rice, maize, and sugarcane. In addition, the bank has credit lines for machinery purchases and agricultural investments. In Panama, the Bank of Agricultural Development also offers sectoral loans for working capital, real estate, and marketing. In some cases, governments still maintain targeted funds for some specific groups of the population at preferential interest rates that are slightly below market rates. Funds for small farmers, for example, are commonplace.

For agriculture as a whole, the financial reforms largely reduced the amount of public resources made available to the sector. The uncertainties of agriculture and a shortage of conventional sources of collateral kept commercial banks from filling the gap. Some advances have been made by governments in providing for land titling and devising new, unconventional sources of collateral.

Fiscal policy reforms. Fiscal policy reforms relate chiefly to the structure and operation of the tax system, public-sector expenditure controls, and privatizing public enterprises. The status of these reforms as of 1998, is summarized in Table 5.5. Most LAC countries implemented tax reforms as part of a broader strategy to increase public revenues. Other measures included improving the tax collection system and related public services (Edwards 1995). A distinctive element of the tax reforms undertaken in most countries in LAC was adoption of a value-added tax (VAT). Although Brazil did not modify its existing tax system as part of more recent reform efforts, it had already introduced a VAT system at the state level beginning in 1967. Venezuela instigated a series of fiscal reforms in 1990, including the introduction of a VAT system, but the economic problems of 1994 forced the government to move to a different, wholesale tax system. As a consequence of these fiscal reforms, the agricultural sectors of many countries that had previously been exempt from taxes were forced to pay a VAT on imported inputs, although several countries continued to exempt agriculture. Moreover, increases in the prices of public services, following trends toward greater cost recovery, led to significant reductions in the implicit subsidies flowing to the agricultural sector.

Tightening public expenditure controls was another reform initiative throughout many public sectors. Countries with large public sectors for example, Argentina, Chile, Mexico, and Peru adopted policies to significantly reduce the number of

Table 5.5 Implementation of fiscal reforms, 1998

Country	Tax Reform	Control of Expenditures	Privatizations
Argentina	Yes	Some	Yes
Bolivia	Yes	Yes	Yes
Brazil	No	No	Yes
Chile	Yes	Yes	Yes
Colombia	Yes	Yes	No
Costa Rica	Yes	No	No
Dominican Republic	Yes	No	Some
Ecuador	No	Yes	Some
El Salvador	Yes	No	No
Guatemala	Yes	No	No
Honduras	Yes	No	Some
Mexico	Yes	Yes	Yes
Nicaragua	Yes	Yes	Yes
Panama	No	Yes	No
Paraguay	Yes	Yes	Some
Peru	Yes	Yes	Yes
Uruguay	Yes	No	Some
Venezuela	No	Yes	Some

Sources: Compiled by authors from IMF (1993,1994, 1995a–f, 1996c–f,1997b–e, 1998a–d) and IADB (1996a, 1996b).

public employees and to restructure the role of the sector itself. Central American countries also significantly reduced the size of their public sectors. An important part of the expenditure reductions involved reducing interest payments on public debt through the so-called Brady arrangements.[6] This was done in Argentina in 1993, Brazil in 1993, Costa Rica in 1989, Uruguay in 1991, and in Venezuela in 1990. These policies negatively affected the agricultural sector because agricultural services, the number of agricultural agencies, and the fiscal transfers to agriculture were all reduced.

Privatizing previously public operations was also an important feature of the reform process. However, unlike the mining and energy sectors, typically there were few public enterprises in agriculture. That said, in Central America, the state played an important role in the processing and handling of export products like sugar and coffee, sometimes encompassing the entire food production/processing chain. For example, in the Dominican Republic, the government owned most of the sugar mills and monopolized the export trade in sugar. With privatization, many government agencies sold their storage facilities, permanently reducing the public sector's ability to influence agricultural prices through commodity purchases.

Trade policy reforms. According to Edwards (1995), the intent of trade policy reforms was to reduce waste, lower import prices, and reallocate domestic resourc-

6 The Brady arrangements consisted of a debt rescheduling process, whereby short-term debt (due in many cases) was exchanged for long-term debt.

Table 5.6 Changes in the levels and ranges of tariffs, 1980s versus 1990s

	1980s			1990s		
		Tariff			Tariff	
	Year	Minimum	Maximum	Year	Minimum	Maximum
		(percentage)			*(percentage)*	
Argentina	1987	0.0	55.0	1998	0.0	33.5
Bolivia	1985	0.0	20.0	1998	0.0	10.0
Brazil	1987	0.0	105.0	1998	0.0	52.0
Chile	1987	0.0	20.0	1998	11.0	11.0
Colombia	1986	0.0	200.0	1998	0.0	35.0
Costa Rica	1986	1.0	100.0	1998	0.0	20.0
Ecuador	1986	0.0	290.0	1998	0.0	35.5
El Salvador	na			1998	0.0	20.0
Guatemala	1986	1.0	100.0	1998	0.0	20.0
Honduras	na			1998	0.0	20.0
Mexico	1985	0.0	100.0	1998	0.0	260.0
Nicaragua	1986	1.0	100.0	1998	0.0	20.0
Paraguay	1984	0.0	44.0	1998	0.0	30.0
Peru	1987	0.0	120.0	1998	12.0	25.0
Uruguay	1986	10.0	45.0	1998	0.0	24.0
Venezuela	1987	0.0	135.0	1998	0.0	35.0

Sources: Data for the 1980s are from Edwards 1995 data for the 1990s are from the IADB tariff database.
Notes: na – not available.

es more in line with comparative advantage. The chronology of policy changes in Table 5.2, shows that all the countries in the region have reformed their trade policies. Most began doing so in the mid-1980s, with the exception of Chile, Mexico, and Uruguay where reforms began earlier during the 1970s. Table 5.6 presents the minimum and maximum tariffs across a range of agricultural commodities for 19 countries in LAC. Almost all the countries reduced the range as well as the average level of tariffs. For Mexico (the only country to increase its maximum tariff), the highest tariff is charged on a few products only, such as agricultural products that compete with domestic production. According to the IADB tariff database, the Mexican mean tariff was only 13.2 percent in 1998, and most of the remaining high tariff rates were in the process of being eliminated as part of the NAFTA and Uruguay Round Agreements. As part of their efforts to liberalize trade, countries also eliminated export taxes—often an equally important source of revenues as import tariffs. In addition, countries eliminated a battery of import licenses and permits, as well as various other nontariff barriers that had been established with the effect of restraining competition from foreign suppliers.

Trade agreements. Trade agreements in Latin America have helped reduce tariff barriers. The Uruguay Round of GATT and various regional agreements have resulted in the reduction or elimination of tariff barriers either generally, or at least within

Table 5.7 Membership in the World Trade Organization and regional agreements, 1998

Country	World Trade Organization status	Regional trade agreements
Argentina	Member	Mercosur
Bolivia	Member	Andean Pact
Brazil	Member	Mercosur
Chile	Member	—
Colombia	Member	Andean Pact
Costa Rica	Member	CACM
Dominican Republic	Member	—
Ecuador	Member	Andean Pact
El Salvador	Member	CACM
Guatemala	Member	CACM
Honduras	Member	CACM
Mexico	Member	NAFTA
Nicaragua	Member	CACM
Panama	Member	CACMa
Paraguay	Member	Mercosur
Peru	Member	Andean Pact[a]
Uruguay	Member	Mercosur
Venezuela	Member	Andean Pact

Sources: Compiled by authors from IMF (1993, 1994, 1995a–f, 1996c–f,1997b–e, 1998a–d) and IADB (1996a, 1996b).
[a]observer only.

the realm of the regional agreements (Table 5.7). The Uruguay Round, in particular, limited maximum *tariffs* and required countries to change their nontariff barriers to tariffs or tariff-rate quotas.[7] It is important to mention that during the reform process, regional agreements like the Central American Common Market (CACM), the Caribbean Community (CARICOM), and the Andean Pact were revitalized, shedding the role they played in earlier periods to help shore up pro-industrial, import-substitution policies.

Although Chile is not a member of any regional trading agreement, it maintains agreements with the Southern Common Market (Mercosur) and bilateral trade agreements with countries that are members of other regional agreements, such as Colombia, Ecuador, and Mexico. An important feature of trade agreements is the presence of a common external tariff, which currently affects most agricultural commodities. However, the main regional trading agreements (Mercosur, CACM, and the Andean Pact) differ in the types of tariffs they apply. While Mercosur members use ad valorem tariffs, the Andean Pact members use price bands that are based on reference prices rather than invoice prices. In the case of the CACM, its members

7 A tariff rate quota is a two-tiered tariff rate import quota. In a given period, a lower "in-quota" tariff rate is applied to the first units imported (also called "minimum access" rate) and a higher "over-quota" tariff rate is applied to all subsequent imports.

have the right to elect the applicable tariff (ad valorem or variable). All three regional agreements currently have Common External Tariffs (CETs).

Argentina now pursues a quite aggressive, outward-oriented trade policy. For example, in 2002 it proposed to the WTO accelerating the implementation of the duty and subsidy reductions agreed to in the Uruguay Round. It has also committed to a 35 percent import tariff ceiling for agricultural products, with current duties being well below this limit. It operates a system of rebates on exports to non–Mercosur countries to reimburse producers for some of the indirect taxes incurred during the agricultural production and marketing stages (for example, VAT). However, as a consequence of its fiscal crisis in March 2002, Argentina imposed a 10 percent export tax on primary product exports (which was increased to 20 percent in April 2002 on grain and oilseed exports, while the meat export tax remained unchanged at 5 percent). Brazil, for its part, now provides export credit and cash advances on exported commodities.

Sector-Specific Policies

Policies specific to the agriculture sector can be divided into six groups. The first group involves parastatals and public enterprises that serve the agriculture sector. The second group is agricultural credit policies. The third, differential exchange rate policies, is included because of its historical importance in the region, although now all the LAC countries included in this report have eliminated their multiple exchange rate systems. The fourth group concerns agricultural input policies, broadly defined to include policies that affect rural roads and other infrastructure, as well as more conventional farm production inputs. These four sets of policies target agricultural producers. A fifth set of policies relates to food assistance programs targeted toward consumers, and a sixth set deals with agricultural research which is discussed separately in the next chapter. Appendix Table 5A.2 summarizes the first four sector-specific policies for LAC (that is, those targeting agricultural producers).

Parastatals and Public Enterprises

Historically, state marketing boards have featured prominently in many agricultural markets throughout LAC, although more recently the *trend* has been toward eliminating all agricultural parastatals and public enterprises. The region's parastatals and public enterprises fall in to two broad classes. The first includes a set of agencies dealing with export markets for specific products, such as coffee, sugar, or bananas. In some cases, these public agencies controlled the whole process from farm to foreign market (such as CEA in the Dominican Republic). In other cases they only controlled the foreign trade (for example, Argentina's National Grain Board, which regulated foreign trade in grains). A second group includes all the marketing boards dealing with important items of consumption. They were created earlier, during the import-substitution period, to provide cheap food for consumers. These

Table 5.8 Presence of parastatals and public enterprises in Latin American and Caribbean agriculture

Country	None	Reduced	Important
Argentina	X		
Bolivia		X	
Brazil		X	
Chile		X	
Colombia	X		
Costa Rica		X	
Dominican Republic			X
Ecuador		X	
El Salvador	X		
Guatemala		X	
Honduras			X
Mexico		X	
Nicaragua		X	
Panama		X	
Paraguay	X		
Peru		X	
Uruguay		X	
Venezuela		X	

Sources: Compiled by authors from IMF (1993, 1994, 1995a–f, 1996c–f, 1997b–e, 1998a–d) and IADB (1996a, 1996b).
Notes: Financial enterprises are not considered.

institutions evolved, and typically the scope of their intervention increased with time. Examples are IDEMA in Colombia, CONASUPO in Mexico, INESPRE in the Dominican Republic, ECASA in Peru, CONAB in Brazil, CNP in Costa Rica, ENAC in Ecuador, ICA in Guatemala, IHMA in Honduras, and ENABAS in Nicaragua. The closure or privatization of most of the agencies was an important step in the policy reform process. Table 5.8 indicates the presence of parastatals or public enterprises in LAC agriculture as of 1988.

In more recent times, the number and scope of public agencies in agriculture has been curtailed, except in the Dominican Republic and Honduras. In the Dominican Republic, the government fully owned and operated 12 of the country's 16 sugar mills, as well as the country's 2 wheat mills, but in 1999 the government concluded a process of privatizing both the sugar and wheat mills. INESPRE's influence in marketing agricultural products has also declined more as a result of a shortage of funds than as a conscious policy decision to reduce its role. However, it still effectively controls the Dominican price for beans, garlic, poultry, and rice (and also maintains a food program targeted to low-income families). While the Honduran government has privatized its grain and sugar facilities, the government-owned IHMA still manages a strategic reserve of grains and sets price bands for grain imports. The government has also continued a program it began in 1997 to compre-

hensively subsidize consumption of a basket of basic goods (beans, rice, vegetable oil, corn, milk, chicken, coffee, and other food staples). Moreover, the government continues to operate BANASUPRO, a chain of retail stores it established in 1974 to market the subsidized basket of staples to all consumers, and even restructured and expanded the geographic coverage of this retail chain in 1997.

Agricultural Credit Policies

The changing nature of agricultural credit policies reflects more comprehensive financial sector reforms in LAC. Many (but not all) countries removed many of the specialized financial instruments intended to promote agriculture including closing agricultural development banks offering subsidized interest rates to primary producers, removing credit lines to fund working capital for agriculture, and banking regulations that required commercial banks to maintain a minimum share of their portfolios in agriculture—which we refer to here as "targeted loans" (Table 5.9).

Below-market interest rates are still used as a means of subsidizing agricultural producers in some countries in LAC. However, the amount of the subsidy is constrained by the availability of government financing. In most cases, tight monetary policy seriously constrained government resources for this purpose. Minimally, the spread between interest rates on agricultural loans from public sources and market rates of interest was reduced.

Currently, only two countries still target lending to agriculture. Paraguay requires commercial banks to assign 10 percent of their portfolios to agricultural loans. In the case of Venezuela, the share of total lending to be targeted to agriculture was 15 percent in 1998.[8] In 2000 the government introduced a program of production loans for small and medium farmers valued at US$10.7 million, which was channeled through commercial banks. In many countries, the lack of credit for peasant farmers has led governments to create "special funds,"—for example, the Bolivian Peasant Development Fund. Similar funds have emerged in Argentina, Brazil, Colombia, Costa Rica, Paraguay, and Peru. Brazil offers production credit at subsidized interest rates, and loans are made available for modernizing the stock of tractors and implements. Small producers of cotton, rice, corn, and wheat receive production loans and pay them off "in kind," with part of their harvest. Loans are subsidized at a 3.75 percent yearly rate. Colombia offers several credit lines, but interest rates are not subsidized. In Brazil, existing debt is also being discounted or forgiven (for example, up to 30 percent for loans of US$5,000 or less), while in Colombia farmers are now offered debt relief, wherein past loans are refinanced at lower rates of interest with "soft" repayment requirements. In the case of Central America and Brazil, funding has also been earmarked for specific crops.

The agricultural banks were a carry-over from the import substitution period; in most cases, they provided subsidized loans. Colombia, the Dominican Republic, Guatemala, Honduras, Mexico, and El Salvador still have agricultural banks. Peru

8 In fact, this regulation was temporarily eliminated in 1997.

Table 5.9 The status of credit policies, 1998

Country	Market interest rate	Targeted funds from commercial banks	Special credit lines	Agricultural bank	Public insurance
Argentina	Yes	No	Few	No	No
Bolivia	Yes	No	Few	No	No
Brazil	No	No	Yes	No	Yes
Chile	Yes	No	Very few	No	No
Colombia	No	No	No	Yes	No
Costa Rica	No	No	Yes	No	No
Dominican Republic	No	No	Yes	Yes	No
Ecuador	Yes	No	No	No	No
El Salvador	No	No	Yes	Yes	No
Guatemala	Yes	No	No	Yes	No
Honduras	No	No	No	Yes	No
Mexico	No	No	Yes	Yes	Yes
Nicaragua	No	No	No	Development bank	No
Panama	No	No	No	Yes	Yes
Paraguay	No	Yes	Yes	No	No
Peru	Yes	No	Yes	Decentralized banks	No
Uruguay	Yes	No	No	Development bank	No
Venezuela	No	Yes	Yes	No	No

Sources: Compiled by authors f from IMF (1993, 1994, 1995a–f, 1996c–f,1997b–e, 1998a–d) and IADB (1996a, 1996b).

and Venezuela eliminated their agricultural banks (which were insolvent with many nonperforming loans) as part of their financial reform processes. Currently, Peru is using small, decentralized rural banks (*Cajas Rurales*), while Venezuela has other financial institutions to support agriculture (FCA, ICAP). Nicaragua and Uruguay still support multipurpose development banks, which have credit access implications for agriculture.

Another financial instrument that was prevalent throughout the region involved subsidized agricultural insurance for farmers. However, as of 1998, Brazil, Mexico, and Panama were the only remaining LAC countries to provide publicly backed agricultural insurance.

Differential Exchange Rate Policies

Typically, agricultural exports in most LAC countries were not only taxed directly, in an ad valorem fashion, but also indirectly as a consequence of undervalued exchange rates. Such was the case in Argentina, which before the Austral plan of 1985 subjected agricultural exports to exchange rates that were 10 to 20 percent below the prevailing market exchange rate (measured as domestic currency per unit of foreign currency). Prior to the unification of its exchange rates in 1996, the Dominican Republic set a special rate for its cocoa, coffee, sugar, and tobacco exports at 7

percent below the market rate. Ecuador maintained differential exchange rates for its exports until 1997. Other countries in LAC—such as Peru during the 1985–90 period—maintained an overvalued exchange rate, thereby implicitly subsidizing its (agricultural) exports.

Agricultural Input Policies

A number of input policies have been used, either as a device to compensate farmers for output price controls or simply as an income-transfer instrument to improve farmer incomes. Table 5.10 presents the status of input policies. The term "some" in the first column of the table indicates that the subsidy was applied to some specific input or group of inputs, but not to all inputs. The term "all" means the subsidy was applied to all inputs, an example of which is a tax exemption or reduction at the point of purchase. In a similar way, the category "some cases" in the second column of the table refers to the total exemption of tariffs on imports of some inputs, while "partial" means the tariff was not completely eliminated, just reduced.

Governments have deployed a multitude of policies to reduce input costs to farmers. For inputs produced domestically by public enterprises, governments often subsidized the input, selling it below cost. One example is the subsidized fertilizer provided by PEQUIVEN, a Venezuelan public enterprise. Though the magnitude of the subsidy has been reduced over time, in 1988 farmers paid 28 percent less than the prevailing market price (ERS 1995–97). Another example involves PRODUCE, a Mexican company administered by ASERCA (the public agency that also administers PROCAMPO, a program of direct aid to agriculture). PRODUCE implements a set of programs initiated in 1998 that are intended to improve the productivity and international competitiveness of Mexican farmers through investments in improved technologies (such as a "fertigation" program, which is a high-tech system for using irrigation canals to deliver liquid fertilizer; inducements to increase farm mechanization; and efforts to improve the quality of pastures for livestock producers). In many cases, governments have coupled input policies to the provision of farm credit, often earmarking loan proceeds for the purchase of fertilizers, seeds, or agricultural machinery as a means of stimulating the uptake of new agricultural practices.

In some instances, tariffs on imported goods used in agriculture were waived (including the elimination of surcharges and value-added taxes paid by the importer). All sorts of variants were tried. For example, in El Salvador the final product was exempted from VAT but its inputs were not, thus generating negative protection (World Bank 1996). On an entirely different tack, many countries promoted land titling with the hope of increasing the amount of private credit extended to farmers and upping their investments in land improvements. Offsetting any deepening of private capital, the post-reform reductions in government spending led to cutbacks of public investments in things like rural roads, rural infrastructure, and irriga-

Table 5.10 Status of input policies, circa 1998

				Rural development				
Country	Input subsidies	Tariff exemption	VAT exemptions	Land titling	Rural roads	Irrigation	Infrastructure	Research and extension
Argentina	No	Some cases	No	No	Yes	No	Yes	Yes
Bolivia	Some	No	No	Yes	Yes	Yes	Yes	Yes
Brazil	Yes	No	No	Yes	Yes	Yes	Yes	No
Chile	No	No	No	Yes	Yes	Yes	Yes	No
Colombia	Some	No	No	Yes	Yes	Yes	Yes	Yes
Costa Rica	Yes	Partial	No	No	No	No	No	No
Dominican Republic	Yes	Yes	Yes	No	No	Yes	No	Yes
Ecuador	No	Yes	Yes	Yes	Yes	Yes	No	Yes
El Salvador	No	Partial	No	Yes	Yes	No	No	No
Guatemala	No	Yes	No	Yes	Yes	No	No	Yes
Honduras	Some	Yes	No	Yes	Yes	No	No	No
Mexico	Some	No	No	Yes	Yes	Yes	Yes	Yes
Nicaragua	No	No	Yes	Yes	Yes	No	Yes	Yes
Panama	Yes	No	No	No	Yes	No	Yes	Yes
Paraguay	Some	No	No	No	Yes	No	No	No
Peru	Some	No	No	Yes	Yes	Yes	Yes	Yes
Uruguay	No	Yes	Yes	No	No	Yes	Yes	No
Venezuela	Yes	Yes	Yes	No	No	No	No	Yes

Sources: Compiled by authors from IMF (1993, 1994, 1995a–f, 1996c–f,1997b–e, 1998a–d) ; USDA (2002); and IADB (1996a, 1996b).

tion. In some countries, loans from multilateral agencies such as the World Bank and IADB were used to help make up the shortfall.

Direct Payments

Direct assistance to producers in Brazil has taken the form of product marketing loans, mainly to help producers confront international competition. In Mexico, a 15-year program of direct payments was put in place in 1994. Payments are decoupled from current and future production, and from the quantity of inputs used. To receive payments, farmers must grow designated crops (corn, dry beans, wheat, rice, sorghum, soybeans, safflower, cotton and barley, destined for use as grain). Other crops may also be eligible for payment if the grower planted designated crops during the spring/summer or fall/winter planting seasons of 1990/91, 1991/92, and 1992/93. About 65 percent of all Mexican producers are participating.

Food Assistance Programs

There is also a range of interventions that target consumers of agricultural products but have indirect implications for agricultural producers. Many fall under the guise of "food assistance" programs, which in Mexico, in particular, constitute an important part of the country's social safety net.[9] They include programs such as LICONSA, which provides milk products to low income families with children who are 12 years old or younger; DICONSA, which distributes food staples at subsidized prices to poor urban and rural residents; DIF, which provides better nutrition for people in certain targeted communities; FIDELIST, which offers food stamps for qualified families, entitling them to one kilogram of free tortillas per day; and Progresa (*Programa de Educación, Salud y Alimentación*, recently renamed *Opportunidades*), which links food assistance to health and education programs for poor people in certain areas (Hoddinott and Skoufias 2003). Progresa was established in 1997; the origins of the other programs are typically earlier than that.

Commodity-Specific Policies in Brief

The previous discussion of commodity-specific policies looked at policies affecting farm prices (for example, price supports) and markets through parastatals, or state enterprises, including policies targeting consumer prices and prices of processed products; policies affecting credit for agriculture; and policies affecting border prices and exchange rates, including policies resulting from regional agreements—for example, the entry of imports from member countries duty free. The details of these

9 Contrary to the intent of these programs, the government of El Salvador introduced a value-added tax on food products in 2000 as a revenue-raising initiative. While this is expected to increase government tax receipts by about US$30 million each year, it is projected to increase food costs for each household by an average of US$38 per year, thereby exacerbating food security problems, especially for poorer households.

policies are summarized in Appendix Table 5A.2 for 18 countries for the entire period of this study. We relied on Valdes and Schiff (1995–96) for estimates of producer subsidy equivalents (PSEs) for Argentina, Brazil, Chile, Colombia, the Dominican Republic, Ecuador, Paraguay, and Uruguay. OECD estimates for Mexico were used, and estimates for Venezuela were reviewed from the U.S. Department of Agriculture for an earlier period (1982–87).

Because of the spectacular growth of poultry and soybeans in LAC agriculture, we were particularly interested in detecting commodity-specific policies that might account for their development over the past four decades. What we concluded is that, over the long haul, poultry did receive a favorable "push" from commodity-specific policies, but the evidence with respect to soybeans is mixed.

Poultry

Poultry, principally chicken, was historically an import substitution product for most countries in the region. Production was subsidized by controlling the prices of the feed inputs maize and sorghum, except in Venezuela, which used support prices until 1990. But border price measures for poultry were especially important in Central America and some Caribbean countries, where high tariffs were applied along with nontariff barriers. The main reason for these measures related to the competition faced by domestic producers from imported U.S. poultry parts. Available evidence from the PSE estimates indicates that, on balance, poultry was subsidized in both Brazil and Mexico. Hence, commodity-specific border price policies appear to help explain what happened with poultry developments.

Soybeans

By the end of the 1990s, soybeans faced a free market in most countries, with no barriers other than generally agreed tariff or price bands, as in the Andean Pact countries. In earlier periods, the policies appear to have been mixed—for example, Brazil protected its exporters, while Argentina taxed them. Other commodity-specific policies may have been in effect that we did not detect, but our findings suggest that the answers to what happened with soybeans in LAC were probably not in the realm of commodity-specific policies, at least as we have defined them here.

Contemporary Policy Concerns (Early 2000s)

General Issues

In more recent years, many countries have refocused some of their policy attention on rural rather than agricultural concerns per se. The rural sector is where a significant share of each country's poor population resides (de Ferranti et al. 2005). Moreover, the agricultural reforms of the past few decades have had mixed con-

sequences for rural incomes, often adversely affecting the incomes of small and resource-poor producers growing import-substitution crops like wheat, corn, or beans. This could lead to pressure to reinstate various "protectionist agricultural policies" rather than directly tackling the fundamental causes of rural poverty (and instigating less distortionary "safety net" policies to ameliorate the adverse effects of policy liberalization). However, as Sumner (1995) succinctly stated, interventionist domestic policies are infeasible unless they occur concurrently with border measures. Therefore, the current trend toward free-trade regimes that took hold during the Uruguay Round negotiations of the WTO means that improvingrural incomes cannot be pursued through interventionist domestic policies such as in the past. In this sense, policies like direct, lump-sum transfers become an alternative for those countries with sufficient fiscal resources for this type of intervention.

Eliminating price support programs has left rural communities more exposed to market fluctuations and lower priced imports. Measures like land titling may have enhanced incentives for onfarm investments, but the elimination of (public) agricultural development banks has made farmers much more dependent for short-term liquidity and investment capital on their own scarce resources and commercial credit, which is not widely available in rural areas.

Currently, agricultural policies are circumscribed largely by the deregulation of trade and their consistency with macroeconomic policies. As de Janvry, Key, and Sadoulet (1997, 3) observed, "For the most part, agricultural policy reforms have occurred in the context of broader economic reforms, and agricultural policy has in most instances been directly dictated by macroeconomic policy, with often little explicit concern for agriculture, rural development, or poverty." In short, agricultural policies must accommodate the environment created by macroeconomic policies. Thus, multiple exchange rates, for example, are no longer feasible instruments for agricultural policy. We illustrate this general notion by briefly reviewing recent agricultural policy developments in Argentina, Brazil, and Mexico, the biggest countries in the region.[10]

In Argentina, contemporary government policies sought to reduce public-sector involvement in the nation's economy. The country's agricultural sector is generally competitive and productive (Schnepf, Dohlman, Bolling 2001). As of 2003, there were no major policies, programs, or subsidies to promote agricultural production or exports. However, the sector remains constrained by limits on private debt and, not unrelatedly, the shortage of new credit. Notwithstanding this significant impediment to development, it seems improbable that the government will substantially increase its presence in the (agricultural) economy. Interventionist agricultural pricing policies appear to be largely a thing of the past, while new pol-

10 A country-by-country summary of agricultural policy developments for other parts of LAC can be found in the supplementary material in this volume.

icy initiatives that influence agriculture appear motivated by broader rural poverty and development concerns (de Janvry, Key, and Sadoulet 1997).

