Strategic Technology Investments for LAC Agriculture: A Framework for Evaluating the Local and Spillover Effects of R&D

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1. Introduction

Latin American agriculture has changed dramatically over the past few decades. The technologies used by the sector, the agencies conducting and funding the research that gave rise to these new technologies, and the international aspects of agriculture and agricultural R&D have changed markedly too. Twenty years ago, most of the domestic R&D throughout Latin America was funded and conducted by public (mainly government-managed) agencies. Aside from a few rich countries like the United States, the United Kingdom, Japan, France, and Germany, much of the farm-level agricultural R&D conducted elsewhere in the world was also paid for and done by public agencies.[1] Many of these technologies were freely available to Latin American farmers and many were indeed taken up by these farmers, including improved wheat, corn, rice, and potato varieties developed with public funding by international research agencies like CIMMYT, CIAT and CIP, and soybean varieties developed by the USDA and various U.S. land grant universities.

The situation is now much different. According to Alston, Pardey, and Smith (1999), by the mid-1990s about half of the agricultural R&D throughout the OECD countries was funded and conducted by private firms. Much of this private research deals with food-processing technologies, but significant amounts are also invested in farm input technologies such as improved machinery, chemicals, and, increasingly, crop varieties and livestock breeds. A strengthening of intellectual property regimes the world over has meant that many agricultural technologies are now subject to patents, trademarks, commercial contracts, and plant variety protection certificates, so the unfettered use of these technologies is no longer possible. It is not just privately developed technologies that are now proprietary—the intellectual property developed by public agencies is also increasingly protected.

The science of agriculture has also changed markedly, with technologies first developed for the medical and information sectors increasingly playing a part in agriculture, either as "stand alone" applications or as part of the new wave of biotechnologies being developed for agriculture. Coupled with the increased international trade in agricultural technologies, these developments point to the possibility of significant economies of size, scale, and scope from consolidating R&D operations. Nonetheless, the biological basis of agriculture often means that the yield and quality characteristics arising from new crop varieties and production practices vary spatially in response to local differences in soil, climate, and other natural factors. This makes the international transfer of agricultural technologies different in some fundamental ways from the spread of many other types of technologies.

Strategic decisions have to be made about how much public funding to invest in agricultural R&D, how to deploy those funds (especially in terms of the institutional design of agencies to distribute, monitor, and conduct the research), and what locational, commodity, and technology orientation to give the research. It is difficult to obtain the information and to define the criteria required to make these decisions. Clearly for those allocating public funds for Latin American research, keeping an eye on investment and technology trends elsewhere in the world is a prerequisite. Identifying areas for effective collaboration among countries within the region can also be useful, especially when the costs of collectively conceived R&D are substantially lowered (compared with conducting the R&D in an uncoordinated fashion) and when there are substantial spillovers among countries of the results of the research.

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[1] See Alston, Pardey, and Smith (1999) for a detailed discussion of agricultural R&D developments over the past several decades throughout the OECD countries.

In this paper 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 finds itself. The economic approach to R&D evaluation we use draws heavily on the multi-market equilibrium framework laid out 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 report ends with an assessment of the approach and a summary of the results found to date.

2. Sectoral Context

In 1997, Latin America accounted for 7.2 percent of the world's agricultural output (measured in GDP terms). Typical of developments throughout much of the world, agricultural output in Latin America has shrunk as a share of total output—from 17 percent in 1965 to about 8 percent in 1997. Nonetheless, the agricultural sector is large and continues to grow. The sector employed about 44.3 million people, or about 21 percent of the region's workforce in 1997. In that same year, agricultural GDP for Latin America was $147.4 billion, compared with $17.7 billion of output in 1965—or $66.6 billion using 1997 prices—,an annual average rate of growth in inflation-adjusted terms of 2.6 percent. However, this rate of growth is unremarkable by world standards, lagging well behind the corresponding rate of growth for developing countries as a group. Latin American agriculture also performed poorly on a (net) production per capita basis, growing by just 0.46 percent per annum over the 1961 to 1997 period—faster than the rate in Africa (which contracted by 0.63 percent per annum), but slower than all other regions of the world.

The regional averages hide a good deal of spatial variation in the size, structure, and performance of agriculture. In 1997, agricultural output accounted for no more than 15 percent of total output for 23 of the 32 Latin American countries for which data were available; it was less than 5 percent of output in Venezuela and Trinidad and Tobago. Agriculture is still a significant sector in some countries—Guyana (39 percent of total output), Nicaragua (34 percent), and Haiti (30 percent). Typically Mesoamerican and Caribbean countries rely more on agriculture than the rest of the region.

Agricultural production throughout Latin America is concentrated in a few large countries. Since 1961, Brazil, Argentina, and Mexico have typically produced nearly two-thirds of the region's agricultural output (measured in gross value terms), and the top ten producers have accounted for 90 percent of the region's output. Livestock production has grown slightly as a share of total agricultural output. By our estimates, in 1961 about 43.6 percent of the region's agricultural output consisted of livestock and livestock products, and this grew to 45.2 percent ($65.2 billion of output in 1989-91 international prices) by 1997.[2] Crop production is still clearly significant; in 1997 it totaled $79.2 billion (1989-91 international prices), or 54.8 percent, of gross output.

2.1 Commodity Details

The companion paper by Pardey, Chan-Kang, and Wood (2000) provides a comprehensive assessment of agricultural production, consumption, and trade trends throughout Latin America over

[2] The gross value measure of agricultural output reported here was constructed by Pardey, Chan-Kang, and Wood (2000). They aggregated annual, national quantity of output measures for 134 crop and 23 livestock categories taken from FAO (1997) using a 1989-91 average of unpublished agricultural commodity prices. These commodity prices were

the past several decades. That paper highlighted the spatial differences in production and productivity patterns, and the data are treated in ways that can be used in making strategic research priority decisions. The analysis includes 157 commodities (including 134 crops and 23 livestock commodities), summed into 16 commodity groups. In this paper we report the results of a more detailed, ex ante, research assessment of eight crops, specifically beans, cassava, maize, potatoes, rice, sorghum, soybean, and wheat. Collectively these eight crops are important, accounting for nearly one quarter of the value of all agricultural output throughout Latin America in 1997, and nearly one half of all crop output. Clearly their economic importance makes them priority crops for an R&D evaluation study. These eight crops vary markedly in their spatial patterns of production and productivity performance over the past several decades, their domestic and regional patterns of consumption, and their trade performance.

Table 1 provides information on the spatial pattern of production for these eight crops in Latin America for 1997. Reading from left to right, the crops are arranged in descending order of importance. Soybean production in 1997 was worth $9.7 billion (1989-91 international prices), representing about 12 percent of the total value of crop output in that year. In this group, maize production ranked second in terms of value of production, followed by rice and wheat. Typically the top 10 producing countries accounted for more than 95 percent of the region's output of each crop. The spatial concentration of production of soybeans and wheat is notable—nearly two thirds of the region's soybean production takes place in Brazil, and Argentina produces the same share of the region's wheat output.