Brazilian agriculture is strongly affected by external shocks, such as capital flights brought about through the appreciation of the real exchange rate. This situation produces two effects: it generates a current account deficit (exports are less competitive and imports are cheaper), which increases pressure for an exchange rate devaluation and increases the nominal interest rate (composed of the real interest rate and the expected devaluation). Both effects negatively affect agriculture. Brazilian farmers are heavily indebted, and the government may help them through debt forgiveness. Assistance through minimum price supports and government procurement has been eliminated, and the likelihood that these policies will return in the near-term is low because the government is struggling to reduce its fiscal deficits. Credit assistance, which has traditionally been an important source of subsidy for farmers, will probably be reduced due to the tight monetary policies that have been adopted to keep inflation in check. Given the currency appreciation, the government has also increased its tariffs (temporarily in many cases) to control imports and protect domestic products from foreign competition. However, these measures are temporary because they cannot be sustained under the arrangements in place for Mercosur. The main source of economic instability (not just for agriculture) is the threat of capital flight and the unexpected transfers of capital this brings about.

Mexico began its package of economic reforms in 1986–87. Although it has been affected by many macroeconomic problems since then (related, for the most part, to its large foreign debt), the reforms continue. The agreement with the WTO and participation in NAFTA represent two major sources of support for a market-oriented economy. The decoupled subsidies introduced under the Rural Alliance Program, and the elimination of CONASUPO (a decentralized public entity responsible for food supplies and regulations), point to a preference for nonprice policies and a commitment to maintaining a low(er) government profile in agriculture. One important factor that could affect the current situation is Mexico's weak macroeconomic situation. Its large foreign debt holdings and continuing heavy reliance on inflows of foreign capital make the country especially vulnerable to external shocks, as illustrated by the collapse of the Mexican peso in December 1994. To promote stability, the government is now focusing on reducing its fiscal deficit and increasing domestic savings.

Commodity-Specific Issues

Typically, commodity markets throughout LAC now experience little direct government involvement. Most of the remaining interventions occur at the sector rather than commodity level, often in the guise of credit or rural development policies. For example, most marketing agencies charged with supporting the prices received by

agricultural producers have been abolished. In their place are various direct payment schemes (such as those provided by PROCAMPO in Mexico), or a process of "negotiated prices," wherein the government serves as a facilitator and moderator (such as in Colombia where the final results of negotiations are known as "price agreements").

The stabilization role that marketing agencies used to play in commodity markets has largely been replaced by border measures like price bands or reference prices. While these measures still stabilize domestic prices, the storage costs entailed in more direct public procurement schemes are avoided.

Border measures, such as import or export licenses and other nontariff barriers were replaced by tariffs and tariff rate quotas after the Uruguay Round Agreement, bounded by the limits set under the agreement. Regional agreements—including Mercosur, CACM, and the Andean Pact, as well as other current bilateral agreements—maintain many agricultural products in a special status for a period of 5 to 15 years, after which they are expected to trade free of duty. The same applies to bilateral agreements, such as those between Chile and Canada, or Chile and the Mercosur countries.

Export taxes have almost completely been eliminated from the region, and the few remaining cases are being phased out. Export subsidies are limited by the Uruguay Round Agreement to rebates of tariffs paid on the inputs used in the production of the exported product. Rebates of domestic taxes (such as VATs) have been eliminated.

Consumption subsidies in the form of price controls have also been largely eliminated throughout the region. Instead, many countries have opted for so-called regulatory offices to protect consumers against cases of imperfect competition. In the Dominican Republic, Honduras, Mexico, and Venezuela, governments offer consumption subsidies through programs targeted at low-income groups. For this purpose, basic food products are sold below market prices. This policy can be expected to continue.

Institutional Arrangements for Agricultural Marketing

In addition to the institutional changes affecting the financial, input, and marketing aspects of LAC agriculture just discussed, there is a fundamentally more potent set of institutional changes afoot regarding the relationships among food production, wholesale, and retail operations. Partly as a consequence of liberalized investment opportunities (which has enabled foreign firms to more readily invest in the region), and partly because of more fundamental forces, such as rapidly urbanizing populations and growing per capita incomes, the structure of food marketing is changing rapidly throughout much of LAC. Retail food sales are quickly becoming the prevailing mode of delivery to consumers, with supermarkets and self-service convenience stores now dominant players in the region's agri-food economy

(Reardon and Berdegué 2002). Rough estimates are that 50–60 percent of LAC's agri-food sales are now through supermarkets compared with just 10–20 percent a decade ago, with these developments being more pronounced in the larger, richer countries of the region. The top supermarket chains (including Wal-Mart, Royal Ahold, and Carrefour) account for an estimated 65 percent of supermarket sales in the region, so that private food-quality standards and supply-chain management decisions made by food retailers are having increasingly pervasive and profound affects on commodity choice, quality, and the timing of delivery by the farm production sector.

Conclusion

Clearly LAC governments have intervened in their economies in myriad ways that have direct and indirect consequences for agriculture and the research that supports this sector. Policies that act as disincentives to agricultural producers (by depressing the prices received by farmers or increasing their costs) have immediate production consequences, but they also can have profound long-run consequences for agricultural productivity and the competitiveness of agriculture in regional and international markets, not least by dampening the demand for agricultural R&D (Schultz 1978; Mellor and Johnson 1984; Alston and Pardey 1993). As Alston, Edwards and Freebairn (1988) showed first, and Alston, Norton, and Pardey (1998) elaborated later, commodity pricing, trade, and other polices act to redistribute the gains from agricultural R&D in ways that are often specific to the policy in place.[11] Models such as those implemented in Chapter 7 of this volume can be used to illustrate the magnitude and direction of these redistributive effects among producers, consumers, and others as a guide to policymaking and those financing agricultural R&D (see, for example, Alston, Freebairn and James 2004).

11 Another way in which the gains from inventive activity can and are redistributed is via changes in intellectual property policy and practice. See Boettiger et al. (2004) for more discussion regarding agricultural R&D in an international context.

Appendix Table 5A.1 Summary of economywide policies applied in Latin America

Argentina	*Monetary policy*	After years of high inflation and economic instability, money supply is tied to level of international reserves, under the "convertibility plan."
	Fiscal policy	Tight fiscal policy; main transfers to the provinces. Important current taxes VAT, income tax and tariffs (15 percent plus 10 percent of statistical tax, temporarily eliminated in 1995 and then re-established at 3 percent). VAT 18 percent until April 1995, then increased to 21 percent.
	Financial policy	Exchange rate overvalued during 1982–84, then undervalued; after 1991, the currency remained overvalued. Exchange rate fixed at one peso per U.S. dollar. Exchange rate taxes eliminated in 1991.
	Trade agreements	Argentina maintains agreements with Latin American countries through ALADI and Mercosur. Since 1995, Argentina has adopted the CET system under the Mercosur. In Mercosur, tariff rates vary between zero and 20 percent, plus 3 percent of statistical tax. Within Mercosur, tariff rates are generally zero.
	Trade policy	Since 1991, all quantitative restrictions on agricultural products have been eliminated Before 1991 trade was taxed with ad valorem export taxes; holdings; consular levies; statistical services tax on exports; export promotion fund contributions; freight tax; tax on the sale, purchase, exchange and barter of foreign exchange. All these taxes were eliminated during 1990–95. Argentina is committed under the Uruguay Round to establish a ceiling of a 35 percent tariff for agricultural imports, plus a 3 percent surcharge. Export rebates ranged from 1.5 to 10 pecent in 1995; currently they range between 1.35 and 10 percent.
Bolivia	*Monetary policy*	Since 1985, Bolivia has maintained a restrictive fiscal and monetary policy. Bolivia began reorganizing its Central Bank in 1992.
	Fiscal policy	Bolivia maintains three taxes that affect prices of domestic and foreign products: (1) VAT (13 percent), (2) a tax on specific consumption that ranges from 10 percent for wine and jewels to 60 percent for beer, and (3) a transaction tax of 2 percent for all goods and services. Initially The VAT was initially set at 10 percent in 1986.
	Financial policy	The NEP abolished exchange rate controls and initiated an auction mechanism to determine the exchange rate. In 1987, a crawling peg system was introduced.
	Trade agreements	Bolivia is member of ALADI, the Andean Group, GATT and complementary economic agreements with Uruguay, Argentina, Chile, and Peru. As part of the Andean Group, Bolivia applies the Common External Tariff. Bolivia signed an agreement with Mercosur to create a free trade zone. Although Bolivia is part of the Andean Group, it is exempt from the application of price bands because of its geographic location and the high cost of transportation.
	Trade policy	All quantitative import restrictions and price controls were eliminated. In August 1985 the government introduced a low uniform tariff (consolidated unified tariff) of 10 percent, and 5 percent for some capital goods. Since 1995, Bolivia has applied a common external tariff that specifies a tariff of 5 to 20 percent for nonmember countries.
Brazil	*Monetary policy*	Brazil has tried various stabilization programs in the past 20 years. In 1990, the currency was changed from the Cruzado to the Cruzeiro, and the country began a structural reform process. In 1994 the government substitued the Cruzeiro with the Real and imposed a tight monetary policy.
	Fiscal policy	The 1990 plan introduced administrative reforms and privatized public enterprises. Since that time, Brazil has not made further major public-sector reform. The VAT for interstate transactions was introduced in 1967, initially set at 15 percent and currently set at 18 percent.
	Financial policy	Under the 1990 plan the government ceased currency controls and began a policy of crawling peg for the exchange rate. Under the 1994 real plan the economy was de-indexed and the currency was permitted to float freely with a floor specified for its value vis-à-vis with the dollar.

	Trade agreements	Brazil, Argentina, and Uruguay formed the Mercosur in 1991. As part of the treaty, Brazil had preferential tariffs for all the members, which are supposed to be eliminated completely. In January 1995 Brazil adopted the tariff of Mercosur (CET) where all tariffs are ad valorem, with a maximum of 20 percent subject to common Mercosur and national exceptions. The maximum was increased to 23 percent across the border. This extra 3 percent is supposed to have been eliminated by the year 2000.
	Trade policy	In 1990, the government initiated an important tariff reduction, from 32 percent in 1990 to 14.2 by the end of 1993 (in 1988 the average tariff was 51 percent, while in 1994 it was 11 percent). All Brazilian importers must be registered with the Foreign Trade Department (DECEX). Imports in Brazil are subject to a number of domestic taxes: IPI (variable on industrial products); ICMS (18 percent levied by individual states); ATP (20 percent of harbor services for imports and exports); AFRM (25 percent of the insurance premium and maritime freight); import guide (a once only payment of $70); plus other small taxes related to harbor services. Sanitary and phytosanitary measures apply for all the agricultural products. Brazil does not have any export subsidy program. In 1997 Brazil eliminated the ICMS for exports.
Chile	*Monetary policy*	Since 1974, Chile has maintained a restrictive monetary policy. During most of the 1980s, the central bank operated, targeting the interest rate through open market operations.
	Fiscal policy	The fiscal aspects of the 1974–75 structural reforms consisted of (1) a reduction in the role of the public sector; (2) public enterprises became self-financing with the capacity of setting their own prices; (3) the sales tax was replaced by the VAT in 1975; (4) a mechanism of monetary correction for the tax system was introduced. The VAT was initially fixed at 20 percent but was decreased to 16 percent in 1988 and increased to 18 percent in 1990 to finance increased public social expenditure.
	Financial policy	The financial aspects of the 1974–75 reform involved deregulating the financial market. In May 1974, interest rates for operations outside commercial banks were freed, while commercial banks were deregulated in October 1975. In 1977 private foreign indebtedness was allowed but size and terms were regulated. In 1979 quantitative restriction on domestic banks were eliminated. The exchange rate is pegged to a basket of three currencies: the dollar, the mark, and the yen.
	Trade agreements	Chile is a member of ALADI and maintains bilateral trade agreements with Mexico (1991), Argentina (1991), Bolivia, and Venezuela (1993). Chile is also a participant in the Agreement on the Global System on Trade and Preferences (though few agricultural products benefits from this treaty). In 1996, Chile signed an agreement with the Mercosur countries as a member with special status. Tariffs for most products traded between Mercosur and Chile are 30 percent, and are supposed to have been phased out by 2004.
	Trade policy	All non tariff barriers were lifted by 1976 and tariffs we re reduce to a range of 0% to 35% in 1977 and then to a flat rate of 10% in 1979 (except for automobiles). After the second adjustment 1985-88, Chile attempted to expand non traditional export through making more expeditious the VAT rebate to exporters, the rebate of indirect taxes to small exporters and the strengthening of PROCHILE a public institution devoted to assist small and medium exporters. A tariff drawback scheme available to all exporters provides for recovery customs duty paid on imported inputs in the production of exports. Surcharges and countervailing duties are not reimbursed. There is a simplified version of drawbacks for import values less that US$ 10 million A rebate is generated from the VAT paid for inputs directed to the production of export goods. Agricultural products require sanitary and phytosanitary tests.
Colombia	*Monetary policy*	The Economic Modernization and Market-Opening Program in 1990 started a tight monetary policy. Policy followed by the Central Bank has focused in stabilizing the peso and reach macroeconomic targets. Monetary control is through the reserve rates.
	Fiscal policy	The program started in 1990 implied a policy of tight fiscal expenditure. Colombia has been changing its VAT rate from 10% before 1990 to 12%. In 1993 it was increased temporarily to 14% but since 1995 it has been increased to 16%.
	Financial policy	The program started in 1990 deregulated the financial sector. Colombia has tried to reduce the cost and the amount of the reserves. About the exchange rate it changed in 1994 from a crawling peg system to a free administered system.

(continued)

Appendix Table 5A.1 (continued)

	Trade agreements	Colombia grants tariffs preferences through ALADI and the Andean Pact. Also has a custom union with Venezuela and with Mexico (G-3). Colombia has a trade agreement with CARICOM and with Chile.
	Trade policy	Import quotas were replaced by variable tariffs using price bands. There are price bands for imports of maize, wheat, barley, sorghum, rice, soybeans and sugar. The price bands are applied for imports of the basic commodities and their derivatives. The price bands are based on a minimum import price (price floor) that depends on production costs, carrying cost margins and supply/demand conditions. The ceiling price is based on a five year moving average price and is changed every six months. Other agricultural products are taxed using the common tariff (0, 5, 10, 15 and 20%). Exports in Colombia were subject to an ad valorem tax. (contribution cafeteria). Currently exports receive a subsidy CERT that is supposed to be for non traditional exports. Coffee does not receive CERT. Its rates range 2.5 to 8.7% of fob value.
Costa Rica	*Monetary policy*	The Central Bank introduced an auction mechanism in 1996 for the placement of government and stabilization bonds.
	Fiscal policy	In 1994 Costa Rica commenced tax reform introducing a new tax code (Sep 1995). It also began budget and expenditure reform and a program of privatization. Before 1997 the VAT was 10 percent; since 1997 it has been 15 percent. Costa Rica plans to privatize a number of state banks and the state insurance company.
	Financial policy	Exchange controls were removed in March 1992. Exchange rates are established by the market and dollar transactions are no longer restricted. In 1995 the government eliminated the monopoly on the sight deposits. The central bank has been modifying exchange rates to target the inflation.
	Trade agreements	Costa Rica is part of the Central American Common Market and GATT.
	Trade policy	Trade policies have been liberalized since 1990, because of the accession of Costa Rica to GATT in 1989 and as part of International Monetary Fund conditions for structural adjustment loans. Costa Rica lowered its tariff from 55 to 45 percent. Since 1993 fruits, vegetables, poultry, breakfast cereals, cereals, beer, and wine have been subject to an ad valorem tax of 19 percent. Cigarettes and candy, excluding chocolate, incur a tariff of 27 percent. Most products also incur a fixed tax with the ad valorem. Some agricultural products are subject to nontariff trade barriers. Nontraditional exports are encouraged through a system of export rebates. Exports also have a system of drawbacks. Currently the tariffs are 3 percent for capital goods, 5 percent for raw materials, and 20 percent for consumption goods. In 1994 the government introduced measures to comply with URA. Costa Rica agreed to eliminate all import quotas and limit tariffs to a maximum of 55 percent (falling to 45 percent by 2005) on most goods, excluding selected agricultural goods.
Dominican Republic	*Monetary policy*	As part of the 1990 reform the practice of compulsory allocation of bank credit was eliminated. Also major reforms in banking supervision and regulation were introduced. However discretion can be used in the allocation of funds to support fiscal programs.
	Fiscal policy	In 1992 the government approved the new tax code introducing a VAT of 8 percent, but it is subject to a high number of exemptions. Nonprocessed agriculture, fishery, and forestry products are exempt from VAT. Before 1992 the VAT rate was only 6 percent. In 1997 public enterprises were reformed and CORDE restructured.
	Financial policy	The exchange rate stability is a goal for the government. Commercial banks are allowed to trade in foreign exchange, but the central bank announces the official exchange rate daily. In 1991 exchange rate controls were eliminated, but this system was abandoned in 1994 and the government adopted a dual exchange rate. The official exchange rate is applied to traditional exports and also imports of basic food imported by INESPRE. Other imports are channeled through the interbank exchange rate. In 1996 the new government unified the exchange rate.
	Trade agreements	One treaty that is especially important for the Dominican Repubic is the U.S. sugar program.
	Trade policy	A new tariff was implemented in 1992. Agricultural imports are charged a basic ad valorem tariff, a surcharge, and a foreign exchange surcharge. Oilseeds and related products are subject to a 3-percent ad valorem tax, and beef a 35-percent tax. Excluding special tariffs (3–5 percent) the tariffs range from 15 to 30 percent.

Ecuador	*Monetary policy*	The government increased the role of market-based instruments of monetary control. The objectives of control of inflation and deficit reduction will imply a tight monetary policy.
	Fiscal policy	In 1992 the budget system was reformed. All the public tariffs were adjusted. The VAT was maintained in 10 percent. The Alarcon administration started a process of reduction of the fiscal deficit. The new administration will probably follow the same path. This will be based mainly in the increase of taxes and elimination of VAT exemptions.
	Financial policy	In 1992 the Government liberalized the investment regulations and passed a new capital markets law. Also the Government abolished all the controls over the interest rates. They had been in place since 1988. With respect to the exchange rate the Government increased the flexibility in its determination. Currently the exchange rate is permitted to float freely between pre determined currency bands.
	Trade agreements	Ecuador is part of the Andean Pact, which is supposed to be a free trade area. The Common External Tariff was adopted in 1995. Imports from Andean Pact enter without tariffs. At the beginning of 1996 Ecuador joined the WTO. Under this agreement the price bands under the Andean Pact were to have been eliminated by 2001.
	Trade policy	The trace liberalization process started in 1989 under the pressure of the International Monetary Fund and Andean Pact. Ecuador has reduced its tariff to 5–20 percent for most of the products. These tariffs are for non–Andean Pact countries. Ecuador uses price bands for many agricultural products.
El Salvador	*Monetary policy*	El Salvador agreed to tight monetary policy with the International Monetary Fund to reduce inflation. This policy has been followed since 1989. Monetary supply is controlled through open market operations issuing Certificates of Monetary Stability backed by the central bank. They are traded in the Salvadorean Stock Exchange.
	Fiscal policy	El Salvador agreed to maintain a low fiscal deficit and continue privatization process and improving tax revenue. In September 1992 the government introduced a VAT of 10 percent. and readjusted all public tariffs (electricity iat 15 percent, water at 30 percent). Electricity rates were increased again in 1994 by 30 percent. In 1995 the VAT was increased to 13 percent.
	Financial policy	The process initiated in 1989 liberalized financial markets. Interest rates and exchange rates are now free. However the government occasionally intervenes in the currency market to avoid excess of swings.
	Trade agreements	El Salvador is part of Central America Common Market that is allowed to impose price bands to nonmembers.
	Trade policy	El Salvador has liberalized its trade. The tariff ceilings were reduced to 20 percent on most agricultural imports and eliminated permit requirements for basic grains and powdered milk in 1992. The monopoly powers of the sugar and coffee parastatals have also been curtailed. El Salvador used price bands for some agricultural goods, and NTBs for some goods. In 1993 intraregional trade in agricultural products was liberalized. In 1994 the government eliminated the price bands and changed them for tariffs.
Guatemala	*Monetary policy*	Although monetary policy is targeted to maintain inflation at a low rate, loans from the Bank of Guatemala increase the liquidity of the system and affect its stability. Monetary policy is based on two instruments to control domestic credit by the government and open market operations (bonds are CENIVACUS and CDS).
	Fiscal policy	Currently the VAT is 10 percent; it was 7 percent prior to 1996. In general the government has had problems reducing its fiscal deficit at the levels agreed with the International Monetary Fund, mainly because it has problems increasing tax revenue.
	Financial policy	In August 1989 the government eliminated interest rate controls and reorganized the banking system.
	Trade agreements	Guatemala is member of GATT and CACM. Under the latter, tariffs are in the range of 1 to 20 percent.

(continued)

Appendix Table 5A.1 (continued)

	Trade policy	Guatemala started the tariff reduction process after joining GATT in 1990. Guatemala started two programs in 1989: free trade zones and maquiladoras. Nontraditional exports receive a rebate of 10 percent of the FOB price if the importing country is part of an agreement with Guatemala, otherwise they receive 15 percent of the FOB value.
Honduras	*Monetary policy*	Since October 1992 the central bank has controled monetary policy through a bi-weekly program of open market operations.
	Fiscal policy	In 1990 Honduras began a public-sector adjustment program.
	Financial policy	In 1990 exchange and interest rates were liberalized. In 1992 the government eliminated the interest rate subsidy on central bank rediscount lines for basic grains. Since 1992 commercial banks and foreign exchange houses can conduct any type of transactions.
	Trade agreements	Honduras is member of the CACM and the GATT since Feb. 1994.
	Trade policy	Trade was liberalized in 1990. Most of the agricultural products are charged with a tariff of 5% ad valorem. Most of imports outside the CACM are subject to tariffs from 5-20%. In 1992 the government eliminated the remaining exports permits and 10% surcharge over imports. Most of exports are taxed with a 1% over the fob value.
Mexico	*Monetary policy*	In 1987 Mexico started its structural reform, tightening the money supply. In general this has been the policy followed. This situation was reinforced after the 1994 crisis in order to reduce the inflationary effect of the devaluation and the dependence of foreign capital to supplement domestic savings.
	Fiscal policy	Since 1987 Mexico has tightened its fiscal policy, privatized public enterprises, and reduced agricultural subsidies. The VAT has been maintained in 10 percent since its introduction in 1980.
	Financial policy	Since 1987 Mexico has relaxed foreign investment regulations and eliminated foreign exchange controls.
	Trade agreements	Mexico is part of NAFTA. Under the treaty a broad number of agricultural products are free to trade among Mexico, Canada, and the United States. Mexico is permitting duty free access to a portion of the market for highly sensitive commodities like maize and dry beans. Licenses have been changed for tariffs that are expected to be phased out in 10–15 years. Agricultural products are under the Agreement on Agriculture (URA) then all the non-tariff barriers should be transformed into tariffs and will be subject to reductions over a period of 10 years. Tariff under the URA has been reduced up to 20% while under NAFTA the commitment was not more than 30-35%.
	Trade policy	Mexico joined the GATT in 1986 and moved further to wards trade liberalization. Reduced trade restrictions, eliminated export subsidy programs and official import and export reference prices. Also Mexico reduced the number of items subject to import license and the average tariff rate. Agricultural products from Non-NAFTA countries pay the binding tariff of 50%. Export subsidies in the form of tax credits and exemptions under CEPROFI were eliminated. The MFN-tariffs for agricultural products range from 0 to 260%. All tariffs between the NAFTA parents will be abolished by year 2009. Mexico applies the method of minimum estimated prices on imports to avoid sub-valuation, but these prices are not used as reference prices. Also Mexico uses actively anti-dumping measures.
Nicaragua	*Monetary policy*	Since the beginning of the reform process in 1990, monetary policies have been very tight. In 1992 the government approved a new central bank chart establishing as its main functions the maintenance of domestic and external stability of the currency and of the domestic payments system. During 1992-94 the Government continues lending to the state banks. In 1995 the CBN suspended all the financing to the public sector and start to recover the government debt. During the period 1996–97 the problem with the money supply has been the public-sector deficit. The agreement with the International Monetary Fund has been a tight monetary policy for the period 1997–2000. Also the BCN eliminated the direct credit allocation policies (mainly to agriculture). The BCN has a commitment to manage the money supply by using open market policies.

	Fiscal policy	The fiscal policy applied in 1990 increased the VAT rate from 10 to 15 percent and also expanded the tax base reducing the number of exempted items. The government also introduced two new taxes: a temporary surcharge on imports and a selective consumption tax, which replaced the luxury goods tax. Public-sector reform also included privatization of almost all public enterprises, a public-sector retrenchment program, an institutional reform of the public- sector functions, and a reform of the public utilities (electricity, water, and sewerage).
	Financial policy	The exchange rate system was unified in 1996, but the central bank continues buying and selling foreign currency at a rate determined by a crawling peg system. The interest rate is fixed by the financial system, that is conformed by three state-owned banks and seven private banks. The three state-owned banks have been reformed but they still have an enormous portfolio of nonperforming loans. In terms of foreign debt the government pursued a debt and debt-service reduction agreement.
	Trade agreements	Nicaragua is part of CACM. Because of its economic difficulties, Nicaragua received special treatment under the agreement.
	Trade policy	Nicaragua has reduced its tariffs as is part of the CACM. Also Nicaragua has eliminated almost all the permits and licenses for all the products from non–CACM countries. Nontraditional exports are subject to export incentives through preferential access to exchange rate and tax reductions. The trade reform reduced the ceiling of import taxes from 40 to 37 percent (includes tariff, surcharge, and a 5 percent stamp tax) and the floor for capital goods from 10 to 6 percent. Nontraditional exports (other than coffee, sugar, beef, and cotton) have received a tax break since 1991, and inputs can be imported duty free and are exempt from the 15 percent VAT. These imports also receive a tax benefit certificate (5 percent of FOB value). It was 15 percent prior to 1996, 10 percent in 1996, and was reduced to 5 percent in 1997. To be eligible for the program the exporter must ship at least 25 percent of the value of production outside the Central American region or export more than US$ 250,000.
Panama	*Monetary policy*	Panama has a unique monetary system. It is tied to the US dollar and 1 Balboa is equal to 1 dollar. Since there is no money creation there is no need for a central bank. Money supply depends directly from the balance of payments result.
	Fiscal policy	In 1992 with the Economic Recovery Loan Agreement with the World Bank, the country started the process of structural reform. The measure has tended in the fiscal side to reduce the state role in the economy (reduction of the fiscal deficit, privatization of public enterprises, elimination of regulatory entities like IMA, BDA, ISA, BHN). The VAT in Panama is 5%. Imports are subject to the VAT but imports of unprocessed agricultural products are exempted, also imports and transfers of inputs used in agriculture. Alcoholic beverages and cigarettes pay a VAT of 10%.
	Financial policy	The interest rate is free in Panama. The Government owns state banks like the National Bank of Panama and the Agricultural Development Bank.
	Trade agreements	Panama is an observer of various integration mechanisms of CACM (not a full member). In 1995 Panama started its process to join WTO that was effective in Sep. 1997.
	Trade policy	Quotas, permits and other quantitative restrictions on imports of various grains, pulses and meats were eliminated in 1993 but trade barriers remained high. Ad valorem for 60 sensible agricultural products range 60-90%. Non traditional exports receive tax credit certificates. The 1995-96 reform reduced the tariffs and eliminated all the non tariff barriers after the customs law (1996). In January 1998 the Government reduced again tariffs and consolidated them from 108 to only 5 (0, 3, 5, 10, 15%) excepting few special cases.
Paraguay	*Monetary policy*	Since 1989 started a monetary policy to tight credit. The Central Bank has accumulated an important quasi fiscal deficit from the 1995 and 1997 crisis of the financial system. The Central Bank controls the money supply through open market operations using short term securities (Monetary Regulation Securities).
	Fiscal policy	The fiscal part of the economic policy initiated in 1989 is the introduction of a VAT of 10%. This is still the current rate. There are an important number of exemptions like sales or transfers of agricultural products in their natural state (its inputs are also exempted).