[Table 1: *Spatial Pattern of Crop Production in Latin America, 1997*]

Yield Patterns

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denominated in international dollars based on an unpublished agricultural purchasing power parity index obtained from FAO.

Figure 1 presents yield trends for the eight crops for the 1961-97 period (corresponding yield levels and annual average growth rates are included in appendix table 1). Average yields for Latin America and four sub-regions are shown. Clearly there is much variation among sub-regions in the yield performance of each crop and significant differences among crops in their past yield performance. For the Latin American region as a whole, cassava yields fell by 0.30 percent annually while yields for edible beans grew by just 0.03 percent per annum. Average yields for all the remaining six crops grew by more 1.5 percent per annum, with yields for maize and potatoes growing by more than 2.0 percent per year.

[Figure 1: *Yield trends in Latin America, 1961-1997*]

For this study we placed a great deal of emphasis on compiling spatially disaggregated production and yield data as a basis for calibrating the multi-market research evaluation model (as described in some detail below). Wood and Sebastian (2000) describe the methods used to construct this spatially disaggregated data set. Here we reproduce two figures presented in Pardey, Chan-Kang, and Wood (2000) that use these new data to summarize the spatial pattern of yield levels and yield growth rates for Latin America. Figure 2 is a series of frequency distributions indicating the amount of Latin American crop production that was produced from areas with 1993-95 average crop yields in various yield classes.[3] The dark shading denotes the production in each yield class coming from Brazil, the white shading indicates production coming from the rest of the region.

[Figure 2: *Distribution of crop production by yield levels and rates of growth*]

Obviously the regional and sub-regional averages plotted in figure 1 mask a good deal of variation in yield performance both within and among countries, and the shapes of the distributions are different for different crops. The bimodal distribution for rice indicates that one quarter of the

[3] GIS procedures were used to form these series from data collected on the basis of statistical reporting units, (SRUs) which consisted of 4,276 municipalities in Brazil, and 225 departments for the rest of Latin America.

1993-5 rice production came from areas with yields between 1.0 and 2.2 tons per hectare—most likely rainfed production systems located mainly in Brazil—whereas 38 percent of the production was grown on land (most likely irrigated) yielding between 4.6 and 5.4 tons per hectare. The comparatively "flat" distribution for maize shows that maize production comes from a diverse range of production systems, while the peaked distributions for soybeans and, especially, wheat indicate that most of the output for these two crops comes from much more homogeneous systems. In fact, 58 percent of Latin America's wheat production in 1993-95 was produced on areas that yielded between 1.9 and 2.2 tons per hectare (mainly land located in the Argentine pampas region).

Figure 3 plots distributions based on yield *changes*, not yield *levels*. More tightly clustered distributions that are more normal in shape are obtained when the frequency distributions are denominated in terms of yield changes rather than levels. We also see that for all the crops some of the 1993-95 production came from areas with declining yields over the 1975-1995 period. Table 2 reports the share of harvested area for each crop in terms of their 1993-95 yield levels and their 1975-95 annual rates of growth in yields. To form these yield classes, the area harvested for each crop was rank ordered from the highest to the lowest in terms of the yield level and then divided into quintiles. We estimate that 58.8 percent of the bean area (i.e., 12.9 plus 45.9) has comparatively low or very low yields. Likewise over 45 percent of the rice and maize areas fall into this class, and nearly 60 percent of the wheat area is so classified. Less than 30 percent of the cassava area has comparatively low yields, while virtually none of the soybean area is classified as such—indeed, 87 percent of the soybean area is clustered in the high to very high yield classes.

[Figure 3: *Distribution of 1993-95 crop production by yield growth rates over 1975-95 period*]
[Table 2: *Area Harvested Stratified by Various Yield Level and Growth Rate Classes*]

Table 2 shows the marked differences in the distribution of areas classified in terms of the yield growth rate rather than yield levels (as was also evident when comparing figures 2 and 3).

Over 70 percent of the area in maize, potatoes, soybean, and wheat experienced positive or highly positive rates of yield growth over the 1975-95 period. In contrast, during the same period yields contracted on over 20 percent of the area harvested for wheat, potatoes, sorghum, rice, and beans and over 45 percent of the cassava area.

In tables 3 and 4 we used GIS techniques to overlay harvested areas for each crop in terms of their yield levels and growth rates in order to identify areas with comparatively high but falling yields, low but rapidly growing yields, and so on. These data reveal many interesting and informative patterns. For example, 62 percent of the soybean area had high *and* growing yields whereas 26.2 percent of the area in sorghum had low and declining yields, as did over 10 percent of the area in wheat, rice, potatoes, cassava, and beans. It is this spatial variation in crop performance that gives force to the use of agroecological zones as a basis for calibrating the supply-shifting consequences of agricultural research.

[Table 3: *Distribution of Area by Yield Level and Growth Intersection, hectares*]
[Table 4: *Distribution of Area by Yield Level and Growth Intersection, percentage*]

3. Perspectives on Regional Research Priorities

Any geographic region is both a part of larger regions and contains smaller sub-regions, whether viewed from an agroecological perspective or a geopolitical or economic perspective. The definition of responsibilities of different institutions, owing allegiance to different geopolitical entities, is made complicated by the mismatch between agroecological and geopolitical boundaries. For instance, within a country, the distinction between responsibilities of provincial governments and national governments over water resources is made complicated when 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 some research that is strictly of local interest and some that is of global interest, as well as the range of in-between possibilities. Since the different organizations will have different responsibilities and objectives, they will have different perspectives and hence may use different criteria for evaluating a given R&D project or investment. One implication is that the assessment of relevant research impacts, and research priorities, is different among organizations.

There are also implications for who should be financing or carrying out particular lines of research. Sometimes this issue is addressed in terms of efficient jurisdictions. Which is the appropriate geopolitical entity to finance or carry out a particular line of research in terms of being able to minimize costs and in terms of having appropriate incentives to make the "right" research investment? Conversely, what is the appropriate "division of labor" for funding and execution of research among (a) national agricultural research systems (NARSs), (b) international research systems, including the international centers comprising the Consultative Group on International Agricultural Research (CGIAR), and others, (c) private foundations and other private entities, and, lastly (d) multinational regional groups of various sizes and configurations? In other words, what should be done by national governments or the CG system, what is left over, and what types of regional organizations are required to get the left-over elements done most effectively and efficiently?

3.1 Setting the Scene

One way to structure thinking about these issues is in terms of spillovers. Clearly, those research investments whose consequences are entirely domestic, within a nation, are the nation's own business. Similarly, those research investments that have global ramifications should in principle be treated as global public goods, and conducted on a correspondingly global basis—but in the absence of a global government, such investments have been more often left to be pursued by a small subset of the richer nations (i.e., 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; some other comparably rich nations, such as France and Japan, have focused their public research investments more towards the applied end of the spectrum). 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 (benefitting from research for which they haven't paid) and in such a setting an 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 by one place, which yields results that are applicable locally and in a number of other places, often closely neighboring. Soybean research is a good example. Within the United States, the results of soybean research conducted in any of the mid-western states (e.g., Iowa) would be likely to be highly (if not equally) applicable in the neighboring states (e.g., Minnesota, Illinois, and Indiana, among others). As a consequence, every such state is likely to free ride to some extent on the investments by the other states in soybean research, as well as not counting benefits to other states from its own research, 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.

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 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; and, 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 a globally optimal investment in soybean R&D, and adoption of the results, is to be made.

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 if not impossible to predict the precise pattern of spillovers in advance, so it would be difficult to optimize a technology trade-restriction policy. Fourth, it ought to be remembered 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 achieved by the CGIAR. The semi-dwarf wheat varieties, which played an important role in the Green Revolution, may have been developed with a view to Mexico and 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 also 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 (such as BID or Fontagro) would have a different measure of benefits and possibly different evaluation criteria and priorities. In short, typically agricultural R&D undertaken in one place 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 done 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 might be different for every project or program of research. As it happens, however, funding and execution of 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 co-ordinate 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 co-ordination 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.

3.2 Economic Indicators of R&D Impacts

Every research institution—be it sub-national, national, or multinational—has a constituency and an implied (if not well-defined) set of objectives. Relative to those objectives, there are benefits from the investment made in research (in terms of poverty alleviation, increases in farmer profits, servings per consumer, or whatever), and it makes sense for the institution to want to achieve the greatest benefit possible from its investment. In other words, maximum net benefits is an appropriate criterion for research priority-setting and management for *every* research institution. What may differ among institutions—or, perhaps, more pointedly, among those who fund the research—is how they define and measure the benefits, both in terms of what constitutes a benefit (and how it might be measured) and to whom it accrues.

A particularly useful (and oft-applied) measure of net benefits considers only the (pecuniary) benefits to the relevant producers and consumers within an affected nation (or other relevant geopolitical entity); without regard to the distribution of those benefits within the nation (or other entity). 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 production, the effects of research on that technology, and characteristics of the affected commodity markets. Also, unlike some other measures, that involve multiple objectives, this measure does not require a weighting of objectives according to their relative importance (which can render the measures meaningless—see Alston, Norton, and Pardey 1998, ch. 7).

Since this measure connects closely to economic models of behavior and welfare economics concepts, there is a very extensive literature and understanding upon which we can draw to implement the measure in different settings, and to understand what is meant by theoretical and empirical results from models of research benefits. And, optimization and priority setting follows naturally. Finally, this measure of benefits can be aggregated over time and across places in order to compare and contrast regional versus subregional imperatives. Other notions of benefits may be more inclusive, and more appealing for some settings, and might share some of the above desirable features, but will usually forego something desirable. For this reason, many economists have revealed a preference for using the narrow conception of national benefits as a criterion for research evaluation and priority setting. Indeed, this type of measure has predominated in both quantitative and theoretical studies of the benefits from agricultural R&D, either explicitly or implicitly. (Alston et al. 2000 provide a meta-analysis and review of the literature that has quantified the benefits from agricultural R&D.)

Many non-economists, and even a few economists, are uncomfortable with the restriction of attention to a simple, single-valued criterion of maximum net benefits (defined as the sum of benefits to producers and consumers within the country). They would say that the benefits of research include things such as poverty alleviation, preservation of natural resources, reduction of unemployment, improved nutrition, improvement in the balance of payments, and so on. As discussed by Alston, Norton, and Pardey (1998), it is important to distinguish between objectives and the means of achieving them, and to be careful of 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, and in particular the effects of research on income distribution, or the distribution of the benefits among groups within the society, is not reflected in this measure.

Those interested in accounting for the distributional effects of research—say, according to what people do for a living, or their income status—can do so using similar approaches, but to do so is much harder, and requires much more information and much 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.[4] 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 the distribution of the benefits from research, so that 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 regions. This same analytical framework can also be used to measure costs and

4 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, the income distributional consequences of lowering staple food prices (from untargeted technologies) are almost universally preferred to the (less substantial) distributional consequences of targeted technologies.

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.[5] These measures are discussed in Alston, Norton, and Pardey (1998).

The modeling approach involves simulating commodity markets over time (looking forward), by defining equations for supply and demand with and without various research-induced changes in supply in one or more places. The results of the simulation are streams of hypothetical quantities and prices (with and without research-induced changes), which, along with the underlying supply and demand equations, are used to compute the measures of economic benefits from the research-induced changes. Hence, along with the benefit measures of primary interest, the analysis also provides information on research-induced changes in prices and quantities which could, if so desired, be used to compute alternative measures of research impacts.

3.3 Using Information from Models in Setting R&D Priorities

The types of models we use here to measure research benefits, were developed to help us explore hypothetical R&D alternatives (or to evaluate specific R&D strategies), and to compare among them. They are not intended to be used as forecasting models, and they are ill-suited for that purpose. Conversely, good forecasting models often have little economic structure and usually cannot be used for policy analysis.

Rather than design a model that would be good for predicting the *level* of price or quantity in a particular future (or, indeed, past) year given predictions (or observations) of other variables, we have designed a model that is good for predicting the *changes* in prices and quantities, relative to a base, when we change technology. The principal advantage of this approach is that we are

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[5] Revoredo (1999) documents the pattern of price distorting policies in Latin America and the Caribbean over the post-WWII period.

conducting a comparative analysis, relative to a base (sometimes called comparative statics). By focusing on the change, relative to the base, we avoid having to be able to predict the base accurately (and, implicitly, all the things that affect the base). Further, by focusing on changes, we are able to use estimates from the literature (or derived from theory) on responsiveness of supply and demand to prices, and these relationships are relatively well understood and we have a good idea about the appropriate values for many of the parameters. Finally, and relatedly, we emphasize the analysis of very small research-induced shifts in supply, changes for which the chosen parameter values are likely to be robust.

In practice, it is not just the change that matters. Benefits also depend on the scale of the industry or the size of the base to which the research-induced technological change applies. Since we are projecting forward, it might be misleading to project forward a constant base when, in fact, we expect an industry to grow or contract for reasons other than the research effects being evaluated. Consequently, we do introduce projections of the base, against which to measure the benefits of small research-induced changes in supply, but we do not imagine that this provides an accurate prediction of the future and would not want there to be any misunderstanding about what the results of the model might mean or how they might be used.

This view of economics and the use of economic models is not confined to the present study. Any economic model is a metaphor for how the real world works, and often the metaphor is good and useful even if the abstraction is such that the details are wildly inaccurate. Krugman (1998, p.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 such as ours is for comparing among alternative scenarios, for seeing how the results change as aspects of the model or the markets being modeled are varied, and thereby developing an understanding (to some extent a quantitative understanding) of the key economic relationships. The specific numerical results for any such scenario might be quite inaccurate or misleading, but if the "errors" are constant across scenarios, then the comparison can still be quite meaningful.