(continued)

Appendix Table 5A.1 (continued)

	Financial policy	Although Paraguay does not have a specific exchange rate policy the Central Bank has the authority to intervene in the exchange rate market to stabilize unusual fluctuations. The financial system is under a major reform after two crises in 1995 and 1997. Interest rates are free but there is still targeted credit.
	Trade agreements	Paraguay joined the GATT in 1993 and is also member of Mercosur. Agricultural products are considered sensitive for Paraguay and the duty free import under Mercosur is not applied. Under the Mercosur rules Paraguay is prohibited of using any sort of minimum price.
	Trade policy	Since 1993 Paraguay used a tariff system with rates 0, 5, 10 for inputs, capital goods and consumer goods. Prior to this scheme Paraguay a two tier schedule with tariffs from 5-35% to generate revenues and 35-70% to items competing with local production or considered to be luxuries. Since 1995 Paraguay adopted the CET tariff system from Mercosur, which consists of 11 rate levels from 0 to 23%. Originally the maximum tariff was 20% but was changed to 23% in 1997. Most of imports pay the consular tax of 7.5%, Shipping and ports fee and the VAT of 10%.
Peru	*Monetary policy*	After 1990 the Government has maintained a tight monetary policy with the money supply as the control variable. Monetary policy is based on three instruments exchange operations, reserve regulation and open market operations using certificates issued by the Central Bank.
	Fiscal policy	The fiscal reform initiated in 1990 was focused on the reduction of the State and reorganization of its functions. Specifically:(1) Reduction of the number of public employees. (2) Privatization of public enterprises of goods and services. (3) Elimination of state monopolies in the marketing of goods and inputs. (4) Promotion of a regulatory agency to safeguard for the free competition (INDECOPI). (5) Restructure of public expenditures and tax reform.
	Financial policy	Interest rates were freed and the Central Bank adopted a crawling peg system for the exchange rate.
	Trade agreements	Peru is member of ALADI, is an observer at the Andean Pact and is granted under the US Andean Trade Preference Act. Also Peru is member of WTO.
	Trade policy	The trade reform of 1990 consisted in eliminate all the restrictions to the international trade and reduce the dispersion of tariffs. The number of tariffs was reduced from 56 to 2: 15% and 25% until April 1997 to 12% and 20% plus a temporary surcharge for all the goods with tariffs equal to 20%.
Uruguay	*Monetary policy*	The Uruguayan Central Bank maintains a conservative monetary policy. The monetary policy is not very important given the policy of free capital movements and exchange rate followed by the country.
	Fiscal policy	Since 1990 the Government has tried to reduce the fiscal deficit through reducing expenditures. Since 1995 the fiscal program has consisted in the adjustment of the public accounts, through increases in the taxes and reduction in the expenditures. Also Uruguay has worked on the reduction of it public sector and the reform of its social security system that is one of the main reasons behind the fiscal deficit The standard VAT rate is 22% but a reduced rate is applied for most of food products, this rate is 14%. Also there are numerous exceptions like exports, sale of unprocessed agricultural goods, sales of fertilizers, inputs and machinery.
	Financial policy	The Government maintains freely convertible currency. A crawling peg system is in effect since 1986 and the Central Bank intervenes to maintain the exchange rate within a band.
	Trade agreements	Uruguay is part of ALADI, GATT and Mercosur, because it is part of the first two 80% of Uruguay's imports are subject to most favored nation tariffs.
	Trade policy	The economy is very integrated to the world market. Reductions in tariffs during the 80's were partially offset by reference prices for some products. The government maintains a four tier tariff system with a maximum ad valorem of 20%. The ad valorem consists in two parts: a single custom duty and an import surcharge both over the cif price or over the reference price.

Venezuela	*Monetary policy*	After the reform in 1989 the monetary policy was maintained tight. After the crisis the increasing fiscal deficit obliged to increase the money supply to finance the deficit. In 1996 with the purpose of reducing the inflation the money policy has been maintained tight again. Fiscal deficit that was the reason for the expansive money policy was targeted to be eliminated under Agenda Venezuela (stabilization plan backed by the IMF).
	Fiscal policy	The Government started in 1989 a structural reform with the purpose to modernize the public sector. The reform consisted of reforms to the tax system that increased the tax collection and reduced the public sector (public employee's retrenchment and public enterprises privatization). The financial crisis in 1994 interrupted the process the VAT had to be transformed in a wholesale tax of 10% It remains Under Agenda Venezuela since 1996, the Government is committed to eliminate its fiscal deficit.
	Financial policy	A unified floating exchange rate was institute since 1989 but the 1994 crisis forced the Government to restart the controls. The controls finished in Apr. 1996, since then the exchange rate is allowed to float within a band.
	Trade agreements	Venezuela is part of the Andean Pact and of the GATT since 1990. Also it has agreements with the CARICOM, and bilateral agreements. In 1993 negotiated a free trade with Chile that contemplates a gradual tariff reduction and coordination of the tariff structure by the year 1999. Also maintains an agreement with Colombia and Mexico since 1995, that established a 10% reduction in tariff per year with the idea of full free trade by the year 2004. The agreement covered all the sectors except agriculture. Also Venezuela is part of ALADI, and has agreements with Mercosur and CACM.
	Trade policy	Tariff rates were reduced in Jan. 1992 to a maximum of 20% over the cif value. In 1995 Venezuela adopted the Andean Pact Common External Tariff. Under that system there are 5 tariff categories 0, 5, 10, 15, 20%. Imports of vehicles are taxed with a special luxury tax of 20%. Under the Andean Pact some sensible products are subject to import price band.

Source: Compiled by authors from IMF 1993,1994, 1995a–f, 1996c–f,1997b–e, 1998a–d ; USDA 2002; and IADB 1996a, 1996b.

Appendix Table 5A.2 Summary of sector-specific policies applied in Latin America

Argentina	*Parastatals or state enterprises*	Before 1991, main agricultural markets were very regulated. In 1992 the Government completed the deregulation of wholesale and retail trade. Also granted authorization to establish wholesale market for fresh produce. The only currently intervention is in the tobacco case where the Special Tobacco Fund is intended to support tobacco farmers. The money for the Fund is collected through an excise tax on cigarettes.
	Credit policy	Credit for agriculture was offered by the Argentine National Bank but at market rates in mid-95 (16% in dollars). The credits are for less than a year. The Government has tried to reach the small farmers with credit lines but they are at market interest rate.
	Exchange rate policy	Agricultural exports had before 1985 a different exchange rate that was 10 to 20% below the market exchange rate. Under the Austral plan in 1985 exchange rate controls were abolished. After 1985 the Government set an official exchange rate that was below than the market. This reduced the appreciation but did not eliminate it.
	Input policy	During the 80's a program for grains that bartered production for inputs through the National Grain Board. Tariffs on agricultural inputs are 15% plus a surcharge of 10% called "statistical tax". Capital goods like certified seeds and trucks are exempted of both tariff and statistical tax. Also under this policy are embryos. Most of transport infrastructure has been privatized. Improvements in railroads will affect positively transports costs.
Bolivia	*Parastatals or state enterprises*	The Government maintained many enterprises that processed and/or marketed agricultural products including milk, poultry, cattle, chestnuts, seeds, oilseeds, maize and sugar. The Government passed a privatization law in 1992. By end of 1995-96 small/medium enterprises were privatized. In 1995 the Government privatized the major processing plant PIL in Santa Cruz.
	Credit policy	Bolivia intervenes in the agricultural credit market through the Peasant Development Fund established in 1991, finances small and medium-sized farmers. A fund for operating capital loans is based on the resources obtained for the sale of donated agricultural inputs.
	Exchange rate policy	Before 1985 the Government maintained a system of controls and multiple exchange rates.
	Input policy	The Government passed in 1995 legislation for regulate land policy. Agricultural inputs donated by foreign government, particularly fertilizer and equipment, are sold by the Ministry of Agriculture 5-10% be low market prices. Imported agricultural inputs are also taxed with tariffs (fertilizers, insecticides and machinery). The Government is committed to improve the transportation infrastructure especially highways from Santa Cruz a major exporter zone and from La Paz. They should benefit exports in general and specially exports to Paraguay, Peru and Chile. Other improvement is in the case of coffee where the Government is applying technical assistant to improve agricultural practices and control diseases.
Brazil	*Parastatals or state enterprises*	The CONAB, the National Food Supply Company administered a program of minimum prices for producers and also intervened the market to stabilize prices. The Government does not intervene anymore and now minimum prices are used for reference prices for loans, since the introduction of the Real Plan.
	Credit policy	Producers of soybeans, wheat, rice, cotton, drybean, cassava and maize have been eligible for production, marketing and credit at below market rates. The program, specifically, that only a fraction of the farmer's costs can be financed with this funds the rest has to be taken from the commercial bank. Only small soybean farmers are subject to the earmarked production credit. Also soybean producers are allowed to seek for credit outside Brazil. Soybean farmers rely less than other farmers on government credit. PROAGRO gives crop insurance at a special premium but farmers have to follow certain agricultural practices. The source for the agricultural funds is from an account from the bank of Brazil since 1986. Commercial banks are not anymore forced to use part of their sight deposits for agricultural loans. In 1997 Government reduced interest rate from 12% in 1996 to 9%. The rate for small farmers is 6%.

	Input policy	Parts of the credit fund given by the Government are to be used by cooperatives on fertilizers, seeds and other inputs. Brazil is engage in investment in the northern part of the country (irrigation projects, technical aid to small farmers) with multilateral funds. Interest rate for loans to buy machinery is 14%.
Chile	*Parastatals or state enterprises*	The only parastatal is COTRISA that is a marketing board for wheat. COTRISA operates a band price for wheat.
	Credit policy	Chile has an agricultural export promotion fund with $7 million in resources, half of which are contributed by the Government.
	Input policy	Chile has promoted irrigation and drainage projects. From 1985-93 the Government has funded 75 projects with a total cost of US$ 26 million.
Colombia	*Parastatals or state enterprises*	The IDEMA, used to offer support prices and purchase and sell storable commodities In 1990 IDEMA's monopoly of state trading was eliminated and focus its work on small farmers but in 1997 was completely eliminated.
	Credit policy	Agricultural credit is channeled through four institutions: FINAGRO, BANCOLDEX, Coffee Bank and Caja Agraria. The first one provides short-term operating loans for farmers, the second provides loans for non coffee exporters. The third provides loans for the coffee region. The fourth lends to small and medium scale farmers. These loans were below market rate.
Costa Rica	*Parastatals or state enterprises*	The CNP, National Council of Production used to intervene and regulate the agricultural market. With the 1994 implementation of the URA, its role was redefined as a marketing related institution in charge of assisting producers with marketing studies. Also a new Department of Agricultural protection was created (USDA-APHIS counterpart). Many parastatals related to specific commodities like coffee, rice, sugar, banana, tobacco has been privatized.
	Credit policy	There are credit programs for production and is limited by Central Bank policies. The Ministry of Agriculture subsidizes interest rates for small producers.
	Input policy	Input policy is through credit programs. Also, the Costa Rica Development Corporation used to own two plants of fertilizer but now CODESA has been eliminated. The government has invested in infrastructure in the banana producing area to increase exports. Imports of inputs pay a reduced tariff of 1% plus a 1% of fixed tax.
Dominican Republic	*Parastatals or state enterprises*	The State Sugar Council is the major producer of sugar. The Government operates 12 of the 16 sugar mills of the country. The Dominican Corporation of State Enterprises controls the country's two flour mills, which are mandated to distribute wheat and wheat flour at fixed prices even if they are below cost. The Government also owns a cigarette company. INESPRE is in charge of the control of some prices. The Agency distributed family food baskets to needy house holds. Also is in charge of the crop purchases for the government programs.
	Credit policy	The State Sugar Council is a major source of credit for the sugarcane growers. The Government's Agricultural Credit Bank offers credit to farmers at an interest rate below market. Normally rice is the most benefited crop by this policy.
	Exchange rate policy	Until end of 1996 the Government maintained two exchange rates: a low official one and a floating exchange rate. The official rate was used to convert currency from traditional exports like coffee, cocoa, tobacco and sugar. The differential in exchange rates was about 7%.
	Input policy	Fertilizer use has been restricted because importers have to obtained foreign currency from the Central Bank and credit letters from Agricultural Bank are sometimes not accepted by the fertilizer companies. Imports and domestic sales of veterinary products, fertilizers and seeds are exempted of the VAT. Imports of agricultural inputs pay a tax of 3%.

(continued)

Appendix Table 5A.2 (continued)

Ecuador	*Parastatals or state enterprises*	The Government Economic Front (a board of many ministries) was in charge of setting some domestic prices. In the past until 1986 ENAC, administered prices of 20 basic commodities. After 1986 ENAC continued buying and selling rice. Also EMPROVIT, guaranteed producers a minimum price for milk. Both agencies are now eliminated
	Credit policy	In the past farmers have benefited with loans from National Development Bank with interest rates below the inflation rate.
	Exchange rate policy	Agricultural trade is conducted at the intervention rate of exchange, which is set for the Government and is different than the one used by the Central Bank. This is in place since Dec. 1992.
	Input policy	In 1994 the Government approved the new Agricultural Sector Law to strengthening properties right for land and water use reducing restriction in private land sales. The INDA was entitled to Issue land titles. Imports of agricultural inputs are exempts of VAT and tariffs although a price band exists for the product. Machinery and tools for agricultural production, animal food, pesticides and fertilizers and the goods required for their production are exempted of VAT.
El Salvador	*Parastatals or state enterprises*	INZUCAR owns six sugar mills that represent 41% of the industry's production capacity. Currently INAZUCAR installation are in process of privatization. INCAFE used to own many coffee installation they are privatized and also INCAFE. The parastatal IRA, that was in charge of grain imports, but it was eliminated in 1992. The IRA also was in charge of a program of support price for maize, beans and rice.
	Credit policy	Currently El Salvador has four credit institutions related to agriculture. The Bank for Agricultural Development that is the financial agent for the rural programs. It is more oriented to poultry and livestock industries. Its interest rates are preferential rates and were reformed in 1992. There are two cooperatives FEDECACES and FEDE-CREDITO they are rural financial intermediaries. The fourth is the Land Bank created in 1991 to foment the acquisition of land for small farmers. The Government gives credit lines especially to rice farmers but at a market rate. Most of the credit (amount) is from the private sector but the Governmental bank has more clients.
	Exchange rate policy	Coffee and Sugar exports are since 1994 converted to domestic currency under the unified exchange rate.
	Input policy	In 1993 tariff rates for imports of capital goods were reduced from 5% to 1%. Agricultural products are subject to VAT though the final product is not taxes with VAT. The Government foments the issuing of land titles. Capital goods are in the process of receiving a 0 tariff in 1999. Since 1992 CENTA, the research and extension agency was transformed in an autonomous agency and is focused mainly on small farmers. In some areas of the country (San Vicente) irrigation projects has been financed with the sale of goods imported under the PL 480 title I program.
Guatemala	*Parastatals or state enterprises*	In the past the Agricultural Commercialization Institute was in charge of setting support prices for basic staples. Currently they are in charge of the Internal Commerce Directorate. Wheat trade and production is regulated by the Regulatory Office of Wheat Trade since 1961.
	Credit policy	In 1970 the Agricultural Development Bank was created to fund agriculture. In practice the bank operated with a below market interest rate and accumulated an important number of non performing loans. In Oct. 97 part of the bank was transformed in BANRURAL a second floor bank. The Government is part of the directory together with rural organizations. The interest rate for loans is the market rate.
	Input policy	Import licenses were required for fertilizers, pesticides and herbicides before Oct. 1995. The Government is designing a program to solve two problems related to land tenure: Uncertainty respect to land titles and people with no land or with too small plots. This in charge of INTA (National Institute of Agricultural Transformation). The agricultural institute of science and technology (ICTA) is in charge of the development and testing of new seeds and technology. Currently, all tools, chemicals and tractors imported into Guatemala pay a tariff of 1% since 1995 (In 1994 it was 5%). Besides all the imports pay VAT (10%).

Honduras	*Parastatals or state enterprises*	The IHMA, used to give support prices for basic grains, control grain trade and ensure adequate supply. Its power over internal prices ended in 1992. Before it lost the trade monopoly. Currently it administers the price band and maintains a strategic grain reserve.
	Credit policy	The National Bank for Agricultural Development, channels financial resources for production and marketing development in agriculture, forestry, poultry, livestock, and fishing. It serves only to agrarian reform farmers and its rate is below the rate offered to independent farmers. In 1996 the Government announced a fund of US$ 42 million for loans to the sector this was channeled in the form of credit guarantees.
	Input policy	In 1992 the Government provided a US$ 2 million subsidy to the coffee growers for their fertilizer purchase to subsidize the decrease in the world coffee price. BANADESA play an important role in the fertilizer distribution The Agricultural Modernization and Development Law passed in 1992 provided a legal framework to streamline the land titling process and land rental. In 1996 tariffs of capital goods were reduced from 5% to 3%. Also raw materials including those in the production of medicines and agricultural inputs to 1%. The surcharge for administrative services that was 1.5% until 1996 was reduced to 0.5%.
Mexico	*Parastatals or state enterprises*	The state intervention has been reduced during the 90's Some agencies has been downsized (CONASUPO, BANRURAL), others has been liquidated (TABAMEX, CONAFRUT ANAGSA, ALBAMEX), others dismantled (AZUCAR, INMECAFE, CONADECA) and others privatized (FERTIMEX, PRONASE). The only exception was the creation of ASERCA in 1991 to assist the formation of private markets. In 1992 CONASUPO privatized its food production industries (ICONSA). Now only is in charge of consumer subsidies of maize, beans and import powdered milk.
	Credit policy	Agricultural credit is granted BANRURAL. This subsidy was reduced in 1987. The remaining subsidy is targeted to low income farmers. AGROASEMEX, the National Agricultural Insurance Company provides insurance with rates below the market rates. Producers of basic products (grains, oilseeds, eggs, meat, fruit, vegetables, and fodder receive the FIRA credit. In 1995 the Government announced credit lines for farmers through Banrural, FIRA and Bancomext. Also the same year the Government started a debt-relief plan "The Emergency Debtor Support Plan" that imposed an interest rate ceiling of 25% on all outstanding loans below 200 thousand pesos until Feb.97. The impact of this program was low in economic terms because the bulk of loans were not included. The credit policy to agriculture crucially depends on the degree of tightness of the monetary policy. PROCAMPO payments can be used as collateral for loans.
	Input policy	Mexican subsidies for irrigation originate in subsidies on water provided through surface irrigation systems. Privatization of the irrigation sys has reduced this subsidy. In 1990 the electricity subsidy was eliminated when the Government adjusted the electricity rate. During years CONASUPO subsidized inputs in order to reduce the prices of the marketing chain. Subsidies to cattle producers have been in the form of feed grain and animal grain program. This subsidy is granted by CONASUPO. The Government also provides assistance to control and eradicate animal pests and diseases. In 1995 the Government started PRODUCE, a program that is part of Rural Alliance. It is a fund to support all the agricultural areas. It is aimed mainly at smaller producers, it produces subsidies for between 20 to 50% for the purchase of farm production and irrigation equipment. PRODUCE will provide subsidy to the livestock sector for pasture improvement and fence construction.
Nicaragua	*Parastatals or state enterprises*	Nicaragua maintained one parastatal: ENABAS that intervenes in domestic markets as a marketing board. ENCAFE a parastatal in charge of the coffee export was eliminated in 1992. The same occurred with the National School of Agriculture. About ENABAS its storage and distribution facilities we re sold in 1992.
	Credit policy	Credit to the agricultural sector is channeled mainly by the National Development Bank (BANADES). In 1995 under the Program for Rural Credit BANADES financed approximately 70% of the requested cost of production.
	Input policy	The Government is committed to solve problems related to property rights of land. In Nov. 97 the Government approved a new property right law. The Nicaraguan Institute of the Agrarian Reform is in charge of the land program. Agricultural inputs are exempted of VAT, but the IMF is pushing for reducing the number of items exempted.

(continued)

Appendix Table 5A.2 (continued)

Panama	*Parastatals or state enterprises*	Panama owns two sugar mills that produce 40% of the domestic production. The Agricultural Marketing Institute was in charge of setting support prices and had the monopoly in the import of basic products.
	Credit policy	Credit for the agricultural sector is channeled mainly through the Agricultural Development Bank. According to the terms with the agreement with the World Bank this bank is supposed to be privatized. Its interest rates for agricultural loans are below the market rate. The Government also possesses an agricultural insurance company (ISA).
	Input policy	There is no direct input policy, except that credit from financial institutions (Agricultural Development Bank and the National Bank of Panama) finance the purchase of inputs and working capital.
Paraguay	*Credit policy*	Most of credit policies are related to cotton. The Central Bank provides rediscounts to private banks loans to the gins or exporters. Private banks are required to have a minimum of 10% of loans to the agricultural sector in their portfolio. Also the Central Bank advances funds to the Development Bank (BNF) to finance agricultural activities of smallholder farmers.
	Input policy	Most of research and development financed by the Government is de dedicated to Cotton.
Peru	*Parastatals or state enterprises*	The Government eliminated its monopolistic intervention in the marketing of agricultural products through ENCI and ECASA. The National Program of Food Assistance (PRONA A) sporadically intervenes to regulate prices.
	Credit policy	In 1992 the Agrarian Bank (BAP) was eliminated, cutting the subsidized credit. They were replaced by funds provided by COFIDE through the Rural Banks. These are for farmers that cannot access to commercial credit. Also the Government offered Agrarian Funds (FONDEAGRO and Rotating Funds) but only in limited amounts of cash and inputs, mainly fertilizers and seeds. Currently FONDEAGROS has been eliminated.
	Exchange rate policy	In 1990 the Government abolished the multiple exchange rates that worked since 1985. Under the previous system exports were given a preferential exchange rate and inputs were allowed to be imported at a very low exchange rate.
	Input policy	ENCI still imports urea to donate it to small farmers. Two important reforms were the openness of a land market and the transference of the water administration to the usury associations.
Uruguay	*Parastatals or state enterprises*	Uruguay has some agricultural parastatals. They participate in the production, processing, and trade of goods such as sugar and alcoholic beverages. Alcohol production is a monopoly of ANCAP.
	Credit policy	Most of agricultural credit comes from the Republic of Uruguay Bank that is a multi-purpose bank government owned. Approximately three-quarters of the total bank credit are for the private sector. Most of the credit is short term credit (less than a year). The bank also administers credit lines offered by multilateral and bilateral institutions for the agricultural sector.
	Input policy	Input policy consists in specific legislation that governs the importation, production, marketing and exportations of fertilizers and their raw materials. Import licenses are required for fertilizers. Domestic fertilizer are exempt of VAT. Other agricultural inputs are duty free.
Venezuela	*Parastatals or state enterprises*	Venezuela possesses some Government owned enterprises like PEQUIVEN that produces fertilizers. Also has privatized or eliminated others like sugar mills. Monopolies in the export of commodity like FOCACAO (for cocoa) and FONCAFE (for coffee) has been eliminated also the Agricultural Marketing Corporation that had the monopoly in the agricultural products marketing.

Credit policy	Agricultural credit is subsidized through the FCA a state entity that supplies funds for agricultural loans to private and public banks. Also ICAP takes funds from FCA to lend to small farmers. In 1994 the Government eliminated Bandagro (Agricultural Development Bank) The Government used to require commercial banks to invest 20% of their portfolio in agriculture. This percentage was reduced to 12% in the context of the structural reform of 1989. In 1995 that percentage was increased to 17%. In 1997 the percentage was reduce to 15% and it is expected to be eliminated. Also until 1997 commercial banks were obliged to lend to the agricultural sector a rate that was 85% of the commercial lending rate.
Exchange rate policy	Until 1989 Venezuela used a multiple exchange rate system. Basic commodities were imported at an exchange rate well below the commercial exchange rate. Allotments of currency for imports were in charge of RECADI.
Input policy	Irrigation fees paid cover only 1-2% of the irrigation cost. The cost of fertilizer is also subsidized. Farmers also receive discounts for electricity, are exempted from income tax and investments in fixed assets are subject to an investment credit. Currently farmers receive a discount between 10-14% for the purchase of urea and NPK in the government owned fertilizer company (PEQUIVEN). In 1989 the subsidy was 77% of the price of fertilizer; in 1990 it was lowered to 44%, 18% in 1992, and 7% in 1993 to be eliminated in Sep 93. In 1996 under the reduction for the use of fertilizer the Government applied again the subsidy (28%) and was reduced again in 1997.

Sources: Compiled by authors from IMF 1993,1994, 1995a–f, 1996c–f, 1997b–e, 1998a–d ; USDA 2002; and IADB 1996a, 1996b.

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Chapter 6

Agricultural Research

Nienke M. Beintema and Philip G. Pardey

Many of the policies discussed in the previous chapter reflect government actions arising from political processes that (regardless of the underlying intent) result in the redistribution of resources rather than the creation of new wealth using the power of the public purse to generate economic growth.[1] Private ingenuity and economic activity provide the lion's share of the wealth creation worldwide. But laissez-faire markets miss certain socially productive opportunities, and it is in these cases—where markets fail— that the strongest case for government intervention can be made. The economic evidence is clear that, left to their own devices, markets would fail to provide the socially desirable amount and mix of investments in health, education, and especially R&D, as well as some important infrastructural and institutional goods and services (for example, law and order and defense).

Research is an inherently risky business. Many lines of inquiry fail to pan out scientifically or economically, some just pay their way, and a few hit the jackpot. (It is for this reason some see R&D as akin to drilling for oil, where a few gushers pay for the many dry holes that are drilled). Economists have long studied the returns to R&D and the overwhelming evidence indicates that overall (that is, factoring in the losers with the winners) the payoffs to investments in agricultural research are particularly high (Alston et al. 2000). Importantly, there is no evidence that the returns to R&D have diminished over time, so equally large returns to current R&D spending are feasible in the future. This suggests that societies would be better off investing more in research—but this begs important public policy questions. Precisely how much should be spent on what types of R&D, who should pay for and conduct the

1 This chapter is a reworked and updated version of Beintema and Pardey (2001). A set of country reports with more detailed data can be downloaded from <http://www.asti.cgiar.org>. For some additional perspectives on agricultural R&D in LAC, see Trigo et al. (2002).

Table 6.1 Public agricultural R&D spending trends in 11 Latin American countries, 1976–2000

	Brazil	Mexico	Other (9)	Total (11)
Total spending	*(million 2000 international dollars per year)*			
1976–80	546	262	413	1,221
1980–85	711	381	441	1,533
1986–90	803	281	569	1,652
1990–95	980	306	580	1,866
1996	1,122	357	671	2,150
2000	1,020	330	700	2,050
Annual growth rates	*(percentage)*			
1976–80	10.3	19.1	4.5	10.5
1981–86	–0.4	–4.3	6.2	0.5
1986–91	4.8	–4.1	–2.9	0.7
1991–96	3.0	3.5	5.6	3.9
1996–2000	–2.3	–1.2	0.5	–1.2
1976–2000	3.3	0.8	2.7	2.6

Sources: 1976–96 data are from Beintema and Pardey 2001; 1996–2000 data were calculated by the authors using spending data for the principal agricultural research agencies from the Agricultural Science and Technology Indicators (ASTI) database and RICYT 2005. Regional totals were scaled up from national spending estimates for 11 countries that represented 85 percent of the Latin American total in 2000.

Notes: Data from 1976 to 1996 are presented as five-year averages. The number of countries included in the "other" and "total" categories are shown in parentheses. Annual growth rates are least-squares growth rates.

research, and what is the right balance between undertaking domestic R&D and tapping technologies developed elsewhere in the world? To even begin properly addressing these questions, it is necessary to know the current and prospective state of play regarding R&D in Latin America, and then to consider the LAC situation within a global context.