R&D in an economic framework. Many economic models focus on a single market for a single commodity at a point in time. At the opposite extreme lie models of entire economies, dealing explicitly with all of the markets for all of the commodities produced and traded, as well as markets for the inputs used to produce them, and macroeconomic relationships (such as models of exchange rates, interest rates, unemployment, and inflation).

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 investments, our model is multiperiod. Given that the emphasis of the present study is on regional research relationships (taking account of geopolitical and agroecological aspects, and spillovers), it was judged to be important to incorporate significant detail on those aspects, so the model is rich in the spatial dimension. This means we have multiple markets for a given commodity, one defined for each country of interest. However, while the model is multimarket in this sense, we model one commodity at a time and we do not model the vertical market structure. Also, we ignore transport costs among countries or regions.

Some such simplifications are always made in economic models and the art is to make simplifying assumptions appropriate to the purpose 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 (ignoring these aspects) should not seriously distort the contrasts we intend to use the model to make. In other words, the model is not meant to provide a realistic representation of reality in all its dimensions, but it can nevertheless provide realistic information about the economic relationships of interest.

In addition to providing ball-park or benchmark type estimates, our modeling approach is powerful for illuminating some of the subtle aspects of what is in reality a very complicated situation. In particular, information will be revealed on important (perhaps unexpected) interdependencies and on what factors determine the domestic and spillover benefits from research conducted in one place versus another.

3.4 Key Elements of our Evaluation Framework

The model used here is designed for comparative static analysis (i.e., comparing and measuring the difference between two alternative hypothetical scenarios) rather than predicting the future, which is much more difficult and hazardous. It is a model specifically designed for the purpose in hand, focused on the particular questions of interest (i.e., it is not a general purpose model that can be used as a "black box" by a nonspecialist to explore even the same types of questions being pursued here, and it is not useful for analyzing different types of questions than the ones for which it is designed—such as the effects of other policies). Finally, although it shares a great deal in terms of the underlying principles and ideas, the model here differs in many details from that of Davis, Oram, and Ryan (1987), which was the first substantial model of research benefits with international price and technology spillovers.

The model here is an extension of the Dream© model, as described in Appendix A (for more detail on the modeling approach, see Alston, Norton, and Pardey 1998). The Dream© model was designed to measure returns to commodity-oriented 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. Linear equations are used to represent supply and demand in each country, with market clearing enforced by a set of quantity identities and price identities (allowing for price wedges to represent price-distorting policies). The Dream© 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, of course, these aspects are 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 inter-relations between supply and demand, through income balance effects, which is what defines a general equilibrium model—it is not a CGE 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 the Dream© model 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 annual 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).

The primary parameterization defines the supply and demand curves in the base year in a way such that the solution of 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 we can solve for a stream of equilibrium 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, representing 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 present values of benefits. In a situation where we know the costs of the research that is 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 one-percent supply shifts of various sorts.

The Dream© model is designed such that it is relatively easy to vary the parameters defining 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. These two innovations both 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.[6]

The second, and more important innovation in the present context, is that we have used information on agroecological zones to define the geopolitical spillovers of technologies. In some of our analysis, of a more-traditional sort, reported below we assume that spillover coefficients are less than one among countries, but one among regions 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.

In other analysis, we assume that the spillover coefficient is one within the same

[6] 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.

agroecological zone, both within and across countries, but zero across agroecological zones, both within and across countries. The magnitude of the shift is the same across countries within the agroecological zone, equal to *k* percent of the base-period price. A more complex treatment allows for the partial transfer of technologies between agroecological zones (within a country) and within agroecological zones (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.[7]

3.5 Simulation Strategies

Technical change could have a multitude of impacts on LAC agriculture. The most significant changes could even occur outside the region. Here, 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 have been 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.

[7] One exception is Davis, Oram, and Ryan (1987). Most studies have made not allowance for interstate or international spillover of agricultural technology. Some have assumed spillover coefficients based simply on proximity (e.g., Huffman and Evenson 1993).

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. Sub-national production data was used to generate plausible, commodity-specific estimates of the spatial distribution of production across the entire region (see Wood and Sebastian 2000). This was an important consideration since a key innovation in this study is the application of this spatially explicit production data for improved estimation of the impacts of technical change on an agroecological basis. This analysis requires production statistics reported on a geopolitical basis to be re-aggregated in an informed way into agroecological zones occurring within (and across) the borders of countries and regions.

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 in a specified base year. As described in section 3.3, the idea is to compare simulated market outcomes under two 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 a base year. Then, to represent alternative scenarios, changes in each year are simulated relative to the base scenario.

The analyst must provide data that describe the initial market conditions (for example, prices and quantities produced and consumed) for that selected base year. But to minimize the possibility of selecting atypical starting 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 the average of, say, three consecutive years.

In our case we defined values for the base year of 1994 as the average of the annual values for the period 1993 to 1995. This period was selected as being the most recent for which IFPRI's sub-national production database was essentially complete (recalling that the sub-national data is an important ingredient in obtaining a reliable picture of the spatial allocation of production). We then selected a target end of simulation date of 2020 to match that used in parallel studies, such as IFPRI's global food perspective study (Rosegrant, Pinstrup-Andersen, and Pandya Lorch 1999). 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 in which new technologies are introduced on a country-by-country basis, and the second is based on a transnational perspective in which new technologies are targeted to specific agroecological zones (AEZs) that may be found in several countries.

For both country-specific and AEZ-specific simulations, two groups of runs were performed. In one group we assumed that the effects of a technical change, or a 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 4 represents a simple two-country or two-AEZ case where the exporter innovates, figure 5 represents the case of an innovating importer). That is, we assumed that the new technology could not pass from the source country (or AEZ) to any other. These were called the "without technology spillover" simulation runs. Notice that the research-induced supply shift in the innovating country (i.e., country A) causes the world price to fall from P_0 to P_1 in both the with *and* without spillover cases. In figure 4, 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 ($S_{A,1}$).

[Figure 4: *Size and distribution of research benefits for traded goods (exporter innovates, no technology spillovers, large country)*]
[Figure 5: *Size and distribution of research benefits for traded goods (importer innovates, no technology spillovers, large country)*]

For the second group of runs we relaxed the technology spillover assumption and allowed the new technologies themselves to be transferred from the source country or AEZ to any other. These were dubbed the "with technology spillover" runs. All runs were made for each of the eight commodities. Table 5 summarizes the overall structure of the simulations conducted for this study.

[Table 5: *Overall Structure of Simulations*]

A technical change in a single country (or AEZ) may give rise to economic impacts on producers and consumers (1) within that country or AEZ, (2) more broadly within the sub-region within which the country or AEZ is located, say the Andean region or the Caribbean, and (3) 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 6 details the sub-regional grouping of countries and the AEZs for each set of simulations (we discuss the definition of the AEZs in section 3.6).

[Figure 6: *Spatial configurations for ex ante agricultural technology assessments*]

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
- 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 (FBS). For any country, in year t, current consumption is given by C_t, where

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

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 annual 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. Tables 6a-h show the base period quantities for each commodity.

[Tables 6a-h: *Base Data for DREAM Simulations*]

Market prices. All commodities were treated as tradable (this restriction is not imposed by the evaluation model, this was simply the benchmark 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 the FAO trade volume and trade value data. For the benchmark 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 US$ 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 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. Tables 6a-h summarize 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 to be used in future simulations that explore the effects of past, current and potential future policy regimes (Revoredo 1999).[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, as well as eliminating 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. Tables 6a-h summarize these parameterizations of supply and demand elasticities.

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[8] The economic evaluation model provides for the explicit definition of price distortions through tax or subsidy policies on either supply, 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). See Appendix A.

[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 (e.g., 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.

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 damping the transmission of price *changes* among regions and, as described in section 3.4, we achieve this through the application of a price transmission elasticity. The price transmission elasticity, w_i, is applied to the price changes arising within an innovating 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 to 0.8. Accordingly, to assure equal prices among all regions, initially (i.e., $P_{i,0} = P_0$), all of the v_i were all set equal to $0.2P_0$.

Autonomous supply and demand growth. The total benefits from a k-percent technical change depend directly on the size of the industry affected, and this will depend in turn 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, income elasticities were estimated by weighting demand elasticities in terms of the fraction of the consumption consumed as food (rather than feed), f_i, and assuming income elasticities of demand of 0.5 for food and 1.0 for feed. Thus, for commodity i

$$\mu_i = 1 - 0.5 f_i$$

Tables 6a-h summarize the derived income elasticities.[10] Notice that cassava, maize, soybeans, and, especially, sorghum are significant sources of feed in many countries so that the derived income elasticities for these crops are greater than the 0.5 assumed for food uses only.

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 in each country.

Representation of Research Effects

Technological change was represented by a k-percent downwards 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 were no producer taxes or subsidies and we ignored transactions costs then PP_0 would be the same as the initial market equilibrium price, P_0). We describe the estimation of the initial equilibrium price in the next section.

To facilitate comparisons among scenarios, we set k at one percent in each case. The value of one percent is sufficiently small such that, over the ranges of induced changes in prices and

[10] See Appendix B for the derivation of income elasticities of demand for commodities consumed as both food and feed.

quantities, our use of linear approximations to represent the supply and demand equations will not result in significant errors. Furthermore, the use of k equal to one percent means that we can interpret the measures of research impacts, expressed in proportional change terms, as elasticities; that is, a one-percent supply curve shift induces a φ percent change in total revenue or producer surplus. Then, these "elasticities" could be used to calculate impacts of different rates of supply curve shifts by multiplying the elasticity times the different values of k. Finally, a value of k equal to one percent is not too far removed from a realistic long-term annual yield growth rate attributable to technical change for some commodities.

The potential of a new technology to reduce unit production costs is realized by 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. For the adoption profile we began at zero in the base year—i.e., the presumed year of release of the technology—rising in sigmoidal fashion to a 100-percent maximum adoption rate five years later (such that the one-percent potential cost reduction from the new technology translated into a one-percent shift in the aggregate supply curve), which, once attained, is assumed to be maintained for the remaining period of the simulation.

3.6 The Agroecological Basis of the Zonal Simulations

Many commodities, and individual technologies within a commodity sector, are particularly well suited to specific production environments. Within the same country, potatoes will be grown in different places than are 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 diurnal and seasonal radiation and temperature patterns found in lowland tropical areas, and others are better adapted to cooler and wetter areas found at higher elevations.

If we can be more explicit about the location and dimensions of geographic zones, according to the extent to which they are suited to the production of a specific commodity, or the application of a specific new technology, we will be better placed to gauge the likely impacts of production innovations.[11] We use the term "agroecological zones" (AEZs) to denote geographical areas within which the potential biophysical impacts of a new technology are likely 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-year production (almost without exception reported on a geopolitical basis) is found in each AEZ. This proportion is a critical determinant of the potential scale of impacts.
- Estimating technology spillover potential—the extent to which technologies generated for one AEZ retain their effectiveness when applied in other AEZs. This requires some understanding of the "agroecological distance" between AEZs, relative to the new technology.

Characterizing AEZs for LAC

The biophysical suitability of locations to support specific commodities and technologies depends on many factors. Key among those are radiation, temperature, and rainfall within the growing season, and their variability from year to year or within a season. These climatological

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[11] Other aspects, like infrastructure, have different spatial dimensions that affect spatial patterns of adoption, and AEZs need not coincide with spatial patterns of adoption. Some agroecological classifications attempt to account for infrastructure dimensions as well as biophysical ones; here we don't.

factors interact with local characteristics, such as the slope of the land and the quality of the soil (including soil texture, depth, drainage, and nutrient status), to determine agricultural potential. 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 agroecological zones depends on the purpose at hand. Koeppen and Holdridge defined broad-based vegetation and ecosystem zones; Holdridge, in particular, is quite widely used in South America. While the Papadakis system was designed specifically for characterizing agricultural lands, its application in practice is relatively limited. The LAC Regional Research Fund for Agricultural Technology, Fontagro, divided LAC (and the southern United States) into several "megadomains" that used a mixture of geopolitical and agroecological factors (Fontagro 1997). FAO (1978) designed a generic set of agroecological zones for accessing 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 data on climate, elevation, and slope (FAO/IIASA 1999)
- Spatial information on irrigation intensity (Döll and Siebert 1998)

A feature of this classification is that, for the first time in such a regional dataset, we have identified existing production areas and distinguished between rainfed and irrigated areas. For some important rainfed zones, flatter and steeper areas are also differentiated.[12] Figure 6 above maps the resulting

[12] 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).

AEZ configuration as well as the country boundaries and the sub-regional geopolitical groupings adopted in this study.

Apart from including a rich set of attributes that can support characterizations of land at the sub-national level, the same 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 those areas in say, the United States, Europe, and Australia, that fall within the same AEZ as a given area in LAC; areas from which new technologies could potentially be taken or, conversely, those areas where technologies developed in LAC might be adopted.

Area and production shares by AEZ. By combining estimates of the location and intensity of agriculture derived from satellite information with an agroecological characterization of agricultural land and digitized data on geopolitical boundaries (figure 6), we determined the area and proportion of agricultural land within each agroecological zone for each country and sub-region within Latin America (table 7). We estimate that about 32 percent of the total land area in Latin America is used for agriculture, of which 75 percent is located in the Southern Cone, 14 percent in the Andean region, 9 percent in Mesoamerica, and less than 2 percent in the Caribbean. Looking within each region, 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 sub-tropics, and the remaining 30 percent in the moderately cool to cold tropics and sub-tropics. There are virtually no crop production areas with temperate climates.