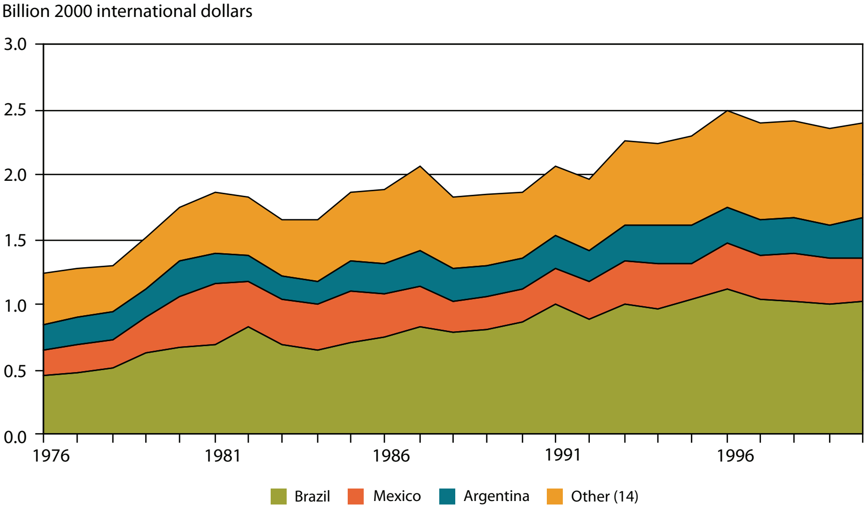
Investment Trends

Public Sector

By 2000 (the latest year for which internationally comparable totals are available), \$23 billion was spent worldwide on public agricultural R&D. Latin American countries spent \$2.4 billion (in international 2000 prices)—about 10.6 percent of the global total, and almost double the amount they spent in 1976 (Figure 6.1). A large disparity exists in the amount of agricultural R&D spending throughout Latin America. Five of the 17 countries spent more than \$100 million (including Mexico, which spent \$330 million), while another 5 countries spent less than \$20 million (Table 6.1).

Countries with large agricultural sectors are likely to spend more on agricultural R&D than those with small sectors. To assess these differences, a common invest-

Figure 6.1 Trends in Latin American public agricultural R&D spending, 1976–2000



Sources: 1976–96 data are from Beintema and Pardey (2001); 1996–2000 data were calculated by the authors using spending data for the principal agricultural research agencies from the Agricultural Science and Technology Indicators (ASTI) database and RICYT (2005). Regional totals were scaled up from national spending estimates for 11 countries that represented 85 percent of the Latin American total in 2000. The number of countries in the "Other" category are shown in parentheses. Growth rates are lease-squares growth rates.

ment indicator is the agricultural research intensity ratio, which measures total public spending as a percentage of agricultural output (AgGDP). In 2000, on average, Latin American countries invested $1.17 for every $100 of agricultural output—almost double the 1976 figure (Table 6.2). But, once again there are wide disparities among countries. Intensity ratios ranged from just 0.09 for Guatemala to over 1.81 for Brazil and Uruguay, well above the ratio observed for most developing countries and at the lower end of the range for the developed countries (which averaged $2.36 of public R&D for every $100 of output).

Agricultural R&D in the richer Latin American countries now seems headed in different directions from those in the poorer parts of the region (Beintema and Pardey 2001). In addition to having comparatively less well-qualified staff, four of the poorer Central American countries for which reliable time-series data are available—Costa Rica, Guatemala, Honduras and Panama—had agricultural R&D spending levels at least 13 percent lower in 1996 than in 1976 (adjusting for inflation). Although funding from nongovernment (often commodity-based producer) organizations grew 10-fold over this timeframe, the growth was from a very small base and was insufficient to offset substantial cutbacks in government spending.

Table 6.2 Public agricultural research intensity ratios, 1976–2000

Country	1976	1986	1996	2000
		(percentage)		
Argentina	0.79	0.95	1.12	1.44
Brazil	0.75	1.00	1.73	1.81
Chile	1.92	1.64	1.43	1.26
Colombia	0.25	0.48	0.53	0.51
Costa Rica	0.53	0.72	0.56	0.60
Guatemala	0.22	0.31	0.13	0.09
Honduras	0.17	0.71	0.34	0.41
Mexico	0.48	0.61	0.88	0.99
Panama	0.64	1.35	1.07	1.08
Paraguay	0.06	0.13	0.18	0.21
Uruguay	0.52	0.77	1.70	2.21
11-country average	0.59	0.79	1.12	1.17

Sources: 1976¬–96 data are from Beintema and Pardey 2001; 2000 data are authors calculations from Table 6.1 and World Bank 2005.

Private Sector

Private research has not stepped in to fill the public research gap. In the rich countries, including North America, Japan, and Western Europe, private firms account for about half of total agricultural research spending (Table 6.3). It would be easy to assume that private participation in Latin American research would be significant, given that large parts of Latin American agriculture are technologically advanced by world standards, the sector has sophisticated private input supply and postharvest and processing sectors in some countries, and GMO use is substantial in Argentina and (despite only recent government approval) Brazil. Yet, private-sector spending on agricultural R&D was only 4.5 percent of total private and public spending in Latin America in the late 1990s.[2] More than half the private spending occurred in Brazil, representing the efforts of national firms and multinational corporations with research operations in Brazil. Countries such as Paraguay and Uruguay conduct little, if any, private agricultural research. A few Central American countries host private research facilities involving U.S.–owned fruit companies. In 1996, private spending on agricultural R&D was estimated to be 7 percent of total spending in Panama and 46 percent of total spending in Honduras. However, by design, much of this private research has a regional orientation, tackling problems relevant to banana, pineapple, and other tropical fruit growers throughout Central America, making national sector shares less meaningful. It seems, therefore, that most of the private technologies used throughout the region are based on research done elsewhere.

2 R&D investments are measured on basis of the location of the performer, irrespective of where the firm may be headquartered.

Table 6.3 Public and private agricultural R&D spending, circa 1996

	Public	Private	Total
Total spending		*(million 2000 international dollars)*	
Latin America, 1996			
Brazil	1,122	45	1,167
Mexico	357	18	375
Other Latin America	256	18	274
LAC total	1,735	81	1,816
Global, 2000			
Developing countries	12,819	862	13,682
Developed countries	10,191	12,086	22,277
World total	23,010	12,948	35,958
Shares		*(percentage)*	
Latin America, 1996			
Brazil	96.2	3.8	100
Mexico	95.2	4.8	100
Other Latin America	93.3	6.7	100
Latin America total	95.6	4.5	100
Global, 2000			
Developing countries	93.7	6.3	100
Developed countries	45.7	54.3	100
World total	64.0	36.0	100

Sources: 1996 LAC data are from Beintema and Pardey 2001; data for 2000 developing and developed country and world totals are from Pardey et al. 2006.

Notes: There are seven countries in the "Other Latin America" category: Colombia, Costa Rica, Guatemala, Honduras, Panama, Paraguay, and Uruguay; the "Latin America total" category includes Other Latin America, Brazil, and Mexico.

Human Capital

The number of agricultural researchers working throughout Latin America grew strongly throughout the 1960s and 1970s, but growth generally stalled in the two decades thereafter, and for some countries the number of researchers even declined. The 11 countries for which time-series data are available employed about 7,800 full-time equivalent (fte) researchers during the late 1970s, growing to 12,600 by the early 1990s (Table 6.4). Most of this growth took place in the first half of this 20-year period. From 1991 to 1996, the total number of fte researchers declined in 5 of the 11 sample countries. In contrast, the number of fte researchers in Colombia and Uruguay grew faster during the early 1990s than in earlier periods (7 and 8 percent per year, respectively).

Degree Status

In 1996, 72 percent of the total fte researchers in the 11-country sample had postgraduate training, with more than one-quarter holding doctorate degrees (Table 6.5). Again, these regional shares are heavily influenced by Brazil and Mexico, and the qualifications of research staff vary markedly among countries. For example, 83

Table 6.4 Public agricultural researcher trends in 11 Latin American countries, 1976–96

	Brazil	Mexico	Other (9)	Total (11)
Total researchers		*(full-time equivalents per year)*		
1976–80	3,335	1,595	2,872	7,802
1980–85	4,034	2,483	3,581	10,099
1986–90	4,684	3,111	4,501	12,296
1990–95	4,943	3,087	4,395	12,425
1996	4,895	3,097	4,582	12,574
Annual growth rates		*(percentages)*		
1976–81	4.5	13.2	2.5	5.4
1981–86	2.4	7.6	5.1	4.6
1986–91	2.5	0.7	1.5	1.7
1991–96	0.6	-1.2	0.7	0.2
1976–96	2.5	4.3	2.9	3.0

Sources: Beintema and Pardey 2001.

Notes: Data from 1976 to 1996 are presented as five-year averages. For Argentina, Paraguay, and Uruguay, 1996 data were only available for the higher education sector and some other major agencies, so we used these data and other information to scale up to an national estimate, adjusting the scaling factor over time because a large proportion of the agricultural faculties were only established during the 1980s and early 1990s. The number of countries in the "Other" and "Total" categories are shown in parentheses. Annual growth rates are least-squares growth rates.

percent of Brazilian agricultural researchers held doctoral degrees, while for 6 of the countries in our sample, more than 60 percent of the researchers held only BSc degrees.

A higher proportion of university staff held PhD degrees compared with staff at other agencies, a pattern that was prevalent among most of the countries in the region. Typically, a much smaller share of the staff working at nonprofit agencies had postgraduate training, so the concentration of these types of agencies in Central America contributes to the generally lower level of training received by researchers in that part of the region. Detailed time-series data on the degree status of agricultural researchers were available for some countries; they point to a significant increase in staff education levels, at least for those countries. For example, in 1976 only a quarter of the fte scientists employed by Brazilian agricultural research agencies held postgraduate degrees and a further 6 percent had received doctorate-level training. The Brazilian Agricultural Research Corporation (Embrapa) along with many other comparable agencies in other countries (for example, in Mexico, Chile, and Uruguay) invested heavily in training their research staff, receiving considerable financial support from agencies such as the World Bank and the Inter-American Development Bank to do so. In Mexico, Colombia, and a few other countries, scientist training commenced quite a bit earlier, in the 1950s and 1960s, as part of technical support provided by U.S. agencies and foundations.

Although the number of postgraduate courses in the agricultural sciences offered by Latin American universities increased substantially over the past few decades, many agricultural science students still seek postgraduate (particularly doc-

Table 6.5 Degree status of public agricultural researchers, 1996

	PhD	MSc	BSc
		(percentage)	
By country			
Argentina	na	na	na
Brazil	31	51	18
Chile	21	28	52
Colombia	11	38	52
Costa Rica	10	26	64
Guatemala	5	15	80
Honduras	14	13	73
Mexico	19	47	34
Panama	8	29	63
Paraguay	3	34	64
Uruguay	7	29	65
By institutional category			
Government			
Principal	23	48	29
Other	17	48	34
Nonprofit	12	28	60
Higher education	29	38	32
10-country average	23	45	33

Sources: Beintema and Pardey 2001.
Notes: In Uruguay, the share of scientists trained to postgraduate level has increased substantially since 1996.

toral) training at foreign universities.[3] There is evidence that in recent years donor organizations downgraded the funding priority they had earlier placed on human capital development, which may have serious consequences for the training of research staff throughout the region in future years. There may also be a bifurcation of scientific capacity developing throughout the region, not least because of the disproportionately larger decline in government funding for research witnessed in recent years for those countries with fewer agricultural researchers possessing higher degrees.

Funding Mechanisms

Beginning in the early 1980s several Latin American countries sought to restructure their main agricultural research agencies along quasi-private or foundation lines. The intention behind this was to gain administrative and research autonomy, enable public research to be more responsive to the changing realities facing agricultural sectors (with more effective links to private research and technology suppliers),

3 Brazil is an exception, reflecting the relatively advanced state of its higher education system. During 1996–98, 97 percent of the Embrapa researchers enrolled in MSc courses and about half the scientists undertaking doctoral studies were studying in Brazilian universities (Beintema, Avila, and Pardey 2006).

and reduce the reliance of nonprofit research agencies on block grant funding from the government. In Ecuador, Honduras, and Peru, a series of institutional changes along these lines were part of the requirements for new funding from international agencies such as the World Bank and IADB; in Argentina the changes were part of a broader series of domestic policy and institutional reforms designed to change, and generally reduce, the role of government in the country's economy (Pardey, Roseboom, and Anderson 1991). While more administrative autonomy was forthcoming in most instances, there is less uniform success in reducing the reliance on government funding (nor are there convincing signs that total funding has grown as a consequence of these financing reforms). More than a decade after the reforms were initiated, the main agricultural research agencies in Brazil, Colombia, Guatemala, Honduras, Mexico, and Panama received 80–90 percent of their funding from the government, about the same share they received before the reforms. However, there are some exceptions. The principal government agencies in Chile and Uruguay did succeed in diversifying their sources of support. In 1989 a commodity tax on agricultural production was created to fund agricultural research in Uruguay; it accounted for more than one-quarter of the National Agricultural Research Institute's income during the 1990s. During this same period, the Agricultural Research Institute in Chile received more than 40 percent of its income from research contracts with the private sector and revenues from the sales of its products and services.

Other countries have sought to fund agricultural R&D by a tax on agricultural exports. Colombia is probably the most advanced country in these terms, where 12 producer organizations are either conducting their own research or financing research done by others mainly through this means (Beintema, Romano, and Pardey 2000). During the past two decades, Costa Rica, Guatemala, and Honduras have also established production tax regimes to fund research, mainly on coffee and sugar. Although producer-financed research based on taxing schemes grew by 8 percent per year from 1976 to 1996 (compared with 3 percent for research spending in total in our 11 country sample), by 1996 spending from these sources accounted for just 4 percent of resources from all sources.

In addition to finding new sources of finance for agricultural R&D, several Latin American countries have created competitive funding mechanisms as an alternative means of disbursing research resources. Competitive funding mechanisms have gained favor among some (but not all) policymakers, donors, and even researchers, and they come with several pros and cons compared with more conventional block grant approaches. They are seen as means of more readily redirecting research priorities; increasing the role of the private and academic sectors in the performance of research; and, perhaps, forging new links among government, academic, and private research agencies. Competitive mechanisms often involve higher transaction costs (for writing and screening proposals, for example) and increased rent-seeking costs (such as lobbying for support), but they may lower the social costs of research by reducing the misallocation of funds that can occur when precedence plays an undue role in allocating funds via block grant mechanisms. Further, competitive

funds tend to increase flexibility but often result in more short-term, applied research at the expense of more basic, longer term research (Alston and Pardey 1996; Echeverría and Elliott 2002). Despite some moves in this direction, a comparatively minor share of total funding is disbursed by competitive means. For instance, only 1 percent of the total agricultural R&D spending in Brazil during 1996–98 was disbursed competitively. This share was higher in Chile, Colombia, and Uruguay, but was still less than 10 percent on average (Beintema, Avila, and Pardey 2001).

Conclusion

It is hard to distill a concise picture of Latin American agricultural R&D based on the available data, and doubly difficult to discern what these trends portend for the future of agricultural R&D in the region. After the generally dismal decade of the 1980s, public investments in agricultural R&D rebounded in some countries during the first half of the 1990s, but the recovery seems fragile and not widely shared across the region. Public research in countries like Brazil and Colombia that did better in the early 1990s suffered cutbacks later in the decade, and many of the poorer (and smaller) countries have failed to experience any sustained growth in funding for the past several decades.

There are worrying indications of an apparent bifurcation of research. The richer countries may be making sufficient investments to stay in the race, in spite of investment slowdowns in many of these countries in recent years. The poorer countries seem to be slipping behind, both in terms of their present and projected abilities to generate new technologies, as well as their capacities to exploit fully the potential for technology spillins from countries both within and beyond the region.

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Chapter 7

Projecting Agricultural R&D Potentials

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Looking Ahead at Agriculture in Latin America and the Caribbean

In this chapter, we use the market and spatial evidence reviewed in Chapters 2, 3, and 4, in conjunction with a multi-market equilibrium displacement model (Dynamic Research EvaluAtion for Management, or *Dream*, which is discussed in more detail below), to assess the potential economic benefits arising from research-induced improvements in the local and spillover productivity performance of important agricultural commodities in LAC. Before doing so, however, we first place these R&D potentials in a broader market context using a recent, updated application of IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT).

IMPACT is a data and modeling platform for food and agriculture projections at a regional and global scale. Because IMPACT takes account of demand, supply, and trade in an international context, its projections are balanced with respect to relative growth opportunities in different regions. In this model, global production and consumption must equilibrate each year. Projecting forward on a year-by-year basis, imbalances between demand and supply at the previous year's prices cause current food prices to adjust to clear the market, thus altering the incentives for farmers and consumers to participate in specific commodity markets. In the case of LAC, IMPACT models each of the four largest agricultural economies—Brazil, Mexico, Argentina, and Colombia—and aggregates the remaining countries into a single "other LAC" subregion. Results summarized here were projected from base conditions in 1997 (three-year averages for 1996–98), through to either 2015 or 2020. IMPACT projec-

tions always include a "baseline" perspective that projects forward the most likely development trajectory using the best contemporary information.[1]

Two of the fundamental drivers in the IMPACT model entail assumptions about future population and economic growth, where economic growth is represented by exogenously projected changes in per capita GDP, a proxy of changing levels of aggregate income. Baseline population projections draw from the United Nations' median population projections (United Nations 1998; Lutz, Sanderson, and Scherbov 2001) for each country, and those for LAC as a region indicate a continued slowing in the rate of population growth in line with developments in many other (but not all) parts of the world. Average population growth rates in LAC were projected to be 1.2 percent per year over the period 1997–2020, compared with 1.7 percent per year over the period 1990–97, such that the overall population of LAC would increase from 486 million in 1997 to 652 million in 2020. Together with GDP growth rates ranging from 3.6 to 4.5 percent throughout LAC, GDP per capita (in 1997 U.S. dollars) was projected to grow generally but differ markedly among countries by 2020, ranging from $17,438 for Argentina to $3,759 for "other LAC" countries. Other factors used to define IMPACT scenarios include the amounts of public investment, projected changes in agricultural productivity, government policies influencing producer and consumer prices (so-called producer and consumer subsidy equivalents), and marketing margins. We summarize the IMPACT results by considering the findings of the most recent set of baseline projections from 1997 to 2015, a year of interest to many countries because of commitments to achieve Millennium Development Goal (MDG) targets by that year (Lutz, Sanderson, and Scherbov 2001). We highlight the baseline scenario results for the major commodity groups: cereals, roots and tubers, soybeans, (sub)tropical fruits, and meats (von Braun et al. 2005).[2]

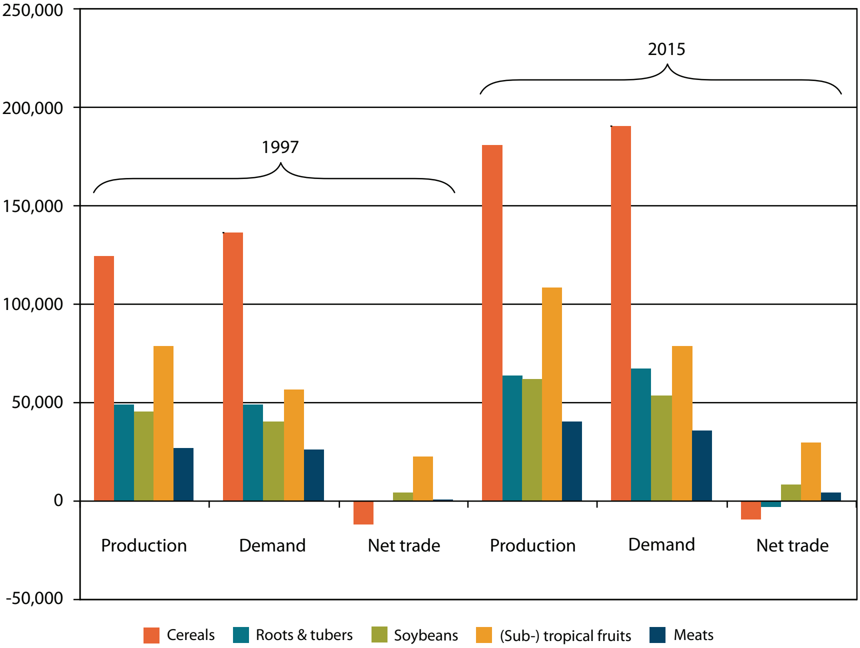
An overall comparison of the projected aggregate changes in LAC production, demand, and net trade between 1997 and 2015 for selected major commodity groups is presented in Figure 7.1. Cereals are deemed to remain the dominant agricultural commodities of the region, although their output growth rates are projected to decline in line with declining growth in demand. Despite projected gains between 1997 and 2015 under these baseline estimates both in cereal productivity (from 2.6 to 3.4 tonnes per hectare on average) and land under cereals (the addition of some 4.5 million hectares), LAC is expected to remain a net cereal importer, although imports are predicted to decline in aggregate.

Figure 7.2 shows the more complex picture of national and subregional imbalances in net cereal trade that underlie the regional trends. Essentially, continued expansion of the already substantial cereal export capacity of Argentina is expected, and a large part of that expansion will be destined for intraregional trade to meet projected growing cereal deficits in Brazil, Mexico, and Colombia. In the remainder

1 For additional details of IMPACT and the construction of model scenarios, see Rosegrant et al. (2001, Chapter 3 and Appendix A).

2 Summary tables of the main results by commodity group for Argentina, Brazil, Colombia, Mexico, and "Other LAC" (countries) are contained in Supplementary Table 7.1a–e.

Figure 7.1 IMPACT baseline projections for Latin America and the Caribbean by major food group

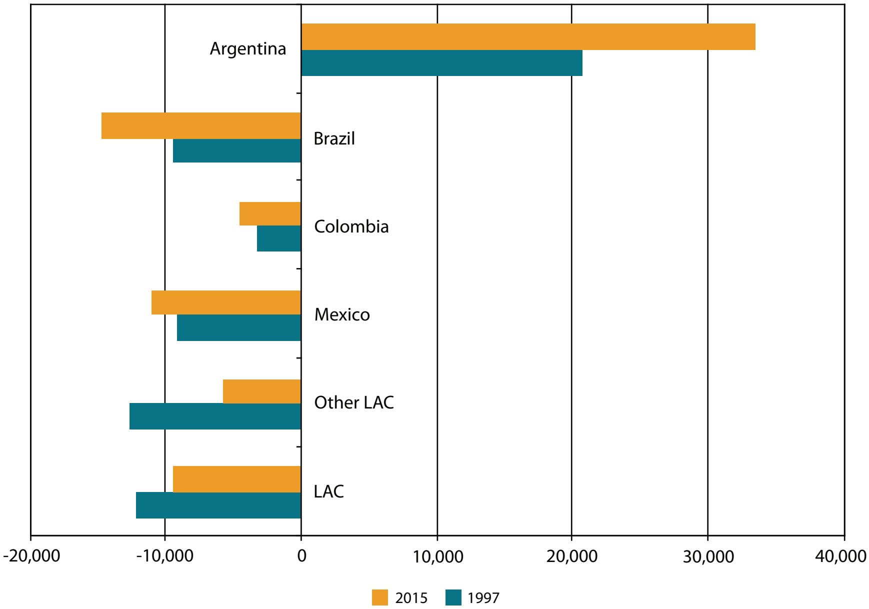


Sources: Compiled by authors from von Braun, Rosegrant, and Cline (2005).

of LAC, cereal production is expected to increase faster than demand, thus reducing reliance on imports. While the absolute increase in maize output (about 30 million tonnes regionally from a 1997 base of 75 million tonnes) will be larger than the combined output for rice and wheat, growth rates for rice and wheat output will be higher. And, continuing past trends reported elsewhere, yield growth is expected to be the primary source of expanded cereal output, particularly for irrigated rice (Figure 7.3).

While the IMPACT projections point to the prospects of sizable improvements in food security, poverty reduction, and the economic status for the region generally, the analysis broaches several issues of direct relevance for the study. First, the model has future yields growing at rates slower than those experienced in the recent past. This assumption is taken as indicative of the increasing cost and complexity of making scientific headway in developing more productive crops and cropping systems, in some instances combined with declining or wavering national commitment to investing in agricultural R&D (see Chapter 6). Second, and as a consequence of these productivity developments, there is expected to be increased pressure to intensify production on the basis of area per unit of time as well as to

Figure 7.2 Projected changes in net cereal trade in Latin America and the Caribbean, 1997–2015



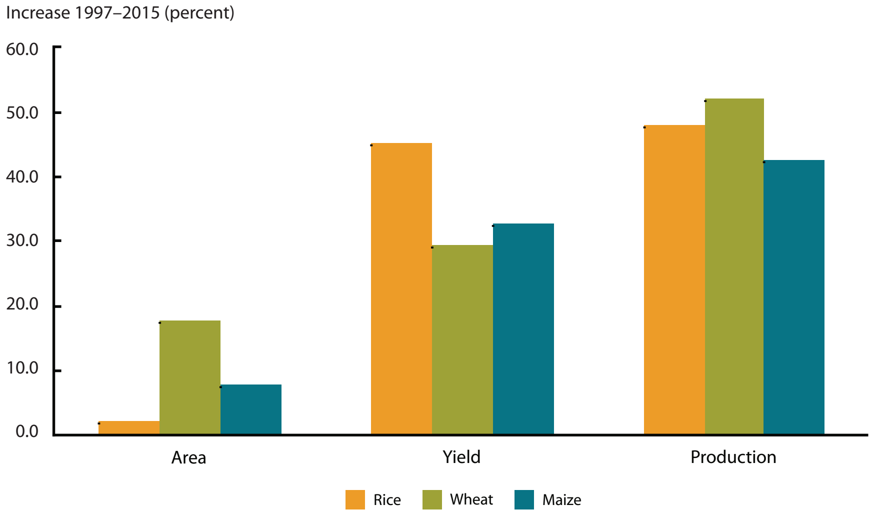
Sources: Compiled by authors von Braun, Rosegrant and Cline (2005).

expand the overall land extent under agriculture. While LAC is well endowed with land that could potentially be used for agricultural production (see Chapter 3), there could still be significant costs associated with such expansion, particularly in terms of habitat and biodiversity loss and the potential for increased agricultural pollution. Third, a notable and recurring theme arising from the various scenarios projected in von Braun et al. (2005) is the growing agricultural and economic disparity projected between the larger, richer LAC countries and the poorer, smaller ones. This set of IMPACT projections suggests that the recently observed diversity among countries in yield growth, market performance, and ability to invest in an enabling environment for agricultural development (including agricultural R&D) will continue in the foreseeable future.

Strategic Assessments of Agricultural R&D Potentials

In this section we lay out an analytical framework for assessing the local and spillover consequences of Latin American research in a way that takes account of the increasingly international context within which the region's agricultural sector exists. The economic approach to R&D evaluation we use relies heavily on the multi-

Figure 7.3 Projected sources of cereal production growth in Latin America and the Caribbean, 1997–2015



Sources: Compiled by authors from results in von Braun at al (2005).

market equilibrium framework presented in Alston, Norton, and Pardey (1998). The major innovation here is to draw on new spatial data and analysis techniques to improve our ability to model the spillover consequences of agricultural research when assessing alternative agricultural R&D investment options from a regional perspective. In addition to describing this evaluation approach in some detail, we report the results of our exploratory efforts to apply this new framework to eight important crops in Latin America. The section ends with an assessment of the approach and a summary of the results found to date.

Economic Indications of R&D Impacts

Every research institution, be it a funding agency or an agency that conducts R&D, has a constituency and a set of objectives. Relative to those objectives, there are benefits from the investments made in research. The institution will want to achieve the greatest benefit possible from its investments, making maximum net benefit an appropriate criterion for research priority-setting and management for *every* research institution.

A particularly useful measure of net benefits considers only the pecuniary benefits to the relevant producers and consumers in a country. This measure has a number of advantages. First, it is well defined and understood, and for many types of research can be measured using information about the technology of produc-

tion, the effects of research on that technology, and characteristics of the affected commodity markets. Also, this measure does not require an elaborate scheme by which to weight objectives.

Since this measure connects closely to economic models of behavior and welfare economics, we can draw on an extensive literature to implement the measure in different settings, and optimization and priority-setting follow naturally. Finally, this measure of benefits can be aggregated over time and across locations to compare and contrast regional versus subregional perspectives. For this reason, many economists have revealed a preference for this narrower definition of national economic benefits for research evaluation and priority-setting exercises.

Many noneconomists, and even a few economists, are uncomfortable with restricting attention to the simple, single-valued criterion of maximum net benefits (defined as the sum of benefits to producers and consumers within a country, less the costs associated with providing them). The reason, they would say, is that the benefits of research produce many other valuable kinds of less pecuniary, and (sometimes) measurable benefits—for example, poverty alleviation, natural resources preservation, unemployment reduction, nutrition improvement, balance of payments increases, and income distribution improvements.

Alston, Norton, and Pardey (1998) have pointed out that it is important to distinguish between objectives and the means of achieving them, and to be careful about double counting. Many of those objectives will be represented effectively in the aggregate measure of net benefits we have in mind. Some others are not, however. In particular the effects of research on income distribution, or the distribution of the benefits among groups within a society, are not fully reflected in this measure.

Accounting for the distributional effects of research, say, according to what people do for a living, or their income status, can be done using similar approaches, but to do so is much harder, requiring more information and more complicated models than measuring the aggregated or net effects. One argument against using income distributional implications as a criterion for research funding and priority-setting is that these aspects are hard to measure. Another, more fundamental, argument is that agricultural research is probably an inappropriate mechanism for addressing income distribution issues.[3] If alternative policies can be used more efficiently or more effectively to address income distribution concerns, then agricultural research can be directed to achieve the greatest net gains for the economy as a whole. Finally, as a practical matter, in our experience (probably as a reflection of the perspicacity of the arguments above) those in charge are usually not prepared to sacrifice much in terms of aggregate net benefits from research for a change in

3 Targeting the benefits from, for example, variety-improvement R&D is particularly difficult, even compared with, say, education subsidies or food subsidies (for which targeting is not altogether easy). In any event, when considering income distribution, the consequences of lowering staple food prices using untargeted technologies are likely to be more pervasive than those from targeted technologies.

Table 7.1 Chronology of selected ex ante R&D evaluation studies for Latin America and the Caribbean

				Spatial focus	
Study number	Year published	Author	Evaluation approach	National and subnational	Other
1	1986	ISA	Scoring	Dominican Republic	
2	1986	Espinosa et al.	Scoring	Ecuador	
3	1987	CIAAB	Scoring	Uruguay	
4	1987	Davis, Oram, and Ryan	Economic surplus		LAC/world
5	1987	Norton, Ganoza, and Pomaredo	Economic surplus	Peru	
6	1991	CIAT	Hybrid		Countries within LAC[a]
7	1992	Palamino and Norton	Scoring	Ecuador	
8	1992	TAC	Scoring		LAC/world
9	1993	Lima and Norton	Scoring	Venezuela	
10	1995	IICA	Scoring		TAC/LAC
11	1995	Medina	Scoring	Central America (six countries)	
12	1997	FONTAGRO	Hybrid		Countries including LAC[b]
13	1998	IICA/IFPRI	Hybrid	Caribbean (eight countries)	
14	1998	IICA/IFPRI	Economic surplus	Andean subregion	
15	1998	IICA/IFPRI	Economic surplus	Mesoamerica	
16	2000	Present study	Economic surplus	—	

Sources: Compiled by authors.

Notes: TAC – Technical Advisory Council of the CGIAR (now replaced by the Science Council).

[a]The CIAT study excluded nontropical areas (such as Argentina and Chile) that lay beyond its ecoregional mandate area.

[b]The FONTAGRO study included the southern United States to highlight the importance of potential knowledge and technology spillovers between the United States and LAC.

the distribution of the benefits from research; consequently, it is often not worth the cost of attempting to incorporate the distributional objective in an analysis.

In this analysis we will be using economic surplus measures to represent the benefits and costs of research-induced technical changes experienced by aggregates of producers and consumers in various countries or subregions. This same analytical framework can also be used to measure costs and benefits to taxpayers (as reflected in changes in government revenues) when government policy distorts commodity markets, and agricultural R&D causes changes in government collections or expenditures. These measures are discussed in Alston, Norton, and Pardey (1998).

Prior R&D Impact Evidence

Table 7.1 presents a chronology of previous, ex ante research evaluation studies of LAC. About half of the studies did not draw on economic methods to assess and prioritize R&D technologies but instead employed scoring approaches. Alston, Norton, and Pardey (1998) have shown that the scoring approaches generate project

rankings that can vary markedly from those obtained from more formal economic approaches. Only five studies used economic approaches; three "hybrid studies" combined economic methods with scoring approaches.

The spatial scope, commodity focus, and international dimensions of these past studies varied as well. The preponderance of the studies provided evidence with a country-specific focus (studies numbered 1, 2, 3, 5, 7, 9, 11, and 13 in Table 7.1), while several took regional approaches (6, 8, 10, and 12). Only a couple of studies sought to span both national and subregional spatial groupings (14 and 15), and only the present study integrates spatial scales ranging from subnational areas to regional groupings.

The commodity coverage is also quite different. The scoring studies included between 30 and 50 commodities but included little economically relevant data on each commodity. Most studies elicited scores for various criteria, then imposed particular weights on those scores for purposes of aggregating them to derive a single indicator. The "hybrid" and formal economic studies took the most data-intensive approach.

Most of the studies paid little attention to the consequences of international trade and technology spillovers. The present study deals with both topics and also allows for the imperfect transmission of domestic price changes to international markets and vice versa. None of the prior studies sought to make agroecology and spatial variation a central element of the analysis. Most relied on national average data, thereby missing the significant spatial variation in the productivity effects of R&D. Moreover, the data used to characterize the agroecological dimensions of this analysis are much richer and more detailed than those included in past studies (particularly, studies numbered 4, 6, 8, 10, 12, 14, and 15). Finally, here for the first time the impacts of technology have been specified consistently in terms of their agroecological and geopolitical domains.

Models as Metaphors

The approach used here involves simulating commodity markets over time by defining equations for supply and demand with and without various research-induced changes in supply. The results of the simulations are quantities and prices (with and without research-induced changes) that, along with the underlying supply and demand equations, are used to compute the economic benefit from the research-induced changes. Hence, along with the benefits measures of primary interest, the analysis also provides information on research-induced changes in commodity prices and quantities that can be used to compute alternative measures of research impacts.

The economic model we use is a metaphor for how the real world works; often the metaphor is good and useful, even if some of its details are inaccurate. Krugman (1998, 19) wrote:

> Economic theory is not a collection of dictums laid down by pompous authority figures. Mainly, it is a menagerie of thought experiments—parables, if you like—that are intended to capture the logic of economic processes in a simplified way. In the end, of course, ideas must be tested against facts. But even to know what facts are relevant, you must play with ideas in hypothetical settings.

How one uses models matters, too. The primary use for models like ours is to compare between alternative scenarios to see how the results change as aspects of the model are varied. This is intended to help us understand more about the key economic relationships.

Different models are suited for different purposes. A suitable rule is to exclude complications that are not central to the focus of the study. Given that the time pattern of research adoption and use is a crucial determinant of net benefits, and varies among different research projects, our model is multi-period. Because the emphasis of the present study is on regional research relationships, it was judged to be important to incorporate significant detail on those aspects. The consequence is that the model is rich in its spatial dimensions. For example, we have multiple markets for a given commodity (one defined for each country of interest). While the model is multi-market in this sense, we model only one commodity at a time. Furthermore, we do not model the vertical market structure, and transport costs among countries or subregions are largely ignored.

Some such simplifications are always made in economic models; the challenge is to make simplifications that are most appropriate for the purposes at hand. Even though we know that markets for different commodities do interact and that transport costs do exist and affect trade patterns, we believe that the abstractions made should not seriously distort the contrasts we intend to make using the model. In other words, the model is not meant to provide a fully accurate representation of reality in all its dimensions but, rather, realistic information about the economic relationships of most interest.

Key Elements of the Model

The model is designed for comparative static analysis (to compare and measure the differences between two alternative situations) rather than to predict or fully profile the future, which is a much more difficult and hazardous task. It represents an extension of *Dream*, which is a model that was designed to measure returns to commodity-oriented agricultural research in an open economy setting, allowing for price and technology spillover effects between a country in which the research originates and the rest of the world.[4]

4 Although our model shares a great deal in terms of the underlying principles and ideas with that of Davis, Oram, and Ryan (1987)—the first substantial model of research benefits with international price

Linear equations are used to represent supply and demand in each country, with market clearing enforced by a set of quantity and price identities (allowing for price wedges to represent price-distorting policies). The model does not include a spatial dimension as such—there are no transport costs and there is no spatial equilibrium mechanism—so it is most applicable as a model of a single country in interaction with the rest of the world, with the equilibrium price being defined at the border of the country of interest. It is a single-commodity model, so there is no explicit representation of cross-commodity substitution effects in production and consumption, although these aspects are of course represented implicitly by the elasticities of supply and demand for the commodity being modeled. Alston, Norton, and Pardey (1998) discuss extensions of this type of model "horizontally" to allow for multiple commodities and interactions among them, as well as the further extension to allow for interrelationships between supply and demand, through income-balance effects, which is what defines a general equilibrium model (it is not a computable general equilibrium model). Finally, the model represents a single production stage, without any "vertical" disaggregation to represent the multiple stages of production. In particular, the supply and demand and market equilibrium are defined in terms of border prices, which will differ from prices received by farmers (or paid by consumers) because of costs of transportation, transactions, product transformation, and so on, that are incurred within countries between the farm and the border. Even with all these simplifications, which make *Dream* tractable, significant effort is needed to parameterize and use the model to simulate market outcomes under various scenarios.

The primary parameterization of the supply and demand equations is based on a set of prices and yearly quantities in a defined "base" period, and a set of elasticities applying at the base. The idea is that the linear approximation implied by these elasticities will be good for small equilibrium displacements, such as those implied by single-digit percentage shifts of supply or demand, regardless of the true (nonlinear) functional forms of supply and demand. Small shifts have the added virtue that the cross-commodity and general equilibrium effects are likely to be small (and effectively represented within the partial equilibrium model), and that the *total* research benefits will not depend significantly on the particular elasticity values used (although the distribution of those benefits between producers and consumers and internationally will depend on the elasticities).

In the base period, the supply and demand curves were parameterized in a way that the solution to those equations replicates the market prices and quantities used to define the curves. The *Dream* model also allows for underlying growth of supply and demand to be built into the model, to project a stream of shifting supply and demand curves into the future that can be solved for a stream of equilibrium

and technology spillovers—*Dream* differs in many details. A computer program and implementation guidelines for the applications reported here can be downloaded free of charge from <http://www.ifpri.org/dream.htm>.

prices and quantities, in the "without research" scenario. These "without research" outcomes can be compared with "with research" outcomes, which are obtained by simulating a stream of displaced supply curves, incorporating research-induced supply shifts. The research-induced supply shifts are defined by combining an assumption about a maximum percentage research-induced supply shift under 100 percent adoption of the technology in the base year, with an adoption function that represents the pattern of adoption of the technology over time.

Finally, measures of producer and consumer surplus are computed and compared between the "with research" and "without research" scenarios, and these are discounted back to the base year to compute the present values of benefits. In a situation where we know the costs of the research responsible for the supply shift being modeled, we can compute a net present value or internal rate of return, but that is not done in this study—the work here is limited to computing the present value of benefits from 1-percent supply shifts of various sorts.

Dream is designed such that it is relatively easy to vary the parameters that define the size and time path of the research-induced supply shifts, the underlying growth rates, and the elasticities that define the slopes of the curves. Thus, it is straightforward to conduct sensitivity analysis and to explore the determinants of particular patterns of results.

In the present application, we have made two important innovations to the general *Dream* framework. Both of these innovations relate to the spatial or geographic dimension, since we are setting out to model a large geographic region within which space matters for trade because of transportation costs and other trade barriers. Specifically, although we do not have an explicit spatial model, we incorporate a spatial element by introducing price transmission elasticities with values less than one, which thus dampen the transmission of price signals among regions. It is a crude treatment, since we have only one transmission elasticity between each country and all others in the region, but it does have the effect of suppressing the cross-country and cross-region price and quantity responses to changes arising in a particular country.[5]

The second, and more important innovation in the present context, is that we have used information on AEZs to define the geopolitical spillovers of technologies. In some of our, more traditional, analysis reported below, we assume that spillover coefficients are less than 1 among countries but 1 among subregions within countries, where spillover coefficients (θ_{ij}) measure the potential research-induced supply shift (K_j) in country *j* as a fraction of the potential supply shift in the source country, country *i* (K_i). Thus, $K_j = \theta_{ij} K_i$, where $K_i = k_i PP_{i,0}$ and, hence, $K_{j,t} = K_j A_{j,t}$ where A_{jt} is the adoption rate in region *j* in year *t*.

5 The current version of *Dream* allows for the explicit inclusion of price wedges between each region and a "virtual" or "base" region, to reflect structural price differences (reflecting different transport and transaction costs, price policies, and the like). This capacity is not used in the present application.

In other analysis, we assume that the spillover coefficient is 1 within the same AEZ, both within and across countries, but zero across AEZs, both within and across countries. The magnitude of the shift is the same across countries within the AEZ, equal to *k* percent of the base-period price. A more complex treatment allows for the partial transfer of technologies between AEZs (within a country) and within AEZs (among countries). Although our representations are in some senses extreme, they do capture the important element that almost all previous studies have treated less well (either ignoring spillovers or representing them with arbitrary coefficients): the potential for technology spillovers geopolitically depends on agroecological similarities.[6]

Simulation Strategies

Technical change could have a multitude of impacts on LAC agriculture. The most significant changes could even occur outside the region. Thus, careful thought must be given to designing technology scenarios that generate information of relevance to likely real-world situations, while recognizing the partial nature of any modeling framework, and respecting the theoretical assumptions and restrictions under which the models were designed to operate. Our guiding principles were to make the analysis as spatially disaggregated as necessary, in terms of defining important markets and agroecological production regimes, but as homogeneous as possible across the simulation parameters so that we can more easily observe and interpret the economic effects attributable solely to technical change. Furthermore, recognizing the interests of potential users we have had to define scenarios that provide insights into the likely magnitude and distribution of R&D benefits from both national and regional perspectives.

Commodities and Base Period

The commodities to be included in the simulation study were selected from among the major crops (in terms of value of production) for which research is most often publicly funded (this excluded, for example, sugar, cotton, and coffee). In selecting the eight commodities; wheat, rice, maize, sorghum, potato, cassava, beans, and soybeans, consideration was also given to the availability of detailed production data. Subnational production data were used to generate plausible, commodity-specific estimates of the spatial distribution of production across the entire region (see Chapters 2, 3, and 4 in this volume). This was an important consideration because a key innovation in this study is the application of this spatially explicit production data to improve the estimation of the impacts of technical change on an agroecological basis. This analysis requires that production statistics reported on a

6 One exception is Davis, Oram, and Ryan (1987). Most studies have made no allowance for interstate or international spillovers of agricultural technology (Alston 2002). Some have assumed spillover coefficients based simply on proximity (for example, Huffman and Evenson 1993).

geopolitical basis be re-aggregated in an informed way into AEZs occurring within (and across) the borders of countries and subregions.

In ex ante agricultural research evaluations, it is common to define economic simulation scenarios running over a number of years (typically in the range of 20 to 30 years) starting from a specified base year. As described above, the idea is to compare simulated market outcomes under alternative research (or technology) scenarios in each of those 20 to 30 years. Most often, a base scenario is defined by projecting each year forward from the base year over the entire period. This simulation is then repeated over the same period assuming a specific intervention is implemented. The relative differences between the "with and without" intervention situation in each year, taken over the entire simulation period, provide the key metrics for assessing the potential economic attractiveness of the intervention.

The analyst must provide data that describe the initial market conditions (for example, prices and quantities produced and consumed) for the selected base year. But to minimize the possibility of selecting atypical base conditions (for instance, as a consequence of short-term climatic, pest, or disease related events), it is usual to construct a synthetic set of base-year data as an average of, say, three consecutive years.

In our case we defined values for the base year of 1994 as the average of the yearly values for the period 1993–95. This period was selected because it was the most recent for which IFPRI's subnational production database was essentially complete (recalling that the subnational data is an important ingredient in obtaining a reliable picture of the spatial allocation of production). We then selected a target simulation end date of 2020 to match the year used in parallel studies, such as IFPRI's global food perspective study (Rosegrant et al. 2001). These decisions fixed our simulation period at 27 years.

Geographic Units of Analysis and Technology Transfer Assumptions

Two major sets of technology simulations were formulated. The first is based on a national perspective within which new technologies are introduced on a country-by-country basis, and the second is based on a transnational perspective within which new technologies are targeted to specific AEZs that may be found in several countries.

For both country-specific and AEZ-specific simulations, two groups of "runs" (simulation exercises) were performed. In one group, we assumed that the effects of a technical change—or research-induced shift in the supply curve—in one country or AEZ on other countries or AEZs were mediated only through the price and quantity effects of commodity trade (Figure 7.4a represents a simple two-country or two-AEZ case where the exporter innovates; Figure 7.4b represents the case of an innovating importer). Simply put, we assumed that the new technology could not pass from the source country or AEZ to any other country or AEZ. These were

Figure 7.4a Size and distribution of research benefits for a traded good (exporter innovates, no technology spillovers, large country)

a. Country A production, consumption, and trade **b. Excess supply, demand, and trade** **c. Rest of the world (region B) production, consumption, and trade**

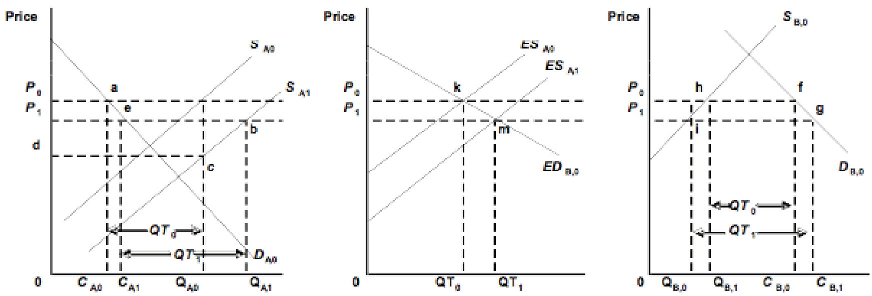
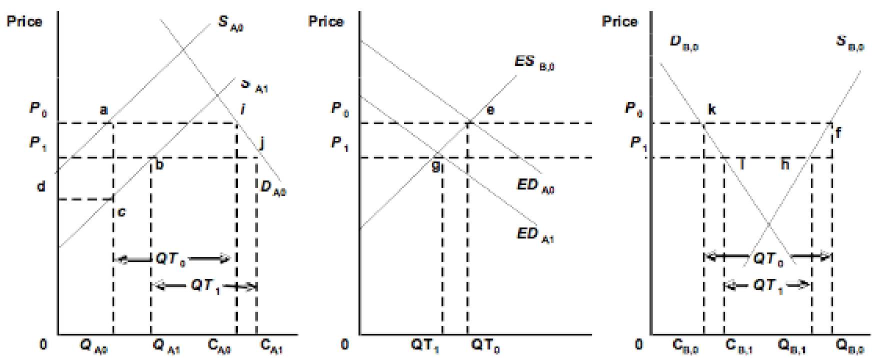


Figure 7.4b Size and distribution of research benefits for a traded good (importer innovates, no technology spillovers, large country)

a. Country A production, consumption, and trade **b. Excess supply, demand, and trade** **c. Rest of the world (region B) production, consumption, and trade**



called the "without technology spillover" simulation runs. Notice that the research-induced supply shift in the innovating country (that is, country A) causes the world price to fall from P_0 to P_1 in both cases. In Figure 7.4a, consumers in both countries and producers in country A gain, while rest-of-world producers lose. From the standpoint of the innovating country, consumer benefits (as measured by the change in consumer welfare) are given by the area P_0aeP_1 behind the demand curve ($D_{A,0}$), and the benefits to producers are given by the area P_1bcd behind the supply curve ($S_{A,1}$).

For the second group of runs we relaxed the technology spillover assumption and allowed the new technologies to be transferred from the source country or AEZ

Table 7.2 Overall structure of simulations

Model parameters	Value	Remarks
Simulation constants		
Base period		1993–95 average (synthetic "1994")
Simulation period		1994 to 2020 (27 years)
Real interest rate	3 percent per year	Used for the calculation of present values
Market conditions		
Initial price		Border price for principal LAC exporter country
Price transmission elasticity	0.8	To reflect imperfect transmission of price changes between markets
Supply		
Initial quantity	Country/zone specific	1994 domestic consumption
Price elasticity	1.0	For all commodities and countries
Exogenous growth		Set equal to projected demand growth for each country
Tax/subsidy	0	Not applied
Demand		
Initial quantity	Country/zone specific	Domestic production
Price elasticity	0.5	For all commodities and countries
Exogenous growth	Country/zone specific	Derived from projected population and income growth for each country
Tax/subsidy	0	Not applied
R&D parameters		
Probability of research success	100 percent	
Adoption profile		
Gestation lag		None
Ceiling level		100 percent after five years
Dis-adoption		None
Functional form		Sigmoidal from base year to year of maximum adoption, linear thereafter
Supply shifts		
Supply shift k	1.0 percent	Percentage of innovating country/zone producer price
Spillover shifts	0.5k	

Sources: Compiled by authors.

to any other. These were dubbed the "with technology spillover" runs. All runs were made for each of the eight commodities. Table 7.2 summarizes the overall structure of the simulations conducted for this study.

A technical change in a single country (or AEZ) may give rise to economic impacts on producers and consumers (a) within that country or AEZ; (b) more broadly within the subregion within which the country or AEZ is located (say the Andean subregion or the Caribbean); and (c) beyond the subregion, at the level of Latin America and the Caribbean. It is useful to aggregate the simulation results accordingly, to provide information relevant to institutional and investment decisions by

each distinct geographic scope of interest. Figure 3.3 maps the subregional grouping of the countries and AEZs we used for each set of simulations.[7]

Initial Market Conditions

As outlined above, the simulation requires a set of market data to be defined for a specified base year. This data set has several components:

- initial quantities produced and consumed;
- initial market prices (assumed to be equilibrium prices);
- price distortions, such as producer or consumer taxes or subsidies;
- the price elasticities of supply and demand;
- structural price differences and price transmission elasticities; and
- the autonomous (non–R&D related) growth in supply and demand.

Production and consumption. National production data were taken from FAO statistics in terms of both quantity and form—that is, "grain" for wheat, rice, maize, and sorghum; "tubers" for potatoes and cassava; and "beans" for dry beans and soybeans. Rice quantities were taken in polished white rice form. Domestic consumption data, expressed in the same quantity and form, were obtained from the FAO Food Balance Sheets (FAO 1999). For any country, in year *t*, current consumption is given by C_t, which satisfies

$$C_t = Q_t + (M_t - E_t) - (S_t - S_{t-1}),$$

where Q_t is domestic production, M_t is imports, E_t is exports, S_{t-1} is stocks carried forward from the previous year, and S_t is stocks at the end of the current year carried forward into the next. Base-period production and consumption were estimated as mean yearly values for the period 1993–95. For the zonal simulations, national production totals were distributed among the various AEZs, as described in the zonal simulation section below. Supplementary Table S7.2 shows the base period quantities for each commodity.

Market prices. All commodities were treated as tradable (this restriction is not imposed by the evaluation model; it was simply the baseline assumption). Under this assumption, the relevant prices are border prices. In the absence of observed border prices, we used implicit border prices (unit values) obtained from FAO trade volume and trade value data. For the baseline runs we estimated the implicit export (FOB) price of the region's largest exporter of each commodity and imposed this as the border price for each country. This approach had the convenience of using prices defined in nominal U.S. dollars for all countries.

In this representation, international (port-to-port) transaction costs are ignored. Perhaps more significant is the implicit assumption that border and producer prices

7 We also provide a discussion of the criteria used to define AEZs in Chapter 3.

are equivalent (even in the absence of price distortions). To the extent that there are significant costs of transportation, transactions, and transformation of products, such that FOB prices substantially exceed producer prices, the absolute value of the technology effect, \$*K*/tonne, will be overestimated when a given value of *k* percent (defined for a farm product) is applied to a price measured at the border. Supplementary Table S7.2 summarizes the base period prices for each commodity.

For the simulations reported in this study, we have ignored the effects of price distortions but have gathered country- and commodity-specific policy information that can be used in simulations to explore the effects of past, current, and potential future policy regimes (see Chapter 5).[8]

Price elasticities. The baseline scenario defines a supply elasticity of 1.0 for all commodities. This simplifies the initial cross-commodity comparison of R&D impacts and eliminates a possible problem of interpreting the supply shift.[9] Demand elasticities were set at a more inelastic value of 0.5, which is typical for food commodities in low- and middle-income countries. Supplementary Table S7.2 summarizes these parameterizations of supply and demand elasticities.

Structural price differences and price transmission elasticities. The evaluation model allows region-specific, base-year equilibrium prices to be represented—a feature we elected not to use in the baseline runs. We did, however, wish to reflect the role of transport and other transaction costs in dampening the transmission of price *changes* among regions, which we achieved through the application of a price transmission elasticity. The price transmission elasticity, w_i, is applied to the price changes arising within a shocked region when those changes are transmitted to other regions. To do this we assume

$$P_{i,t} = v_i + w_i P_t,$$

where $P_{i,t}$ is the price in region *i* in year *t*, v_i is the structural price wedge between region *i* and the global market equilibrium price P_t, and w_i is the price transmission elasticity between region *i* and all other regions. A coefficient of $w_i = 1.0$ would represent perfect, costless, free trade among regions, while a coefficient of 0 represents a closed economy (autarky) in which that region's market is independent of all others. For the baseline runs, we arbitrarily set the price transmission coefficient at 0.8. Accordingly, to assure equal prices among all regions, initially (that is, $P_{i,0} = P_0$), all of the v_i were set to equal $0.2P_0$.

8 The economic evaluation model allows the explicit definition of price distortions through tax or subsidy policies on either supply or demand, or both. Thus, for a given initial market equilibrium price P_0, we can define tax-equivalent price policies that allow equivalent producer prices, PP_0, and consumer prices, PC_0, to be calculated as (a) $PP_0 = P_0 - T^Q$, and (b) $PC_0 = P_0 + T^C$, where T^Q is a per unit producer tax and T^C is a per unit consumer tax (subsidies are negative taxes).

9 A horizontal (quantity-direction) supply shift can be converted to an equivalent vertical (price-direction) shift by dividing by the supply elasticity. That is $k = j / \varepsilon$, where *j* is the percentage shift in the quantity direction (for example, from a *j* percent increase in yield), and ε is the supply elasticity. As discussed by Alston, Norton, and Pardey (1998), unreasonably large *k* shifts may be implied by combining a *j* shift with a very small elasticity. Yield shifts translate into price direction shifts most naturally when the supply elasticity is one.

Autonomous supply and demand growth. The total benefits from a k percent technical change directly depend on the size of the industry affected, and this in turn will depend on the projected rate of demand growth over the simulation period. Demand increases were projected on a country basis using projected growth rates of population, n_t, as well as projections of growth in per capita consumption arising from income growth. National population growth rates and projections up to 2020 were obtained from the U.S. Bureau of Census (1995). Per capita consumption growth was estimated on the basis of growth rates in real income, proxied by current projections of the growth rate of GDP per capita, g_j, and the commodity-specific income elasticity of demand, μ_i. Thus, for commodity i in country j and year t.

$$\pi^C_{i,j,t} = n_{j,t} + g_j \mu_i,$$

where $\pi^C_{i,j,t}$ is the growth rate of demand for commodity i in country j in year t. To account for the distinction between food and feed markets, we first assume income elasticities of demand of 0.5 for food use and 1.0 for feed use of grains (see the Appendix to this chapter for details). Then we weighted these income elasticities in terms of the fraction of the consumption consumed as food (rather than feed), f_i. Thus, for commodity i

$$\mu_i = 1 - 0.5 f_i.$$

Supplementary Table S7.2 summarizes the derived income elasticities.