By far the most dominant agroecology within the extent of agricultural land in LAC is the flat, rainfed, sub-humid, warm sub-tropics/tropics that occupies 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 sub-tropics (AEZ 31) is the next most extensive area, accounting for some 16 percent of the agricultural land in LAC. 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 much of the agricultural area in the Southern Cone, AEZs 21 and 43 jointly account for about half the agricultural area in the Andean region. The agricultural land in Mesoamerica is agroecological diverse, although AEZ 44, the rainfed, sloping, warm sub-tropics and tropics—more popularly known as the "well-watered hillsides"—accounts for about 30 percent of the agricultural land in this sub-region.

[Table 7: *Agricultural Land by Agroecological Zones*]

We have also developed a department-level production database for the whole of LAC. For some countries, such as Guatemala, sub-national production data could not be obtained while for other countries, like Brazil, more detailed data were available at the municipio level. For the eight commodities of this study the departmental database is essentially complete for 1975-95. A great deal of effort was spent on data checking, reaggregation, interpolation, and extrapolation using routines we developed for the purpose. All sub-national production data were recalibrated to correspond to published FAO data at the national level.

A mathematical programming approach—coupled with GIS data and biophysical suitability criteria—was used to allocate areas of production, based on data organized by geopolitical units, within sub-national production areas. For instance, suppose a department produces 10,000 hectares of maize, 8,000 hectares of soybeans, and 4,000 hectares of potatoes. The different crops will be allocated to particular locations within the department, depending on their agroecological comparative advantages (at the level of pixels delineated in units of 25 square kilometers) such that the total area of 22,000 hectares and the total for each crop is preserved. This crop-specific allocation uses satellite data interpretations of the location of agriculture and its spatial intensity, maps of the spatial variation of biophysical production potential for each crop, any other existing data on the spatial distribution of crops and pasture, cropping intensities, and crop prices. This method, as described in more detail in the companion report by Sebastian and Wood (2000), was used to make crop-specific production maps corresponding to the base period for the simulation runs (1993-95). By using the GIS to overlay country boundaries, agroecological zones, and crop distribution maps, it was possible to derive area and production shares by AEZ and by country for each commodity (see table 8).

[Table 8: *Crop Area and Production by Agroecological Zones*]

A significant share of the harvested areas for the eight crops in this study occurs in just four agroecological zones. 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 acreage. We estimate that about 46 percent of the harvested area for potatoes occurs in the moderately cool to cool tropics (AEZ 21) while 27 percent of the harvested area for beans lies in the flat, semi-arid, tropics (AEZ 45). An indication of the concentration of crops according to their agroecological extent is given by the share of total harvested area that occurs within the two most important agroecological zones for each crop. Table 8 shows 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. The region's potato and wheat areas have exceptionally limited agroecological extents—75 percent of the potato area occurs in two zones and 88 percent of the wheat area.[13]

For most commodities, the zonal pattern of harvested area corresponds closely to the pattern of production. However, there are two exceptions to this general pattern. 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 6 shows that AEZ 45 is primarily found in north-eastern Brazil, where there is a preponderance of poor people working land with limited agricultural potential and where beans are a staple food, whereas AEZ 31 includes the major commercial bean producing areas of Argentina whose output 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 in area harvested and output produced primarily reflects the differences in the extensive, rainfed cultivation of rice in the Cerrados region (AEZ 43) and the irrigated production systems that prevail in the south of Brazil (AEZ 30).

AEZ-Specific Changes in Technology

The 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 country-wide basis, they are defined for specific agroecological zones. Nevertheless, in implementing AEZ-specific technological changes, we retain countries as the unit of analysis. A one percent unit cost reduction, k_z, in a particular AEZ is modeled as a simultaneous displacement in each country in proportion to the share of national production derived from the innovating AEZ; a vector of c country-specific supply shifts:

$$k_z = [\, k_{z1} \,, k_{z2} \,, k_{z3} \,, \ldots, k_{zc} \,]'$$

[13] Sebastian and Wood (2000) present a more detailed treatment of the agroecological extent of each crop.

where the k_{zi} are the country-specific supply shifts resulting from a one-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 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 we simulate for LAC have relatively small impacts on world prices so, in reality, the losses to producers in non-innovating AEZs are likely to be small. The benefits to innovating producers (i.e., 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.

3.7 Comparison With Previous Studies

Table 9 presents a chronology of previous, ex ante research evaluation studies that included Latin America. About half the studies drew little if any on economic methods to evaluate and prioritize R&D—they used some type of scoring approach, which as Alston, Norton, and Pardey (1998) describe, will generate rankings that can vary markedly from those obtained using more-formal economic approaches. Moreover, the choice of weights and the scoring units used to conduct the analysis interact in arbitrary, subtle, and sometimes surprising ways to affect the ranking of the R&D programs. Five studies used more-formal economic approaches, and three "hybrid" studies combined economic evaluation methods with scoring approaches to prioritize R&D.

[Table 9: *Chronology of Selected Ex Ante, R&D Evaluation Studies for Latin America*]

The spatial scope, commodity focus, and international dimensions of the studies vary too. The preponderance of studies (studies numbered 1, 2, 3, 5, 7, 9, 11, and 13 in table 9) have a country-specific focus, and several (6, 8, 10, and 12) took a regional approach. Only a few studies (14 and 15), sought to span both national and sub-regional spatial groupings, and only the present study provides a basis for dealing in an integrated fashion with spatial scales ranging from sub-national areas through to a regional grouping.

The commodity coverage is also quite different. The scoring studies included between 30 and 50 commodities, but with little economically relevant data on each commodity (for example, some had quantity produced or exported but most had only value of production). Most of the empirical elements used in these studies involved the elicitation of scores on various criteria and the imposition of weights on these scores. The "hybrid" and formal economic studies took a more data-intensive approach. Davis, Oram, and Ryan (1987) included 12 globally significant commodities. The present study covers eight of the most important crops (by value) in Latin America (and additional data have been assembled but not processed to include a further five commodities).

Most of the studies paid little attention to the consequences of international trade and technology spillovers. None of the scoring and few of the hybrid approaches included an explicit treatment of either aspect. The present study dealt explicitly with both of these aspects, and also allowed for the imperfect transmission of changes in domestic prices to international markets. Given the long time it takes to generate and diffuse new technologies, the dynamics of the R&D process (and its supply-side representation in an evaluation model), as well as the counterpart dynamics of population and income effects that have consequences for demand, are critical elements of a meaningful evaluation exercise. Both features are treated explicitly in the present model but one feature or the other (or both) are absent from most of the other studies in table 9.

As Alston, Norton, and Pardey (1998) describe, one of the critical determinants of the measured benefits from R&D is the magnitude (and timing, as just discussed) of the productivity and cost-reducing consequences of R&D and its subsequent supply-shifting effects. The productivity consequences of most agricultural technologies vary according to the location of production because of agroecological and other factors. None of the prior studies has sought to make this spatial variation in R&D effects a central element of the analysis. Many of the earlier studies relied on national average data, and thereby missed the significant spatial variation in the productivity effects of R&D as we quantify in this paper and describe in additional detail in the companion paper by Sebastian and Wood (2000). Moreover, the data used to characterize the agroecological dimensions of this analysis are much richer than those used in the past studies (4, 6, 8, 10, 12, 14, and 15) that included some agroecological element. Finally, this is the first study to allow for a consistent, joint representation of technology impacts by agroecological and geopolitical domains.