To allow the baseline simulations to be made in terms of constant prices over time it was assumed that the exogenous (non–R&D induced) growth in supply would keep pace with (be equal to) the growth rate in demand.

The Location of Production

Conducting simulations based on AEZs rather than geopolitical boundaries requires developing a zonal rather than geopolitical sense of the location of production. To do this we first developed a department-level production database for the whole of LAC, drawing on data obtained from numerous national and subnational statistical surveys. For some countries, like Guatemala, subnational production data could not be obtained, while for other countries, like Brazil, more detailed data were available at the county level (the level immediately below the state or department). For each of the eight crops included in our simulations, the departmental (or state-level) database is essentially complete for the 20 year period 1975–95. Much effort was spent on checking these data, their re-aggregation, interpolation, and extrapolation using routines especially developed for the purpose. All subnational production data were calibrated to correspond with the published FAO national totals.

A mathematical programming approach—coupled with geographic information systems (GIS) data and biophysical suitability criteria—was used to allocate areas of production, based on data organized by geopolitical units within subnational production areas (You and Wood 2004). For instance, suppose a department (state) produces 10,000 hectares of maize, 8,000 hectares of soybeans, and 4,000 hectares of potatoes: the different crops are allocated to particular locations within the de-

partment, depending on their agroecological comparative advantages (delineated in units of 25 square kilometers that correspond to our mapping pixels), such that the total area of 22,000 hectares and the total area for each crop are preserved.

Our crop-specific allocation procedure used satellite data interpretations of the location and of spatial intensity agriculture, maps of the spatial variation in the biophysical production potential of each crop, and any other existing data on the spatial distribution of crops and pasture, cropping intensities, and crop prices. This produced crop-specific production maps for the base period (1993–95). Overlaying country boundaries, agroecological zones, and crop distribution maps using a GIS made it possible to derive harvested area and production shares for each commodity by AEZ and country (see Table 3.7 and Appendix Table 7A.1).

Significant shares of the harvested areas of the eight crops in this study are found in just four AEZs. About 32 percent of the region's harvested area for cassava occurs in AEZ 43, as does 31 percent of the rice area, and 19 percent of the harvested area under sorghum. AEZ 31 accounts for 29 percent of the maize area, 40 percent of the soybean area, and 60 percent of the harvested wheat area. About 46 percent of the harvested area for potatoes falls in the moderately cool to cool tropics (AEZ 21), while 27 percent of the harvested area for beans lies in the flat, semiarid, tropics (AEZ 45). An indication of the concentration of crops according to their agroecological extent is the share of total harvested area that lies within the two most important AEZs for each crop. We estimate that 37 percent of the sorghum area lies within two zones, along with 43 percent of the bean area, and 48 percent of the maize area (Appendix Table 7A.1). The region's potato and wheat areas have exceptionally limited agroecological extents, with 75 percent of the potato area and 88 percent of the wheat area being found in just two AEZs.

For most commodities, the zonal pattern of harvested area corresponds closely to the pattern of production, although there are two exceptions. The most extensive cultivation of beans occurs in AEZ 45, containing some 27 percent of the harvested area and 19 percent of LAC production, yet the largest production share occurs in AEZ 31, which accounts for 20 percent of the bean production and only 14 percent of the harvested area. Figure 7.6 shows that AEZ 45 is primarily found in northeastern Brazil, where poor people working land with limited agricultural potential predominate and where beans are a staple food, whereas AEZ 31 includes the major commercial bean- producing areas of Argentina, output from which is primarily exported. For rice, AEZ 43 accounts for the dominant share of harvested area—some 31 percent of the region's total rice area—but only 17 percent of the production, while the 22 percent of harvested area in AEZ 30 provides 34 percent of production. This disparity here primarily reflects the differences between the extensive rainfed cultivation of rice in the Cerrados region (AEZ 43) and the irrigated production systems prevailing in southern Brazil (AEZ 30).

Representation of Research Effects

Technological change was represented by a *k*-percent downward displacement of the supply curve (referred to as *K,* and defined more precisely as the net reduction in the average and marginal costs of producing one unit of output as a consequence of adopting a new technology). *K* is an absolute amount, obtained as the product of the proportional reduction in cost per unit of output, *k*, and the initial producer price, $PP_{0,}$ that is, $K = k\,PP_0$ (if there are no producer taxes or subsidies and we ignore transaction costs, then PP_0 is the same as the initial market equilibrium price, P_0). We describe the estimation of the initial equilibrium price in the next main section.

To facilitate comparisons among scenarios, we apply an equal, one-time supply curve shift of 1 percent in each case (that is, *k* equals 1 percent). The value of 1 percent is small enough, over the ranges of induced changes in prices and quantities, to enable our use of linear approximations to represent the supply and demand equations without significant error. Furthermore, the use of *k* equal to 1 percent allows us to interpret the measures of research impacts, expressed in terms of proportional change, as elasticities; that is, a 1-percent supply curve shift induces a ϕ percent change in total revenue or producer surplus. Thereafter, these "elasticities" can be used to calculate the impacts of different rates of supply curve shifts by multiplying the elasticity by the different values of *k*.

The potential of a new technology to reduce unit production costs is realized through its adoption in farmers' fields, and the simulation model provides a stylized means of specifying the functional form, maximum rate of adoption, and time lag (time to attain maximum adoption rate) associated with technology adoption. For the baseline simulations we set all these parameters to be the same for each country or AEZ, and for each commodity. We selected a sigmoidal functional form for the uptake phase of the diffusion process—that is, a 100-percent maximum adoption rate (such that the 1-percent potential cost reduction from the new technology translated into a 1-percent shift in the aggregate supply curve) and a five-year lag from the release of the technology to its full adoption (which once attained is assumed to be maintained for the remaining period of the simulation).

AEZ–specific changes in technology. One group of simulations involves the research-induced displacement of country-specific supply curves, with and without spillovers—a more conventional modeling approach. Our more novel AEZ–specific simulations are designed to reflect the reality that farmers' output and technology choices are conditioned, among other things, by the agroecological context in which production takes place. Here, we model technological changes within AEZs, regardless of geopolitical boundaries. Instead of modeling supply shifts on a countrywide basis, they are defined for specific AEZs. Nevertheless, in implementing AEZ–specific technological changes, we retain countries as the unit of analysis. A 1-percent unit cost reduction, *k*, in a particular AEZ is modeled as a simultaneous displacement in each country in proportion to the share of its national production derived from the innovating AEZ—a vector of *c* country-specific supply shifts:

$$\boldsymbol{k}_z = [\,k_{z1}, k_{z2}, k_{z3}, \ldots, k_{zc}\,],$$

where k_{zi} are the country-specific supply shifts resulting from a 1-percent supply shift in AEZ *z*, and

$k_{zi} = Q_{zi} / Q_i$,

where Q_{zi} is the production in AEZ *z* of country *i*, and Q_i is the total production in country *i*.

One limitation of this approach is that the *net* producer benefits estimated at a the national level reflect not only the gains made by producers in the innovating AEZ but also the losses incurred by producers in other AEZs in the country. Since their production costs remain unchanged, producers in non-innovating AEZs are disadvantaged if they face lower market prices as a result of an expansion in production in the innovating AEZ. Because our baseline simulations include the rest of the world, the changes in technology simulated for LAC have relatively small impacts on world prices, so the losses to producers in non-innovating AEZs, in reality, are likely to be small. The benefits to innovating producers (within the innovating AEZ) within a country are equal to the national producer benefits plus the losses incurred by non-innovating producers within the country.

Evaluation Results

In this section we present results from various simulations, designed to represent alternative approaches for incorporating information about research spillovers into our regional commodity supply and demand model. We simulate prices and quantities and present values of economic surpluses (the benefits to producers, consumers, and in total) for each country and for the regional and subregional aggregates, for each scenario of interest. The focus of the analysis is the economic surplus effects of country-specific and AEZ-specific research-induced supply shifts—in particular, the distribution of those effects between producers and consumers and among countries.

First, we develop a set of baseline estimates of the effects of exogenous shifts in demand and supply on equilibrium prices and quantities, absent technical change. In all of our base scenarios we assume that both supply and demand are growing at the same rate in each country but at different rates among countries.

All of the simulation experiments are conducted in terms of research-induced supply shifts from the baseline; so we measure and report changes in prices, quantities, gross values of production, and economic surpluses accruing to various groups of producers and consumers *all expressed relative to this base*. The first type of new technology scenario simulated is one in which a single country experiences a 1-percent improvement in technology such that, after an adoption process is completed, supply shifts down by an amount per unit equal to 1 percent of the prevailing price in the base year. We conducted this type of simulation in each country for each of our eight commodities. The results show the effects in an innovating country that is the "source" of a new technology, as well as in other countries when the innovating

country adopts improved technology and the other countries do not. In this case, the only cross-country effects are through price spillovers, and such effects arise only when the innovating country is a large trader in the commodity of interest and, hence, able to influence world prices by changing the quantity it produces and consumes.

In the second type of scenario, a modification of the first, we allow for partial technological spillovers among countries for the range of commodities and countries considered in the first set of simulations. In this case, when the source country experiences a supply shift by an amount per unit, K (equal to 1 percent of the base price), all other countries experience a supply shift of half that amount per unit (that is, $\frac{1}{2}K$).[10]

In this type of scenario, even when the source country is not a large trader, price effects will rise for commodities for which the LAC region as a whole is significant in the world market. Hence, in this scenario, we have both price and technology spillovers such that the total global effects of the technology will be much greater in many cases, but the distribution of those benefits will also be quite different from the distribution in the absence of technology spillovers. Sometimes technology spillovers make the source country better off; sometimes the source country would prefer not to allow other countries to adopt its research results.[11]

Both of these scenarios emphasize the geopolitical boundaries as important in terms of defining the interest groups and the technological spillover potential. More realistically, however, spillover potential is defined by agroecological boundaries more than geopolitical ones. In the next set of scenarios we use information on AEZs to take into account the agroecological determinants of the potential for spillovers among geopolitical regions. In presenting and discussing the results from these simulations, however, we retain the geopolitical focus, because that remains the primary basis on which decisions are made about the types of technology to create. To do this, we assume that technology developed in one country as applying in a particular AEZ within that country, is equally applicable within the same AEZ in other countries. Hence, the spillover coefficient from one country to the next depends on the extent to which the relevant agroecology is shared between the two countries.

In practice, a 1-percent supply shift experienced in a particular agroecology is translated into a k-percent supply shift in a particular country (including the source country), where k is the fraction of that country's total production that is sourced from the agroecology in question. Since we have assumed supply elasticities equal

10 The choice of spillover coefficients at this stage is clearly arbitrary and illustrative. Information on spillover potential, obtained, say, from consultation with agronomists and others, could be used to define more empirically meaningful spillover coefficients. Such measures would be expected to vary depending on the type of technology being considered. They should also depend on agroecological factors, which are explored below.

11 If, however, a small country were interested in reducing consumer prices for a traded good, it would pay to promote the adoption of a local innovation by large-country producers in order to reduce world prices.

one, it is straightforward (a) to convert a given percentage supply shift in the price direction in an AEZ of interest into an equal percentage quantity direction shift, (b) to add that up across AEZs within a country, and then (c) to convert the output-share weighted average of shifts (0 and 1 percent times respective shares 1-*k* and *k*) into a *k* percent shift in the price direction (where *k* is the share of output from the zone experiencing the 1-percent shift), applicable to the national supply function. With non-unitary supply elasticities, more care must be taken to assure a correct translation of a vertical supply shift, applicable within an AEZ, into an equivalent set of country-specific vertical supply shifts.

The use of AEZ–specific supply shifts means that, within a country, some producers benefit (those in the innovating zone) and others (those outside the zone) do not; and, where prices are affected, the non-adopters of the technology will be losers. The measures of country-specific benefits to producers from the AEZ–specific technological change are net measures, equal to the benefits to the beneficiaries minus the losses to the other producers.

Baseline Estimates

The basic data used to define the baseline simulations were reported in Supplementary Table S7.2. The table includes the base quantities produced and consumed, and prices for each of the commodities in each of the producing counties, organized by the subregions to which they belong. The table also includes the price elasticities of supply and demand (always 1.0 and 0.5, respectively, for now), food/feed shares, and parameters defining the underlying growth rate of demand.

Table 7.3 provides beginning-period and simulated end-period estimates of the quantities produced and consumed and the prices for each commodity in the absence of research-induced supply shifts. Here, the baseline changes in quantities and prices over time are attributable entirely to the underlying growth of supply and demand for each commodity for each country and region of the world. It can be seen that, over the period 1994–2020, most of the prices did not change appreciably, reflecting the assumptions of equal growth rates of supply and demand, country by country. The notable exception is soybeans, a reflection of the relatively large fraction of soybeans traded, leading to some inequality in the growth rates of global supply and global demand arising from county-to-country differences in internal growth rates. The table shows substantial growth in production and consumption for each of the commodities both in LAC and globally typically around 60–80 percent over the period with consumption tending to grow faster than production for LAC.

One-Percent, Regionwide Commodity-Specific Shifts

Appendix Table 7A.2 shows the total benefits from 1-percent supply shifts in each of our eight commodities, in turn, throughout the LAC region. This can be thought of as representing a case where any country in the region develops a technology,

Table 7.3 Changes in baseline prices and quantities in the absence of technical change

Year	Region	Beans	Cassava	Maize	Potatoes	Rice	Sorghum	Soybeans	Wheat
Price					*(U.S. dollars per ton)*				
1994		646.19	180.70	113.38	158.83	336.30	92.56	230.35	135.37
2020		642.96	180.73	111.62	158.83	336.33	90.47	221.29	134.98
Production					*(1,000 tons)*				
1994	LAC	5,079	30,272	69,736	13,150	19,058	8,473	37,867	18,381
	ROW	11,424	131,728	455,264	269,850	517,942	52,765	85,133	532,023
	World	16,503	162,000	525,000	283,000	537,000	61,239	123,000	550,404
2020	LAC	8,222	56,133	130,893	23,644	32,253	15,357	71,138	30,820
	ROW	13,252	203,148	810,599	419,654	787,822	88,137	153,138	827,232
	World	21,475	259,281	941,493	443,299	820,075	103,494	224,276	858,052
Consumption					*(1,000 tons)*				
1994	LAC	5,141	30,189	71,069	13,670	21,150	11,389	33,077	27,894
	ROW	11,363	131,811	453,931	269,330	515,849	49,850	89,923	522,509
	World	16,503	162,000	525,000	283,000	537,000	61,239	123,000	550,404
2020	LAC	8,338	55,949	136,477	24,461	35,802	20,293	64,204	47,710
	ROW	13,137	203,332	804,958	418,838	784,273	83,183	159,958	810,334
	World	21,475	259,281	941,434	443,299	820,075	103,476	224,162	858,044

Sources: Calculated by authors.

and it is adopted simultaneously, with equal effect, in every other country—a 100 percent spillover. The upper block (denominated in present value terms for the period 1994– 2020) refers to the benefits in thousands of U.S. dollars, while the lower block refers to the distribution of the total. For instance, the first row shows that a 1-percent supply shift for beans would generate $715 million in benefits to LAC. Of this total, $443 million (62 percent) would go to the Southern Cone, $212 million (30 percent) to Mesoamerica, and smaller benefits to the Andean and Caribbean subregions. If every country experienced a 1-percent yield improvement in all eight crops, the total benefit to LAC would be worth $8,488 million, of which 73 percent would go to the Southern Cone, 13 percent to Mesoamerica, 12 percent to the Andean subregion, and 2 percent to the Caribbean.

Comparison of Total Benefits Among Crops

Comparing among commodities, the different total benefit measures essentially reflect the different sizes of the bases to which the 1-percent shift was applied. Hence, soybeans show a benefit of $1,989 million, followed by maize ($1,859 million), then rice ($1,428 million), and so on. Along with the variation in total benefits, the shares of benefits among subregions differ among crops. The Southern Cone gains 95 percent of the benefits from soybean yield increases; it also dominates the picture in general, and for almost every crop (Appendix Table 7A.2). The two exceptions are the lower valued crops for the region as a whole: the Mesoamerican subregion gains 52 percent of the benefits from sorghum yield increases, and the Andean subregion gains 46 percent of the benefits from potato yield improvements.

In Table 7.4, the same information as in Appendix Table 7A.2 is presented in a different order, so as to show the ranking within each subregion of the different commodity-specific supply shifts in terms of the size of the regional benefits. Hence, for LAC as a whole, the ranking is soybeans, maize, rice, cassava, beans, wheat, potatoes, and sorghum. But the ranking is different among the different subregions of LAC, with the exception of the Southern Cone, which dominates the region and follows the same commodity order as LAC, apart from transposing rice and cassava. In addition, Table 7.4 shows the percentage LAC–wide supply shift required to achieve the same benefits within a subregion as given by a 1-percent shift for the region's top-ranked commodity. For instance, a 2.8 percent supply shift in beans would generate the same benefit as a 1-percent supply shift in soybeans $1,989 million for LAC as a whole.

Distribution of Benefits between Producers and Consumers

The middle panel of Appendix Table 7A.2 shows the fractions of total LAC benefits accruing to LAC producers for each type of LAC–wide commodity-specific supply shift, within each subregion of LAC. For LAC as a whole, the producer share of benefits ranges from 77 percent (beans) to 97 percent (potatoes, rice, and wheat); the corresponding consumer shares range from 23 to 3 percent (that is, 100 minus the

Table 7.4 Ranking and supply-shift relativities: 1-percent, regionwide, commodity-specific shifts

	Caribbean			Southern Cone			Mesoamerica			Andean subregion			LAC		
Rank	01 Crop	SSR[a]	Benefit	02 Crop	SSR[a]	Benefit	03 Crop	SSR[a]	Benefit	04 Crop	SSR[a]	Benefit	05 Crop	SSR[a]	Benefit
		(1,000 U.S. dollars)			*(1,000 U.S. dollars)*			*(1,000 U.S. dollars)*			*(1,000 U.S. dollars)*			*(1,000 U.S. dollars)*	
1	Rice	1.0	70,870	Soybeans	1.0	1,880,270	Maize	1.0	518,498	Rice	1.0	387,860	Soybeans	1.0	1,989,380
2	Cassava	2.3	31,096	Maize	1.5	1,213,463	Beans	2.4	212,474	Potatoes	1.7	222,374	Maize	1.1	1,859,466
3	Beans	4.3	16,565	Cassava	1.7	1,104,749	Wheat	4.7	109,570	Cassava	3.1	126,741	Rice	1.4	1,427,932
4	Potatoes	6.0	11,856	Rice	2.1	883,151	Sorghum	5.4	96,528	Maize	3.4	115,648	Cassava	1.6	1,272,900
5	Maize	7.4	9,585	Beans	4.2	443,362	Rice	6.0	86,052	Soybeans	7.4	52,182	Beans	2.8	714,568
6	Sorghum	31.4	2,259	Wheat	4.3	432,791	Potatoes	9.5	54,719	Beans	9.2	42,168	Wheat	3.6	557,517
7	Soybeans	32.1	2,209	Potatoes	9.4	200,793	Soybeans	10.9	47,467	Sorghum	14.7	26,403	Potatoes	4.1	480,219
8	Wheat	56.9	1,246	Sorghum	30.5	61,677	Cassava	50.3	10,314	Wheat	27.9	13,909	Sorghum	10.6	186,867

Sources: Calculated by authors.

[a]SSR indicates supply shift relativities.

producer share). This outcome, where producers get most of the benefits, reflects the fact that the market equilibrium response to the research-induced supply shift is mostly to adjust quantities produced and consumed, with comparatively small changes in prices; for these commodities, the LAC region as a whole is not so large in trade as to have much influence on world prices. This is captured in the model through small LAC shares of world production and consumption, combined with modest underlying demand elasticities and nearly complete price transmission, which means that LAC as a whole faces relatively elastic demand for its exports (or supply of imports) from the rest of the world. The differences in producer shares of benefits among the commodities reflect different shares of world production and consumption. The very high share for potatoes, for example, comes from a very low LAC share of global production, such that LAC faces a very elastic export demand. In contrast, soybeans has the lowest producer share because, compared with the other eight crops, LAC is relatively important in global production of soybeans.

Within Subregions

In this instance, the benefit to an individual country is essentially proportional to the size of the industry of interest within that country. Consumers in every country benefit from the same price change, which is then applied to the total quantity consumed. Similarly, producers in every country benefit by the same amount per unit (the per unit cost saving minus the price change), which is then applied to the total quantity produced in the country. By the same argument, the benefits to individual producers (or consumers) are proportional to production (or consumption) and are similar across countries for similar-sized producers (or consumers). This outcome changes when we introduce trade barriers or transaction costs, which means that consumer (or producer) price changes are not the same in every country; the outcome will also change when we have country-specific (or AEZ–specific) supply shifts with incomplete spillovers among countries (or AEZs).

Spillovers to the Rest of the World

Suppose we had a technology developed in LAC (or in a country in LAC) that was adopted everywhere in LAC (that is, with 100 percent technology spillovers among countries within LAC) and partially adopted in the rest-of-the-world (ROW). To measure the effects of a 50 percent technology spillover to ROW, we repeated the same experiments as above (that is, commodity-by-commodity, 1-percent supply shifts throughout LAC) but with a 0.5 percent supply shift in ROW. The results are summarized in Table 7.5. It can be seen that the benefits to ROW are quite substantial and much greater than the benefits within LAC in some cases (for example, rice and wheat), such that the global benefits are much greater with the technology spillover. Interestingly, the technology spillovers to ROW do not have much influence over the total benefits to LAC or to particular regions within LAC from the given supply shifts in LAC. In contrast, however, the technology spillovers to ROW have a

Table 7.5 Total and producer benefits: 1-percent, regionwide, commodity-specific shifts with rest- of-the-world spillovers

	Latin America and Caribbean							
	Southern cone	Mesoamerica	Andean subregion	Caribbean	Total	United States	Rest of the world	LAC share of world
				(1,000 U.S. dollars)				*(percent)*
Total benefits								
Beans	438,952	214,826	44,360	17,734	715,872	65,689	598,951	0.52
Cassava	1,102,535	9,354	127,506	30,560	1,269,955	5,136	2,501,725	0.34
Maize	1,179,160	532,845	138,740	21,682	1,872,427	2,462,665	3,350,005	0.24
Potatoes	201,872	49,129	223,018	10,734	484,753	339,115	4,183,481	0.10
Rice	875,566	101,637	400,181	97,190	1,474,574	206,206	17,941,961	0.08
Sorghum	57,751	116,950	26,403	2,288	203,392	133,177	378,441	0.28
Soybeans	1,782,189	86,294	54,480	4,625	1,927,588	1,107,687	1,232,127	0.45
Wheat	445,595	131,418	54,658	18,595	650,265	620,292	6,887,456	0.08
All	6,083,621	1,242,453	1,069,346	203,407	8,598,826	4,939,967	37,074,147	
Producer share of total benefits			*(percent)*					
Beans	0.56	0.54	0.49	0.48	0.55			
Cassava	0.60	0.69	0.59	0.61	0.60			
Maize	0.64	0.60	0.48	0.25	0.61			
Potatoes	0.65	0.62	0.65	0.57	0.64			
Rice	0.66	0.55	0.63	0.46	0.63			
Sorghum	0.67	0.47	0.62	0.61	0.55			
Soybeans	0.55	0.15	0.46	0.00	0.53			
Wheat	0.63	0.54	0.13	–	0.55			
All	0.61	0.54	0.57	0.42	0.59			

Sources: Calculated by authors.

big influence over the distribution of the given benefits to LAC (or particular regions of LAC): the producer share of benefits to LAC is much reduced, ranging from 53 to 64 percent compared with 77 to 97 percent in the absence of spillovers. This happens because the spillovers to ROW give rise to big changes in world prices, and, from LAC's point of view, the main effect is to change the distribution of welfare between producers and consumers, with a net effect that is positive for an importer or negative for an exporter.

One-Percent Country-Specific Shifts

We conducted experiments to assess the consequences of research-induced technical changes, such as yield improvements, which we represented as 1-percent supply shifts, country-by-country, commodity-by-commodity. With 8 commodities and 21 countries, this would mean 168 experiments, except that some commodities are not produced in every country; nevertheless, the number of experiments totaled 151. We then repeated each experiment, allowing for a 50 percent spillover of the same supply shift into every other country. The full set of results is reported in the Supplementary Table S7.3, in terms of benefits to producers and consumers in each country, and then summarized across countries into regions, LAC as a whole, and the world, experiment by experiment. Here we will discuss some illustrative examples.

Country-Specific Supply Shifts without Technology Spillovers

A primary point to note is that, in most cases, the individual countries do not produce enough of the commodity in question to be able to appreciably affect the world price for the commodity. Hence, for country-specific supply shifts with no technology spillovers, the total research benefit is approximately equal to 1 percent of the value of production in the innovating country (compounded over time according to the adoption path and the discount factor), and all benefits accrue to producers within the country. This would be the way to read most of the entries in Supplementary Table S7.3, which shows the total benefits, country-by-country, commodity-by-commodity of 1-percent supply shifts without technology spillovers. The corresponding information has been summarized in Figure 7.5. Figure 7.5a shows the benefits to producers and consumers, and total benefits to the innovating country, commodity by commodity; Figure 7.5b shows the corresponding benefits for the LAC region that contains the innovating country, and Figure 7.5c shows the corresponding benefits for LAC as a whole. The different spatial aggregates are considered because different decisionmakers and different types of decisions require information on the effects of a given technological change on the country, the region, or LAC as a whole.

The upper section of Figure 7.5 shows, country-by-country, the benefits to the innovating country from a 1-percent shift of the supply of beans. The corresponding sections of Figures 7.5b and 7.5c show the benefits to the subregion in which

Figure 7.5 Total, producer, and consumer benefits: 1-percent, country- and commodity-specific shifts without spillover

a. Benefits to the innovating country

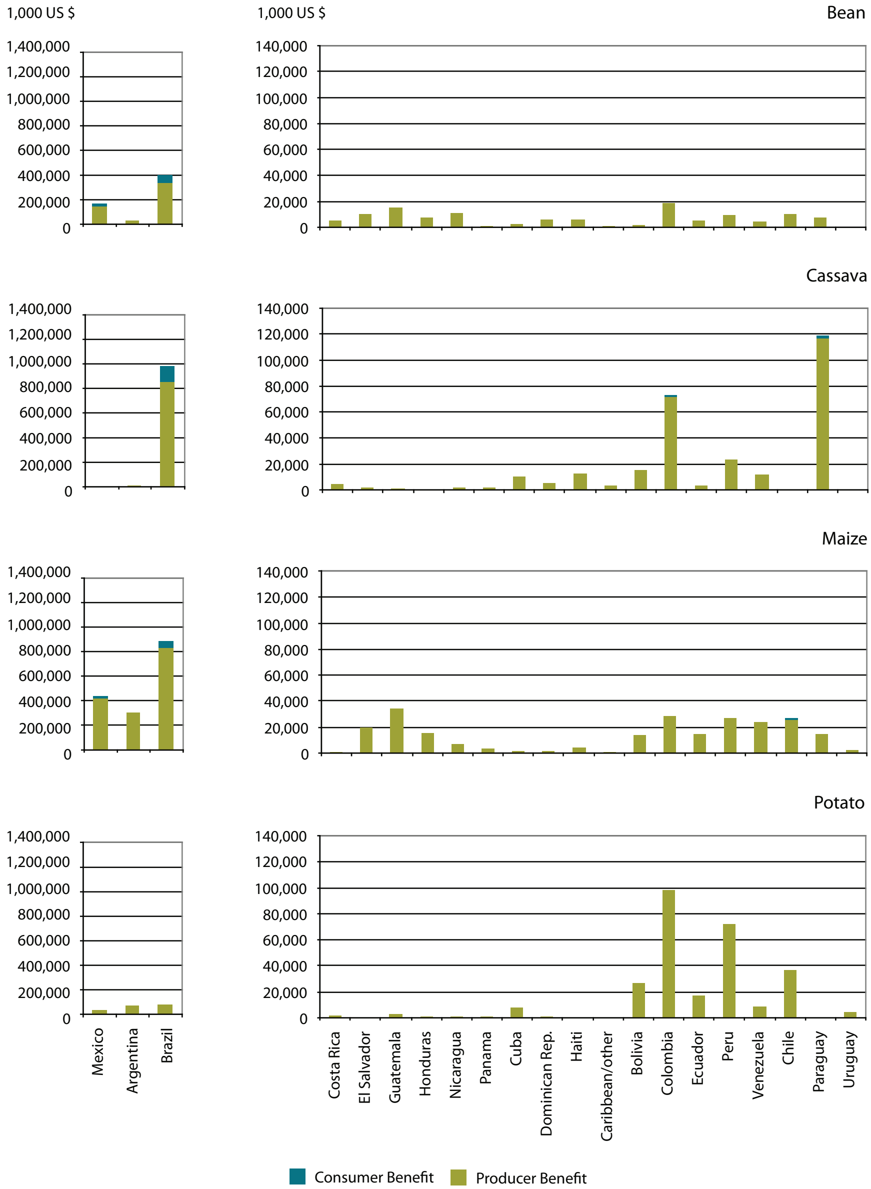


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Figure 7.5 (continued)

a. (continued)

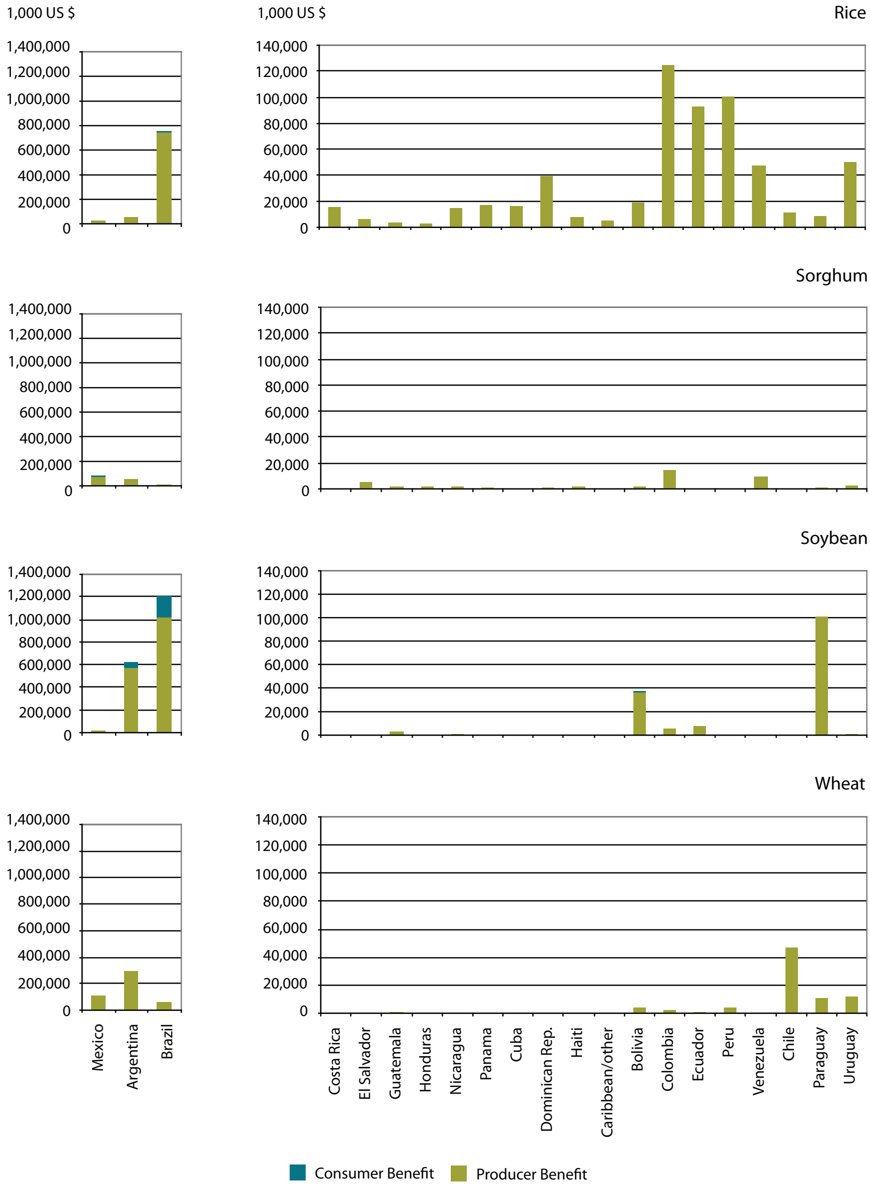

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Figure 7.5 (continued)

b. Benefits to the subregion where the innovating country is located

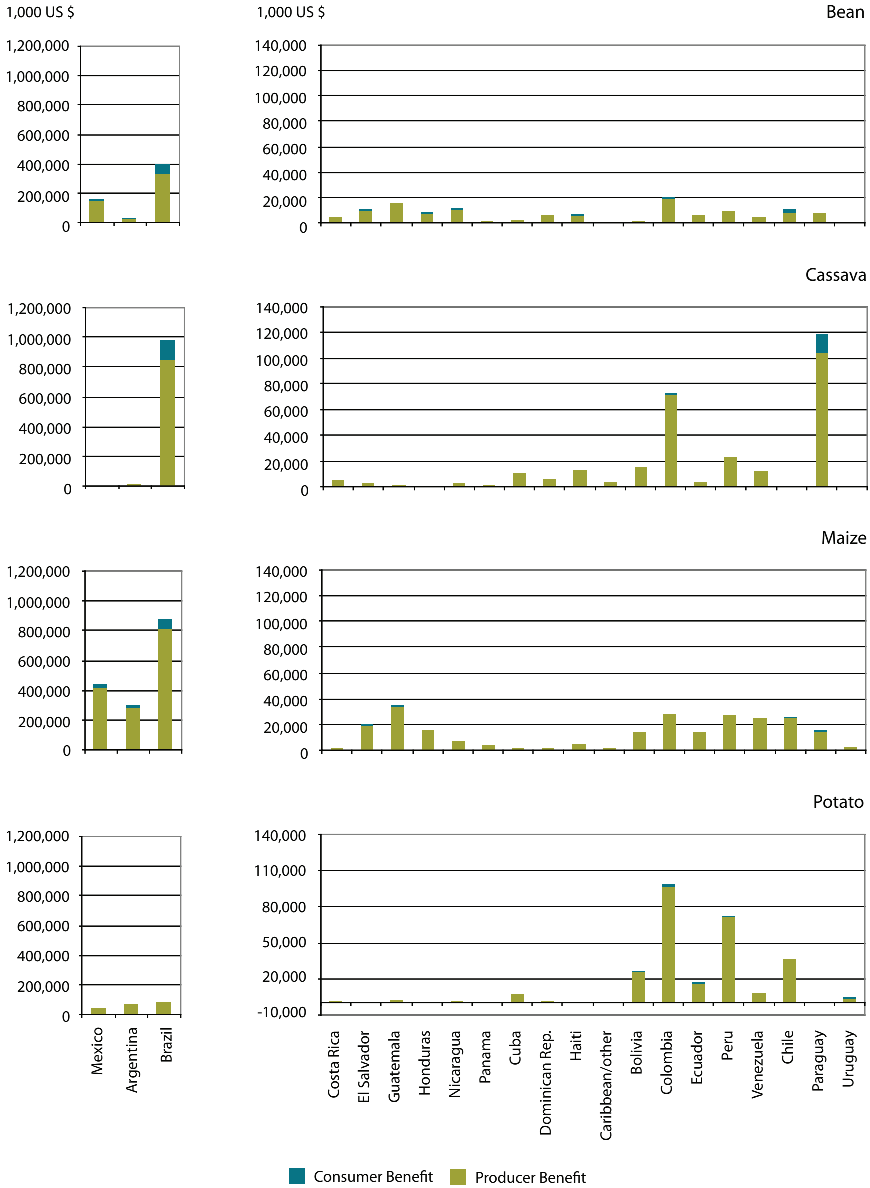

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Figure 7.5 (continued)

b. (continued)

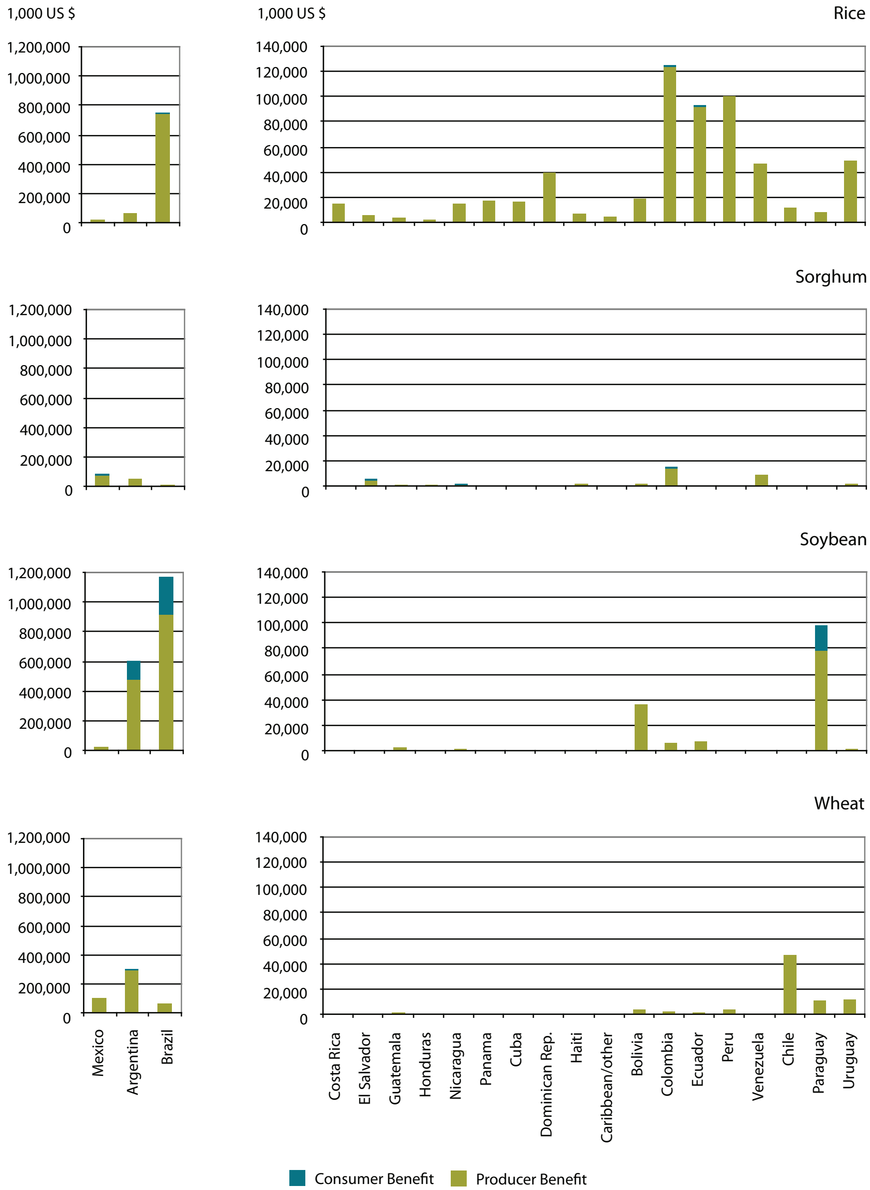

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Figure 7.5 (continued)

c. Benefits to Latin America and the Caribbean as a whole

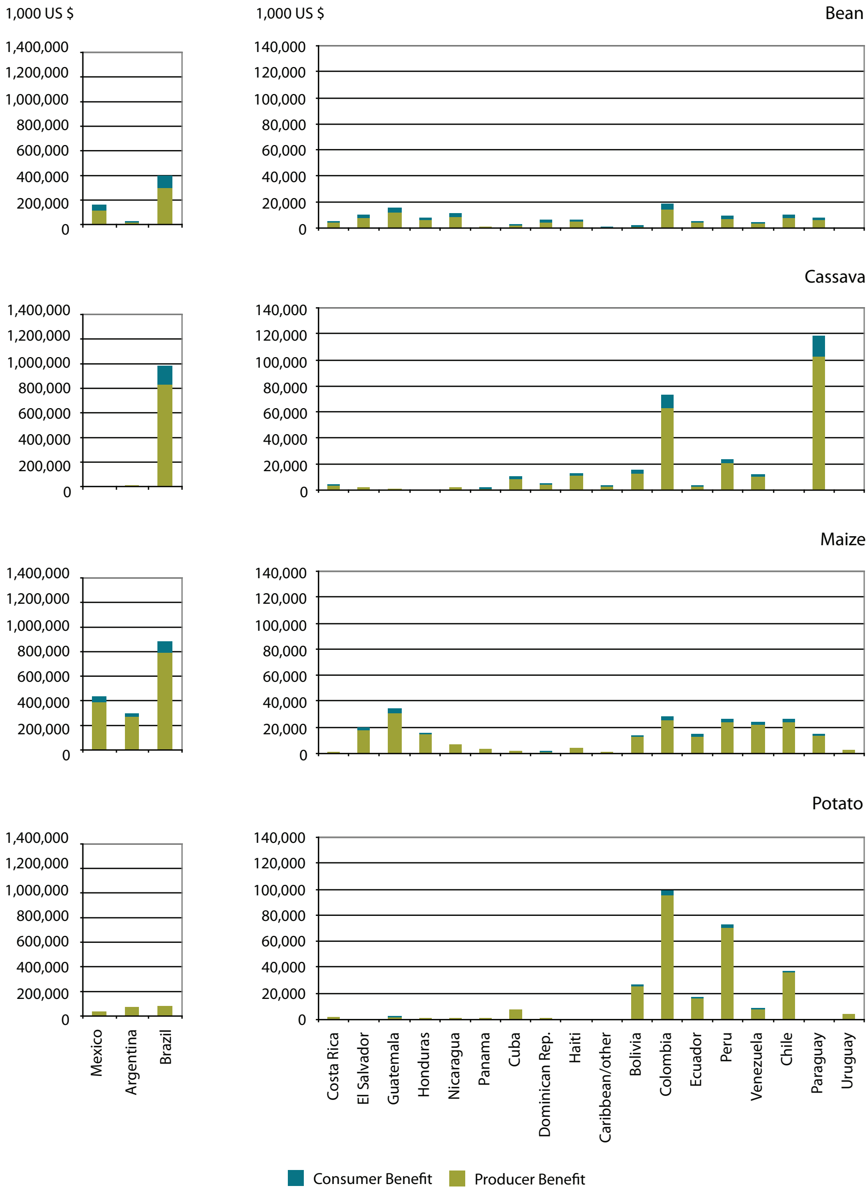

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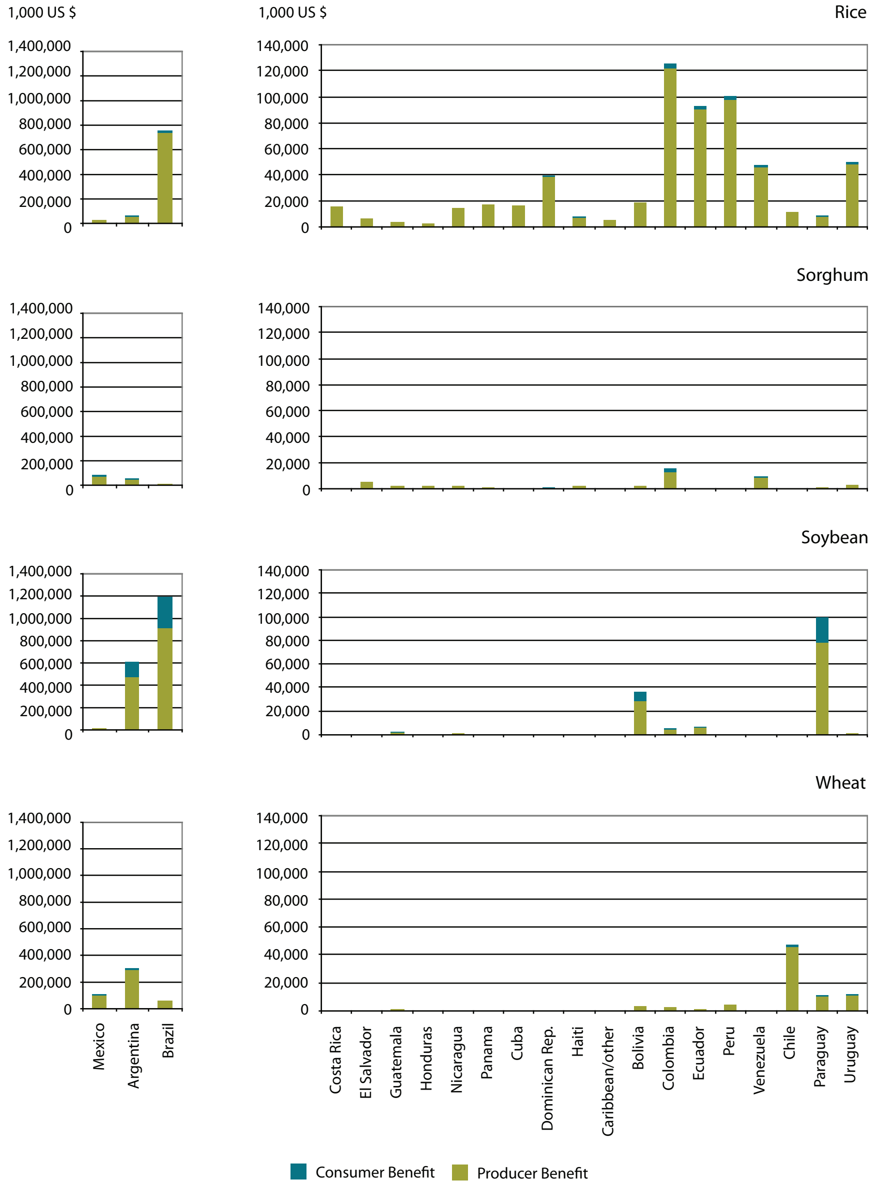
Figure 7.5 (continued)

c. (continued)



the innovating country is found and to LAC as a whole, respectively. Consider the case of innovations by Brazil. Figure 7.5a shows that most of the $403 million in benefits to Brazil accrue to producers ($339 million) with a much smaller share to consumers ($64 million). Figure 7.5b shows that, for the Southern Cone, in which Brazil is found, essentially the same figures as for Brazil apply for regional total benefits, except that the consumer share has risen; and the same again occurs as we move to LAC as a whole.

As we go to larger spatial aggregates, we increase the number of consumer beneficiaries from the lower price, but we also add non-innovating producers who lose from the same lower price and whose losses roughly balance the gains to the additional consumer beneficiaries. A similar pattern can be seen when Mexico is the innovator, except that the consumer shares of benefits are smaller because Mexico is a smaller producer of beans and thus has less influence on the world price. In every other innovating country (that is, except Brazil and Mexico), essentially all of the own-country benefits from bean yield improvements accrue to producers (because, as noted above, there are no appreciable price effects), but there are some cross-country benefits to consumers (offset in terms of national net benefits by losses to producers).

For most of the other seven commodities, the story is simpler because the price and consumer welfare effects of country-specific yield improvements are relatively minor. The main exceptions are soybeans in Argentina; maize in Mexico; and cassava, maize, rice, and soybeans in Brazil. And, in general, it can be seen that the subregional and total LAC effects are essentially the same as the total effect in the innovating country. Hence, the main effect of going to larger aggregates is to change the distributional story for a given supply shift within the aggregate.

The other key feature of the results shown in Supplementary Table S7.3 and Figure 7.5 is that the subregional and LAC impacts of the country-specific supply shifts in terms of both the total welfare gains and the distribution of those gains are driven primarily by the size of the industry in the innovating country as a share of the regional, LAC–wide, and global industry. Hence, benefits arising from innovations in Argentina, Brazil, and Mexico have to be measured on a different scale than those for the other countries, and it is only innovations in those countries that can have appreciable effects on prices and thus on consumer welfare for commodities other than beans.

Country-Specific Supply Shifts: 50-Percent Technology Spillovers

Next, we repeat the same set of experiments, this time allowing for 50-percent technology spillovers. This means that when an innovating country's supply of, say, beans, shifts by 1 percent, every other country's supply curve of beans also shifts by half of 1 percent. In some senses, these experiments fall between our two sets of experiments above: (a) commodity-specific, regionwide, 1-percent shifts (equivalent to a country-specific shift with 100-percent spillovers to all countries within LAC

and a 50-percent spillover to ROW), and (b) commodity-specific, country-specific shifts without any spillovers to any other countries.

Even though, in most cases, the individual countries do not produce enough of the commodity in question to be able to appreciably affect the world price for the commodity themselves, any country whose new technology is partially adopted by the rest of LAC and the world can cause a change in the world price through technology spillovers. Hence, for country-specific supply shifts, with 50-percent technology spillovers to the rest of LAC and the world, the total research benefit to LAC is approximately equal to half of the benefit from a 1-percent, LAC–wide supply shift (with or without the 50-percent technology spillover to ROW).

Supplementary Table S7.4 shows the total benefits, country-by-country and commodity-by-commodity, of 1-percent supply shifts with 50-percent technology spillovers. The corresponding information has been summarized in Supplementary Figure S7.1. Supplementary Figure S7.1a shows the benefits to producers and consumers, and total benefits to the innovating country, commodity-by-commodity; Supplementary Figure S7.1b shows the corresponding benefits for the subregion containing the innovating country; and Supplementary Figure S7.1c shows the corresponding benefits for LAC as a whole. Again, the different spatial aggregates are considered because different decisionmakers and types of decisions require different information on the effects of a given technological change on the country, the subregion, or LAC as a whole.

In a counterpart to Figure 7.5a for the without-spillover experiments, the first section of Supplementary Figure S7.1a shows the benefits to the innovating country (country-by-country) of a 1-percent shift of the supply of beans. The corresponding sections of Supplementary Figures S7.1b and S7.1c show the corresponding benefits to the subregion in which the innovating country is found, and to LAC as a whole. Consider the case of innovations by Brazil. Supplementary Figure S7.1a shows that, of the $407 million in benefits to Brazil, $211 million accrues to producers and $196 million to consumers. The technology spillovers mean that the global outcome is much more like the outcome from a LAC–wide supply shift, than from a country-specific supply shift without any spillovers, with substantial consumer gains because of the effect on the world supply and thus the world price. Indeed, comparing the country-commodity elements in Supplementary Figure S7.1 with the counterparts in Figure 7.5 (for country-specific shifts without spillovers), it can be seen that the main effects of the spillovers on the benefits to countries, LAC subregions, or LAC as a whole, are to change the distribution of given total benefits between consumers and producers. Of course, the main effects from the global viewpoint are to increase the total benefits substantially and to greatly reduce the LAC share of the total benefits.

To illustrate and emphasize this last point more clearly, Figure 7.6 represents the change in producer and consumer benefits for innovating countries (or their subregions or LAC) as they introduce technology, giving rise to 1-percent commodity supply shifts with 50-percent spillovers to other countries. The pattern is clear

Figure 7.6 Differences in producer and consumer benefits with and without spillovers: 1-percent, country- and commodity-specific shifts

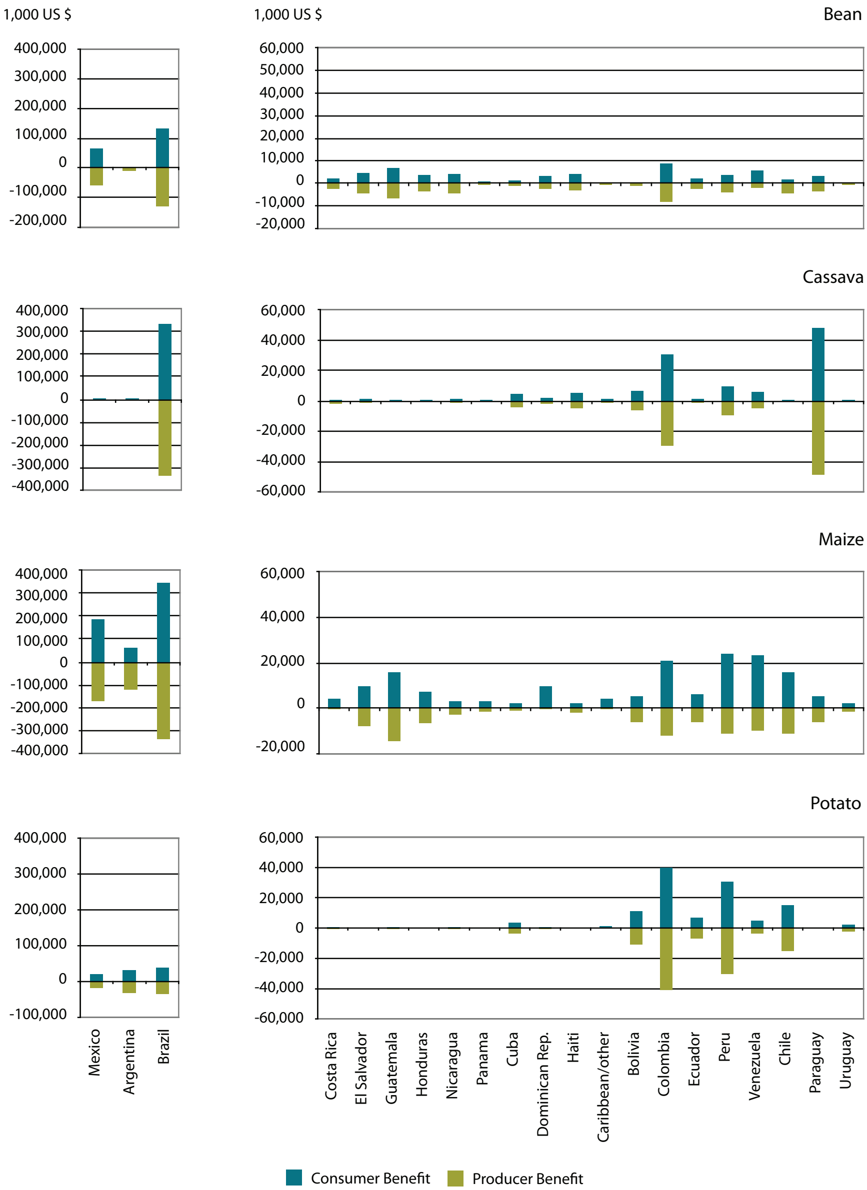


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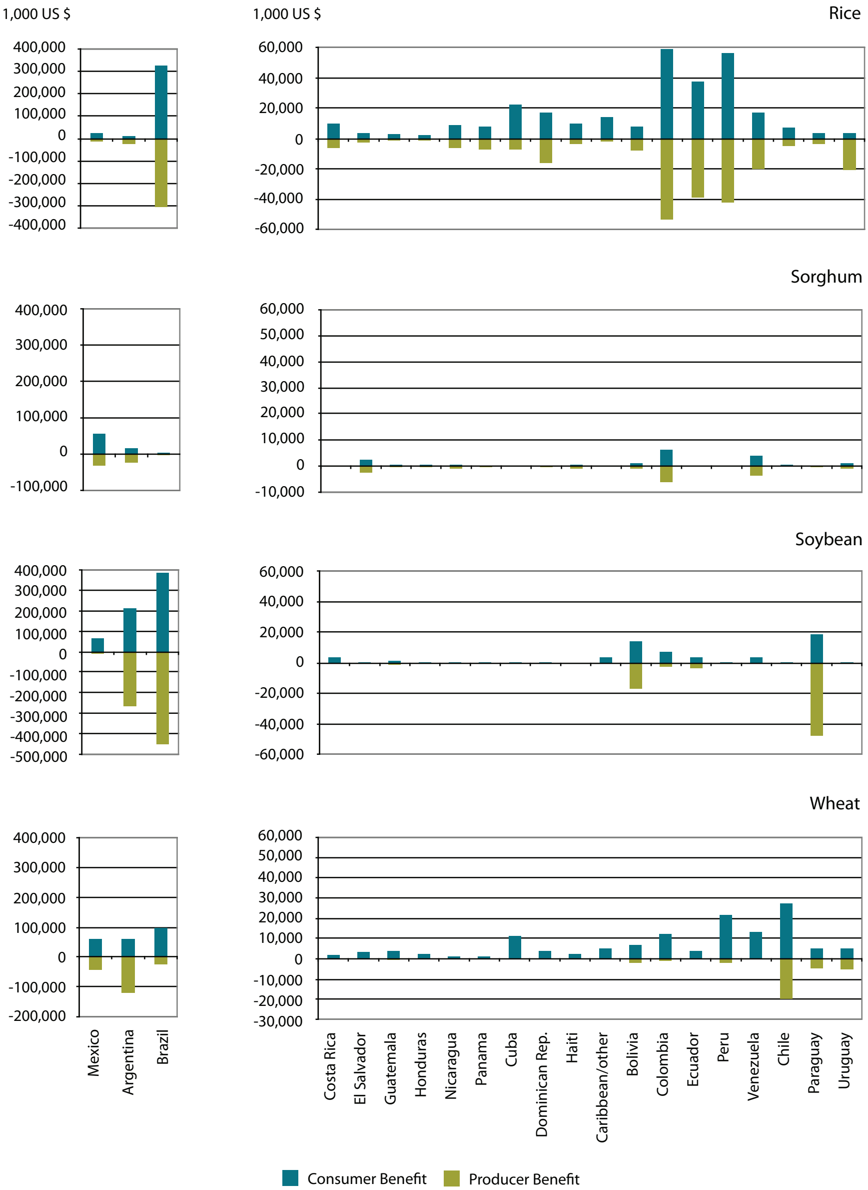
Figure 7.6 (continued)



and self-explanatory: the main effect of introducing spillovers is to increase consumer benefits and reduce producer benefits by a similar magnitude.