4. Evaluation Results

In this section we present results from various simulations, designed to represent alternative approaches to incorporating information about knowledge spillovers into our regional commodity supply and demand model. We simulate prices and quantities and present values of economic surpluses (benefits to producers, consumers, and in total) for each country and for the regional and sub-regional aggregates, for each scenario of interest. It 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, that are the focus of the analysis.

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 supply and demand are both growing at the same rate in each country but different rates among countries.

All of the simulation experiments are conducted in terms of research-induced supply shifts relative to this baseline, so that we are measuring and reporting 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 one-percent improvement in technology such that, after an adoption process is completed, supply shifts down by an amount per unit equal to one percent of the prevailing price in the base year. We conducted this type of simulation in each country, commodity by commodity for each of our eight commodities. The results show the effects in an innovating country that is the "source" of a new technology, and in other countries, when the innovating country adopts improved technology and the others 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-country trader in the commodity of interest, able to influence world prices by changing its quantity produced and consumed.

The second type of scenario is a modification of the first type of scenario in which 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 one percent of the base price), all other countries experience a supply shift by half of that amount per unit (i.e., ½K).[14]

[14] The choice of spillover coefficients at this stage is clearly arbitrary and illustrative. Information on spillover potential, obtained from consultation with agronomists and others, say, could be used to define more

In this type of scenario, even when the source country is not itself a large-country trader, there will be price effects for every commodity for which the LAC region as a whole is significant in the world market for the commodity. Hence, in this scenario we have both price and technology spillovers such that the total effects of the technology globally will be much greater, in many cases, but the distribution of those benefits also will 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.[15]

Both of these scenarios emphasize the geopolitical boundaries as important in terms of defining the interest groups and in defining 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 agroecological zones (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 is the basis on which decisions are made on which 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 one-percent supply shift experienced in a particular agroecology is translated

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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.

[15] However, if 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.

into a *k*-percent supply shift in a particular country (including the source country), where *k* is the fraction of the total production in that country that is sourced from the agroecology in question. Since we have assumed supply elasticities equal to one, it is straightforward to convert a given percentage supply shift in the price direction in an agrecological zone of interest, into an equal percentage quantity direction shift, to add that up across agroecological zones within a country, and then 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 one-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 benefit; and, in the case 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.

4.1 Baseline Estimates

The basic data used to define the baseline simulations were reported in tables 6a-h. These tables include the base quantities produced and consumed, and prices for each of the commodities in each of the producing counties, organized by the regions to which they belong. They also include 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 10 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 in both LAC and globally—typically around 60-80 percent over the period—with consumption tending to grow faster than production for LAC.

[Table 10: *Changes in Baseline Prices and Quantities in the Absence of Technical Change*]

4.2 One-Percent Region-wide Commodity-Specific Shifts

Table 11 shows the total benefits from one-percent shifts in supply of 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 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 to 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 one-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 regions. If every country experienced a one-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 region, and 2 percent to the Caribbean region.

[Table 11: *Total and Producer Benefits—One Percent, Regionwide, Commodity-Specific Shifts*]

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 one-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 regions differ among crops. The Southern Cone gains 95 percent of the benefits from soybean yield increases, and dominates the picture in general and for almost every crop (table 11). The two exceptions, where the Southern Cone does not reap more than half the LAC benefits from a one-percent supply shift, are the lower-valued crops for the region as a whole: the Mesoamerican region gains 52 percent of the benefits from sorghum yield increases, and the Andean region gains 46 percent of the benefits from potato yield improvements.

In table 12, the same information as in table 11 is presented in a different ordering, so as to show the ranking within each region of the different commodity-specific supply shifts in terms of the size of the regional benefits. Hence, for the region as a whole, the ranking is soybeans, maize, rice, cassava, beans, wheat, potatoes, and sorghum. But the ranking is different among the different subregions, with the exception of the Southern Cone, which dominates the region and has the same ordering as LAC, apart from switching rice and cassava. In addition, table 12 shows the percentage LAC-wide supply shift required to achieve the same benefits within a region as given by a one-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 one-percent supply shift in soybeans—$1,989 million for LAC as a whole.

[Table 12: *Ranking and Supply-Shift Relativities—One Percent, Regionwide, Commodity-Specific Shifts*]

Distribution of Benefits between Producers and Consumers

The middles panel of table 11 shows the fractions of total LAC benefits accruing to LAC producers for each type of LAC-wide commodity-specific supply shift, within each sub-region. For the region 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 percent to 3 percent (i.e., 100 minus the producer share). This outcome, where producers get most of the benefits, is a reflection of 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 the world price. 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 combine to mean that the LAC region 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 comes from a very low LAC share of global production, leading to a very elastic export demand facing LAC; soybeans has the lowest producer share because, compared with the other eight crops, LAC is relatively important in global production of soybeans.

Within Sub-regions

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 by 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 mean that consumer (or producer) price changes are not the same in every country; it 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 (i.e., 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 the ROW, we repeated the same experiments as above (i.e., commodity-by-commodity one-percent supply shifts throughout LAC), but with a 0.5 percent supply shift in the ROW. The results are summarized in table 13. It can be seen that the benefits to the ROW are quite substantial, and much greater than the benefits within LAC in some cases (e.g., rice and wheat), such that the global benefits are much greater with the technology spillover. Interestingly, the technology spillovers to the ROW do not have much influence over the total benefits to LAC or to particular sub-regions within LAC from the given supply shifts in LAC. In contrast, however, the technology spillovers to the ROW have a big influence over the distribution of the given benefits to LAC (or particular LAC subregions): 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 the ROW give rise to big changes in world prices, and from LAC's point of view, the main effect of these price changes arising from ROW adoption of the technology 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.

[Table 13: *Total and Producer Benefits—One Percent, Regionwide, Commodity-Specific Shifts, with ROW Spillovers*]

4.3 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 one-percent supply shifts, country-by-country, commodity-by-commodity. With eight commodities and 21 countries, this would mean 168 experiments, except that some commodities are not produced in every country; nevertheless the number of experiments is large at 151. Then we repeated each of the same experiments, allowing for a 50 percent spillover of the same supply shift into every other country. The full set of results is reported in the appendix tables 2 through 7, in terms of benefits to producers and consumers in each country, and then summed up across countries into sub-regions, the LAC region, and the world as a whole, 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 one percent of the value of production in the innovating country (compounded over time according to the adoption path and the discount factor), and all accrues to producers within the country. This would be the way to read most of the entries in appendix table 2, which shows the total benefits, country-by-country, commodity-by-commodity of one-percent supply shifts without technology spillovers. The corresponding information has been summarized in figure 7 panels a through c. Figure 7, panel a shows the benefits to producers and consumers, and total benefits to the innovating country, commodity by commodity; panel b shows the corresponding benefits for the sub-region that contains the innovating country; panel c shows the corresponding benefits for the LAC region as a whole. The different spatial aggregates are considered because different decision makers, and different types of decisions, require information on the effects of a given technological change on the country, the sub-region, or the region as a whole.