One-Percent AEZ–Specific Shifts with No Zone-to-Zone Technology Spillovers

While domestic policies, institutions, and infrastructure collectively influence average crop yields, agroecological conditions have a significant (in some cases overriding) influence in determining crop yields, and, especially, the location-specific response of crops to new technologies. Thus it is more natural to use agroecologies rather than countries as the spatial unit of analysis when assessing technology transfer potentials throughout Latin America and elsewhere in the world. Here we recast the analysis by measuring the supply-shifting consequences of R&D on a zone-by-zone rather than a country-by-country basis. Three broad agroecological areas were defined, broken down into 12 AEZs. As Figure 3.3 made clear, these zones are not necessarily contiguous and most zones span multiple countries, so that innovations in one zone can affect multiple countries, even in the absence of zone-to-zone spillovers.

Table 7.6 shows the subregional and LAC–wide benefits from research-induced zone-specific technical changes that were represented as 1-percent supply shifts on a zone-by-zone basis for each of the eight crops. Thus, for example, the upper block of results gives the total benefits arising from a 1-percent supply shift in each of the seven AEZs in which bean production occurred in 1993–95. Since the results refer to different (zone-specific) changes in technology, it would not make sense to sum the measures of benefits across zones (that is, across technical changes) within a geopolitical region.[12] It does, however, make sense to sum across LAC subregions for a single zone-specific technological change (this amounts to adding up benefits within a zone, across geopolitical borders), and we do this for each of the eight crops. This allows us to compare the total benefits and their distribution among countries and subregions arising from different zone- and crop-specific technological changes. Comparing among LAC subregions within a zone we see, for example, that almost all the benefits from innovations in bean production within zone 31 accrue to Southern Cone countries ($116,473 of a total of $117,516). In contrast most of the benefits from improvements in bean technology applicable in zone 40 accrue to Mesoamerican countries.

Table 7.6 makes it clear that the geopolitical incidence of R&D benefits is markedly affected not only by the crop being researched but also by the agroecological orientation of the R&D. Several questions can be addressed using the information in this table. Suppose, for the sake of argument, that it is equally easy (that is, would cost the same) to achieve a 1-percent zone specific improvement in productivity of

12 It might make sense to add up the measures of benefits across zones if we had in mind a simultaneous release of two different technologies applicable in different zones or, equivalently, partial spillovers between zones of a zone-specific technological change.

any of the eight crops. Then, we can determine which type of technological change would be preferred by each of the LAC subregions, or LAC as a whole, simply by comparing the benefit estimates in Table 7.6.

First, consider LAC as a whole. Among all the technological changes represented in Table 7.6, LAC would benefit most from a 1-percent improvement in productivity in soybeans in zone 31 (worth $700 million), followed by maize in zone 31 (worth $599 million), and then soybeans in zone 43 (worth $567 million). The Southern Cone would rank these top three types of productivity increases in soybeans and maize in the same order as LAC as a whole, but the other subregions would rank the technological changes differently. For instance, Mesoamerica would gain most from an improvement in maize productivity in zone 44 (worth $172 million) and would also gain substantially from maize productivity improvements in zones 42, 43, and 45, ($27 million, $26 million, and $82 million, respectively) as well as sorghum in zone 45 ($33 million)—all in the warm tropics and subtropics. In the Caribbean, the highest-ranking technological changes are for rice in zone 40 ($29 million) and cassava in zone 44 ($14 million), with significant gains from rice improvement in other zones (42, 43, and especially 44)—again, all in the warm tropics and subtropics. In contrast, in the Andean subregion, perhaps not surprisingly, potatoes rank high, with the greatest benefits from productivity gains in zone 21 ($203 million); the next-highest ranking is rice in zone 21 ($101 million)—the cold tropics.

Alternatively, we can ask, commodity-by-commodity, where should the research be focused among AEZs so as to yield the biggest payoff to LAC as a whole (or particular LAC subregions)? For beans, the answer is not clear. Four zones (21, 32, 44, and 45) offer roughly equal benefits to LAC from 1-percent productivity gains (about $120 million). But these different zones are distributed quite differently across subregions, so the options imply very different patterns of benefits within LAC (for example, Mesoamerica reaps most of the benefits from bean productivity gains in zone 44, while the Southern Cone reaps most of the benefits from bean productivity gains in zone 45).

For cassava, the highest payoff is from productivity gains in the warm tropics and subtropics, especially zones 43 ($334 million), 44 ($252 million), and 42 ($237 million), with most of these benefits accruing to the Southern Cone. For maize, the ranking is more pronounced, with zone 21 in the cold subtropics ($604 million) well ahead of the next-ranked zones 44 ($292 million) and 43 ($280 million); note also that the subregional distribution of benefits is very different between these zones. For potatoes, zone 21 offers the highest payoff, mostly in the Andean subregion. For rice, zone 31 offers the greatest payoff to LAC as a whole ($396 million), almost entirely within the Southern Cone; the next-highest ranked zone is zone 43 ($224 million) with somewhat less-concentrated benefits. For sorghum, zone 45 offers the highest payoff ($38 million). For soybeans, as noted earlier, zones 31 ($700 million) and 43 ($567 million) offer the greatest payoff, almost all within the Southern Cone. Finally, for wheat, zone 31 dominates ($271 million) and, again, the benefits accrue almost entirely within the Southern Cone.

Table 7.6 Total benefits: 1-percent, AEZ-specific shifts without zone-to-zone spillovers

	Cold tropics		Cold subtropics			Warm tropics and subtropics					
	20	21	30	31	32	40	41	42	43	44	45
						(1,000 U.S. dollars)					
Beans											
Mesoamerica		40,366.3		448.8		32,280.9		5,345.4	13,777.4	66,503.1	21,083.9
Caribbean		214.1		206.0		2,987.5		1,527.4	474.7	4,715.9	212.7
Andean subregion		24,247.1		387.7		129.2		682.6	6,217.6	5,690.5	893.8
Southern Cone		57,244.6		116,473.8		3,767.3		18,560.3	62,559.3	47,920.9	99,051.0
LAC	0	122,072.1	0	117,516.3	0	39,164.9	0	26,115.7	83,029.0	124,830.4	121,241.4
Cassava											
Mesoamerica		−27.9				−3.4	44.8	−74.2	−125.0	3,291.0	−52.8
Caribbean		−14.3				7,453.0	6,817.9	575.3	1,711.6	13,878.8	−27.3
Andean subregion		35,710.4				1,451.9	11,590.0	15,525.2	19,981.5	27,599.7	4,331.4
Southern		39,050.0				−2.0	20,704.1	221,968.6	312,800.1	207,762.0	136,757.7
LAC	0	74,718.2	0	0	0	8,899.5	39,156.8	237,994.9	334,368.2	252,531.5	141,009.0
Maize											
Mesoamerica		16,676.7		1,572.0				26,972.3	25,903.9	172,326.4	82,246.1
Caribbean		1,269.4		1,012.3				834.4	2,096.5	3,946.0	202.4
Andean subregion		5,584.3		2,393.7				3,180.5	27,096.0	14,832.1	6,268.5
Southern Cone		32,754.3		599,111.1				38,719.1	224,777.6	101,018.5	31,581.5
LAC	0	56,284.7	0	604,089.1	0	0	0	69,706.3	279,874.0	292,123.0	120,298.5
Potato											
Mesoamerica	18,141.2	22,695.4		41.1		1,190.2				408.2	
Caribbean	118.2	740.2		27.3		5,505.7				465.3	
Andean subregion	6,809.2	203,044.8		26.2		1.6				9,190.3	
Southern Cone	8.2	38,120.0		106,350.8		2.2				5,116.1	
LAC	25,076.8	264,600.4	0	106,445.4	0	6,699.7	0	0	0	15,179.9	0

Rice											
Mesoamerica		1,682.7	127.3	341.5		6,052.9		10,660.4	14,781.0	38,635.8	
Caribbean		401.8	213.7	572.8		28,564.7		5,486.4	13,059.1	10,190.7	
Andean subregion		100,845.1	106.4	286.0		17,708.3		29,360.8	37,412.0	46,618.0	
Southern Cone		37,555.0	147,375.5	395,714.5		−16.0		39,226.5	158,550.3	55,732.1	
LAC	0	140,484.6	147,822.9	396,914.8	0	52,309.9	0	84,734.1	223,802.4	151,176.6	0
Sorghum											
Mesoamerica		18,267.2		962.2	3,825.3				2,134.6	3,856.2	32,972.8
Caribbean		36.5		1.5	1.1				1.8	1,066.4	2.3
Andean subregion		5,929.3		14.5	10.0				10,977.4	2,962.3	2,184.1
Southern Cone		−44.0		25,074.3	14,387.5				16,049.2	1,461.8	2,877.7
LAC	0	24,189.0	0	26,052.5	18,223.9	0	0	0	29,163.0	9,346.7	38,036.9
Soybean											
Mesoamerica				10,174.9	3,670.5			2,906.2	8,240.9	5,447.6	13,200.1
Caribbean				777.7	111.5			137.6	630.0	266.5	144.9
Andean subregion				760.3	108.8			1,032.7	13,836.0	7,284.8	22,767.8
Southern Cone				688,637.3	96,610.4			119,723.3	544,461.4	225,130.3	94,565.8
LAC	0	0	0	700,350.2	100,501.2	0	0	123,799.8	567,168.3	238,129.2	130,678.6
Wheat											
Mesoamerica	62,197.9	22,248.1		773.4	18,367.8					89.5	
Caribbean	142.8	86.2		607.0	76.2					30.6	
Andean subregion	1,180.7	7,422.4		1,428.9	6,651.6					510.6	
Southern Cone	113.5	8,790.3		268,490.7	7,715.2					13,157.9	
LAC	63,634.9	38,547.0	0	271,300.0	32,810.8	0	0	0	0	13,788.6	0

Conclusion

The new approach to evaluating the future consequences of agricultural R&D presented in this chapter can inform the allocation of R&D resources at different spatial scales of decisionmaking be it among crops and AEZs within a country, for a subregional grouping of countries, or for LAC as a whole. We use an explicit economic framework to evaluate the benefits from R&D based on extensive spatial analysis to capture the locally variable, productivity-enhancing consequences of research. We illustrate the use of this framework with an assessment of the amount and distribution of the benefits that would accrue over the 1994–2020 period from R&D conducted on eight of the most important crops (by value) in Latin America.

Several features of our method and results are noteworthy. Our approach is the first to jointly estimate the agroecological and geopolitical incidence of the benefits from R&D in a consistent fashion. We first provide results based on a more conventional, country-specific representation of the consequences of R&D. Then we extend the analysis to allow for the substantial differences in the yield-enhancing effects of research within as well as among countries, wherein agroecological zones rather than countries become the geographic unit of analysis. Given that AEZs span some but generally not all LAC countries and that different crops are produced with different intensities in different zones, this approach adds significantly to our ability to accurately and meaningfully estimate the size and distribution of the economic benefits from research.

As described in the previous section, the distribution of the benefits from R&D has many dimensions that are directly relevant to those funding the research. For instance, although in some cases the total benefits to LAC are similar, different zone-specific research programs may imply quite different distributions of benefits within LAC. In some cases, the total benefits to LAC are the net result of large gains in one LAC subregion or another (often in the Southern Cone), and small gains or even losses in other LAC subregions. Losses to producers in a region can arise if they are unable to adopt the technology very extensively (for instance, if the subregion does not include much of the relevant zone or does not grow much of the crop in the relevant zone), but the adoption by producers in other subregions causes prices to fall. If the subregion is an exporter of the commodity in question, the losses to its producers might exceed the benefits to its consumers from the price fall, and the subregion would experience a loss from the technological change.

International trade in commodities and technologies is an increasing feature of economic life for most sectors of most economies. In our analysis we have demonstrated the important effects that price and technology spillovers have on the size and, more significantly, the distribution of the benefits from R&D within LAC. Comparing between simulations "with" and "without" technology spillovers from LAC to the rest of the world, we show that these spillovers do not have much influence on the total benefits to LAC or to particular subregions within LAC. However, they do have a big influence on the distribution of the benefits between producers and con-

sumers within LAC (or a particular subregion in LAC). For most of the crops in this study, spillovers to the rest of the world lowered the share of the gains from R&D accruing to producers in LAC. This stems from the world-price effects that these spillovers bring about. Spillovers change the distribution of benefits between producers and consumers, with a net effect that is positive for an importer and negative for an exporter.

While our approach offers new insights into the consequences of technical change for LAC agriculture, it also opens up new opportunities for deepening our understanding of these issues in ways that can improve policy decisions. One obvious extension is to expand the coverage of commodities. Another is to test the sensitivity of our results to changes in the baseline parameters used in our simulations of the effects of R&D. We took explicit account of the underlying growth in demand (and supply) associated with the projected growth in population and income (and other factors) when estimating the benefits from research. We also made aspects of international trade explicit and allowed for an incomplete transmission of changes in domestic prices to changes in prices in international markets. Our model is designed so that we can try alternative parameterizations of all these aspects. Perhaps the most fruitful line of inquiry would be to extend the agroecological analysis by using our zone-specific data to allow for differences among zones in the projected rate of productivity gains, and to allow for spillovers among zones in addition to the spillovers among countries within the zones we have reported here.

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Appendix 7A. Income Elasticity of Demand for a Factor of Production

Suppose a factor of production, Z, is used to produce two consumer goods, X and Y. The demand for Z is then the sum of the two demands $Z(X)$ and $Z(Y)$, such that

$$dZ = dZ(X) + dZ(Y).$$

Taking the derivative with respect to income (I) we get

$$dZ/dI = dZ(X)/dY + dZ(Y)/dI.$$

Using the chain rule,

$$dZ/dI = [dZ(X)/dX][dX/dI] + [dZ(Y)/dY][dY/dI].$$

Now, multiply and divide by I/Z to convert to elasticities, where E(Z, I) is the elasticity of demand for the input, Z, with respect to income

$$(dZ/dI)(I/Z) = E(Z,I)$$
$$= \{[dZ(X)/dX][X/Z(X)]\}\,\{[dX/dI][I/X]\}\,[Z(X)/Z]$$
$$+ \{[dZ(Y)/dY][Y/Z(Y)]\}\,\{dY/dI][I/Y]\}\,[Z(Y)/Z].$$

Let us define,

$$[dZ(X)/dX].[X/Z(X)] = 1.$$

The elasticity of demand for Z in the production of X with respect to total production of X is a scale elasticity that we can assume is equal to 1 for present purposes (similarly for $[dZ(Y)/dY].[Y/Z(Y)]$ and for all outputs using X when we go beyond two). $[dX/dI][I/X] = E(X,I)$ is the income elasticity of demand for X. $[dY/dI][I/Y] = E(Y,I)$ is the income elasticity of demand for Y. $[Z(X)/Z] = s(X)$ = the fraction of the total amount of the input, Z, that is used to produce the final good, X. $[Z(Y)/Z] = s(Y)$ the fraction of the total amount of the input, Z, that is used to produce the final good, Y. Then,

$$E(Z,I) = s(X)E(X,I) + s(Y)E(Y,I).$$

If we have many different uses of Z, then the general rule is that the income elasticity is equal to the share-weighted sum of the income elasticities of demand for the final product (where the shares are the shares of the total quantity of the input used in production of the different products), that is:

$$\text{i.e., } E(Z,I) = \sum_{i=1}^{n} s(i)E(i,I),$$

where the $s(i)$'s sum to 1.

Note, also, that if the "input" were used as a "final" product in some use (for example, food versus feed wheat), it would not matter. We would still use the income elasticity of demand for wheat multiplied by the fraction of all wheat used as food plus the elasticity of demand for meat (say) multiplied by the fraction of wheat that is used as stock feed. In other words, the income elasticity of demand for an input is equal to a weighted average of the income elasticities of demand for the products it is used to produce, where the weights are the fractions of the input allocated to the particular products.

Appendix Table 7A.1 Crop area and production by agroecological zone

Agroecological zone[a]	Beans	Cassava	Maize	Potatoes	Rice	Sorghum	Soybeans	Wheat
					(percentage)			
Harvested area								
Aez20	0.56	0.45	1.40	3.17	0.58	1.46	0.02	1.37
Aez21	12.50	4.99	11.20	45.97	7.12	11.02	2.25	3.68
Aez30	2.21	3.41	0.70	2.40	7.62	0.13	1.07	1.21
Aez31	14.03	6.88	29.35	28.61	21.82	18.16	39.94	59.54
Aez32	0.69	0.00	2.12	1.99	0.00	12.83	5.13	28.67
Aez40	2.29	1.46	1.23	2.10	1.96	1.87	0.06	0.10
Aez41	2.19	3.25	2.07	0.03	1.88	6.12	0.83	0.11
Aez42	3.76	14.21	6.86	1.65	7.59	2.38	5.07	2.03
Aez43	15.36	32.30	18.16	1.67	30.48	18.67	28.64	0.46
Aez44	16.18	18.32	16.03	3.63	14.16	6.91	7.95	0.88
Aez45	27.34	14.20	9.43	8.69	5.40	18.15	6.86	1.32
Aez46	2.89	0.52	1.44	0.11	1.39	2.30	2.19	0.65
Total	100	100	100	100	100	100	100	100
Crop production								
Aez20	0.9	0.5	1.4	3.5	0.9	2.1	0.0	2.6
Aez21	15.4	5.7	10.5	41.4	7.5	8.7	2.6	2.9
Aez30	2.9	3.3	1.4	1.8	11.7	0.1	1.0	1.3
Aez31	20.2	10.0	38.0	34.0	34.2	22.6	38.1	57.9
Aez32	1.2	0.0	3.3	2.0	0.0	15.1	5.8	30.1
Aez40	3.1	0.7	1.1	2.5	1.9	1.5	0.1	0.2
Aez41	2.2	3.1	1.8	0.0	2.4	4.6	0.9	0.2
Aez42	3.7	17.8	5.6	1.8	6.8	1.7	5.4	1.9
Aez43	12.6	28.5	16.3	1.7	16.8	20.4	30.0	0.4
Aez44	16.2	17.7	14.0	3.3	11.5	4.0	7.6	0.6
Aez45	18.7	12.5	5.4	7.9	4.8	16.1	6.2	1.1
Aez46	2.9	0.4	1.3	0.1	1.5	3.0	2.3	0.8
Total	100	100	100	100	100	100	100	100
					(1,000 tons)			
Production	2,123.22	14,820.35	35,475.44	5,107.88	9,692.55	5,180.89	25,667.02	13,615.42

Sources: Calculated by authors.

[a]See Table 4.6 for a complete listing of AEZ definitions.

Appendix Table 7A.2 Total, producer, and regional benefits: 1-percent regionwide commodity-specific shifts

	Southern Cone	Mesoamerica	Andean subregion	Caribbean	LAC
			(1,000 U.S. dollars)		
Total benefits					
Beans	443,362	212,474	42,168	16,565	714,568
Cassava	1,104,749	10,314	126,741	31,096	1,272,900
Maize	1,213,463	518,498	115,648	11,856	1,859,466
Potatoes	200,793	47,467	222,374	9,585	480,219
Rice	883,151	86,052	387,860	70,870	1,427,932
Sorghum	61,677	96,528	26,403	2,259	186,867
Soybeans	1,880,270	54,719	52,182	2,209	1,989,380
Wheat	432,791	109,570	13,909	1,246	557,517
All	6,220,256	1,135,621	987,286	145,686	8,488,849
			(Proportion)		
Producer share of total benefits					
Beans	0.78	0.76	0.73	0.71	0.77
Cassava	0.87	0.91	0.86	0.60	0.86
Maize	0.92	0.90	0.85	0.67	0.91
Potatoes	0.97	0.96	0.97	0.96	0.97
Rice	0.98	0.96	0.97	0.95	0.97
Sorghum	0.92	0.84	0.90	0.90	0.88
Soybeans	0.80	0.36	0.73	0.001	0.78
Wheat	0.97	0.96	0.77		0.97
All	0.88	0.86	0.91	0.80	0.88
Subregional share of total regional benefits					
Beans	0.62	0.30	0.06	0.02	1.00
Cassava	0.87	0.01	0.10	0.02	1.00
Maize	0.65	0.28	0.06	0.01	1.00
Potatoes	0.42	0.10	0.46	0.02	1.00
Rice	0.62	0.06	0.27	0.05	1.00
Sorghum	0.33	0.52	0.14	0.01	1.00
Soybeans	0.95	0.03	0.03	0.00	1.00
Wheat	0.78	0.20	0.02	0.00	1.00

Sources: Calculated by authors.

Chapter 8

Innovation Implications

Philip G. Pardey, Stanley Wood, and Reed Hertford

The agricultural productivity patterns for LAC reviewed in the previous chapters were mixed. Overall, in terms of basic land and labor productivity and corresponding yield indexes, progress within LAC lagged in comparison with other developing (especially Asian) countries. There were exceptions to these general trends, notably the chicken meat and soybean sectors, which are instructive. Both commodities benefited from enabling input and trade policy regimes, which on balance—but not in any uniform sense—have shifted toward less government intervention. Equally, and perhaps more importantly, productivity-enhancing technologies were available for both commodities and they were aggressively adopted. Many of these technologies spilled into countries in the region from the rest of the world (and especially United States). Being a broad-acre crop, soybeans are more circumscribed by agroecological influences than confined (often climate controlled) chicken production systems. Thus, realizing technological spillins to Argentina, Brazil, and elsewhere in the region required substantial local screening and adaptive research, tailoring the technologies to fit local agroecological realities.

Actively scouting for technological opportunities from outside, and adapting those technologies as required, has become and will continue to be critical to the success of LAC agriculture. This is true whether the technologies come from other countries in the region or from countries elsewhere in the world. Moreover, many LAC countries are simply too small to support full-blown domestic research capabilities in all but a small number of areas (if that), and certainly in fewer areas than may prove productive for local food and agricultural economies. Looking forward, these scale and scope problems are likely to become even more pronounced as the changing basic science (especially the biotechnological basis) of agricultural innovation increases the investment thresholds required to sustain homegrown innovation initiatives.

In dealing with these realities, the first requirement is to reverse the current downward trends and refinance LAC agricultural R&D. Certainly the evidence suggests that more, not less, R&D will be an economically valuable use of society's scarce resources. Reassessing national research priorities is also critical—especially picking those few areas in which more basic research is to be done locally, while also reorienting R&D institutions toward the more applied research in other areas where identifying and effectively tapping potentially valuable spillins from elsewhere proves the better option. Some countries are actively pursuing such strategies. Brazil, for example, established research labs in Montpellier, France, and Beltsville, United States, staffed with Brazilian researchers conducting joint research with host country collaborators.[1] Continued judicious liberalization of trade and investment will further open borders to trade in ideas and inputs (increasingly as proprietary intellectual property).[2]

Other options for collectively conceived and funded R&D are possible. Some are already well progressed, others are largely latent, although the basic institutional arrangements are already in place. The Latin American Fund for Irrigated Rice (*Fondo Latinoamericano de Arroz de Riego* or FLAR) is one of the more advanced initiatives; it was founded in 1995 to conduct R&D, especially rice breeding and other activities related to irrigated rice.[3] In 2002, public and private agencies from 12 counties, plus CIAT and IRRI, pooled almost $600,000 for FLAR sponsored rice research. The research is tightly focused on rice research overseen on a day-to-day basis by a technical director (mainly involving varietal improvement), and the countries represented by paying members of FLAR have access to the improved varieties and the national benefits that flow from them.

FONTAGRO is another multilateral initiative launched in 1998 with the backing of IADB to pool funds for a broad regional research agenda. In this case national government funds are committed to a collectively managed endowment, the yearly earnings from which are allocated on a competitive basis for research throughout the region. In principle the funds can be allocated to relevant research conducted

1 These spillins have tangible economic consequences. For example, new evidence for Brazil estimates that upwards of 20 percent of the $12.5 billion in benefits derived since 1981 from improved soybean varieties is attributable to spillins from the United States, and similarly up to 12 percent of the benefits from improved edible beans varieties are spillins from international research (Pardey et al. 2006a). Continuing to capture these spillin benefits is critical for the furtherance of Latin American agriculture, not least because around 93 percent of the world's total agricultural R&D—that is, $33.38 billion in 2000 prices, of the $35.96 billion total in 2000—takes place elsewhere in the world (Pardey et al. 2006b).

2 Further opening to trade will exert even more short-term pressure on domestic producers to be internationally competitive, albeit with attendant adjustment costs and the policy pressures to deal with these costs. However, as producers reallocate resources to adjust to these pressures, open trade generates dynamic efficiencies over the longer run, which are of benefit to domestic consumers and LAC economies generally.

3 The institutional and financial details regarding FLAR are described in Binenbaum, Pardey, and Sanint (2006). The design principles for FLAR were inspired by the Australian research and development corporations. Such corporations are industry-specific institutions—for example, for the grains, cotton, dairy, grapes and wine sectors—that generate check-off funding via commodity levies that is matched with general taxpayer funds to support agricultural R&D (Alston, Pardey, and Smith 1999).

by (both public and private) national research organizations and regional research entities such as CGIAR centers operating in LAC, as well as North American agencies conducting research of relevance for LAC. As of 2004, the endowment fund total grew to around US$34 million (far short of its original goal of $200 million), which generated about $1.5 million in R&D funding in 2003 (but which leveraged an additional $1.8 million funding to reach a 2003 R&D portfolio value of $3.3 million). This amount of investment is significantly smaller than could be used productively. A key economic idea sustaining FONTAGRO is the many research opportunities that go begging in LAC because the threshold levels of investment to effectively conduct the research are beyond those that would justify a go-it-alone strategy—notwithstanding the sizable regional benefits that would be realized from research results that spill well beyond the boundaries of any one innovating country.

Beyond its funding role, FONTAGRO is a ready-made forum for assessing agricultural research and technology initiatives throughout the region (which, by design, encompasses critical North and South America linkages). Thus, in addition to funding some of the research put to it, FONTAGRO could serve the region well by generating and circulating information on the likely transnational (and agroecological) incidence of the potential benefits from alternative research strategy and research investment futures. Such information could help inform debate within and among national agricultural science and technology institutions, and foster collaborative initiatives designed to ensure that cross-country spillovers are captured cost-effectively. Hopefully this book has helped to articulate the nature and magnitude of the (potentially large) economic gains to be reaped by deploying agricultural R&D resources more effectively throughout Latin America and the Caribbean.

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