[Figure 7a-c: *Total, producer, and consumer benefits—one percent, country- and commodity-specific shifts, without spillovers*]

The upper section of figure 7 shows, country-by-country, the benefits to the innovating country from a one-percent shift of the supply of beans. The corresponding sections of panels b and c show the corresponding benefits to the sub-region in which the innovating country is found, and to LAC. Consider the case of innovations by Brazil. Figure 7a 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 7b shows that, for the Southern Cone region, in which Brazil is found, essentially the same figures as for Brazil apply for sub-regional total benefits, except that the consumer share has risen; and the same again as we go to the LAC region 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, as a result of Mexico being a smaller producer of beans and thus having less influence over the world price. In every other innovating country (i.e., except for 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 sub-regional and regional total 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 appendix tables 2 through 4 and figure 7, panels a through c is that the regional and sub-regional 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 sub-regional, regional, 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, a series of country-by-country, commodity-by-commodity, country-specific one-percent supply shifts. Now, however, we allow for 50-percent technology spillovers. This means that when an innovating country's supply of, say, beans, shifts by one percent, every other country's supply curve of beans also shifts by half of one percent. In some senses, these experiments fall in-between our two sets of experiments above: (a) commodity-specific, region-wide, one-percent shifts (equivalent to a country-specific shift with 100-percent spillovers to all within-LAC countries and a 50-percent spillover to the 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 the LAC and the ROW 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 ROW, the total research benefit to LAC is approximately equal to half of the benefit from a one-percent, region-wide supply shift (with or without the 50-percent technology spillover to the ROW).

Appendix tables 5 trough 7 show the total benefits, country-by-country, commodity-by-commodity of one-percent supply shifts with 50-percent technology spillovers. The corresponding information has been summarized in figure 8, panels a through c. Figure 8a shows the benefits to producers and consumers, and total benefits to the innovating country, commodity by commodity; figure 8b shows the corresponding benefits for the sub-region that contain the innovating country; figure 8c shows the corresponding benefits for the LAC region as a whole. Again, the different spatial aggregates are considered because different decision makers, and different types of decisions, require information on the effects of a given technological change on the country, the sub-region, or the region as a whole.

[Figure 8a-c: *Total, producer, and consumer benefits—one percent, country- and commodity-specific shifts, with spillovers*]

In a counterpart to figure 7a for the without-spillover experiments, the first section of figure 8a shows, country-by-country the benefits to the innovating country from a one-percent shift of the supply of beans. The corresponding sections of figures 8b and 8c show the corresponding benefits to the sub-region in which the innovating country is found, and to LAC. Consider the case of innovations by Brazil. Figure 8a 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 region-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 figure 8 with the counterparts in figure 7 (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 substantially increase the total benefits and to greatly reduce the LAC share of the total benefits.

To illustrate and emphasize this last point more clearly, figure 9 represents the change in producer and consumer benefits, for innovating countries (or their regions or LAC) as they introduce technology giving rise to one-percent commodity supply shifts with 50-percent spillovers to other countries. The pattern is clear and self explanatory: the main effect of introducing spillovers is to increase consumer benefits at the expense of a reduction in producer benefits of a similar magnitude.

[Figure 9: *Differences in producer and consumer benefits with and without spillovers—One Percent, Country- and Commodity-Specific Shifts*]

4.4 One-Percent AEZ-Specific Shifts, 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 over-riding) 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 into12 agroecological zones. As figure 6 made clear, these zones are not necessarily contiguous and most zones span multiple countries, so that innovations in one zone can effect multiple countries even in the absence of zone-to-zone spillovers.

Table 14 shows the sub-regional and LAC-wide benefits from research-induced zone-specific technical changes, that were represented as one-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 one-percent supply shift in each of the seven agroecological zones 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 (i.e., across technical changes) within a geopolitical sub-region.[16] It does, however, make sense to sum across sub-regions 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 its distribution among countries and sub-regions arising from different zone- and crop-specific technological changes. Comparing among sub-regions 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 14: *Total Benefits—One Percent, AEZ-Specific Shifts, Without Zone-to-Zone Spillovers*]

[16] 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.

Table 14 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 (i.e., would cost the same) to achieve a one-percent zone specific improvement in productivity of any of the eight crops. Then we can determine which type of technological change would be preferred by each of the sub-regions, or the LAC region as a whole, simply by comparing the benefit estimates in table 14.

First, consider the LAC as a whole. Among all the technological changes represented in table 14, the LAC would benefit most from a one-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 sub-region would rank these top three types of productivity increases in soybeans and maize in the same order as LAC as a whole. The other sub-regions would rank the technological changes differently. For instance, the Mesoamerican sub-region 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) as well as sorghum in zone 45 ($33 million)—all in the warm tropics and subtropics. In the Caribbean region, 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 sub-region, and 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 agroecological zones, so as to yield the biggest payoff to the LAC region (or particular subregions)? For beans, the answer is not clear. Four zones (21, 32, 44, and 45) offer roughly equal benefits to the region from one-percent productivity gains (about $120 million). But these different zones are distributed quite differently among sub-regions so the alternatives imply very different patterns of benefits within LAC (e.g., 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 sub-region. 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 regional distribution of benefits is very different between these zones. For potatoes, zone 21 offers the highest payoff, mostly in the Andean sub-region. 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.

5. Conclusion

In this paper we describe a new approach to evaluating the future consequences of agricultural R&D and present results that can help allocate R&D resources at different spatial scales of decision-making—be it allocating resources among crops and agroecological zones within a country, or for sub-regional grouping of countries, or for the LAC region as a whole. We use an explicit economic framework to evaluate the benefits from R&D that involves an extensive amount of 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 agroecological zones span some but generally not all countries in LAC, 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 incidence of the economic benefits from research.

As described in the previous section, the incidence 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 (e.g., the case of beans). In some cases, the total benefits to LAC are the net result of large gains in one sub-region or another (often large gains in the Southern Cone), and small gains in other sub-regions, or even losses in some sub-regions (negative entries in table 14). Losses to producers in a sub-region can arise if they are unable to adopt the technology very extensively (for instance, if the sub-region 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 sub-regions causes prices to fall. If the sub-region 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 sub-region 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 sub-regions within LAC. However, they do have a big influence on the distribution of the benefits between producers and consumers within LAC (or a particular sub-region 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 significant 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 on LAC agriculture, it also opens up new opportunities for deepening our understanding of these issues in ways that can improve policy decisions. One obvious and planned 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. Our model took explicit account of the underlying sources of growth in demand (and supply) due to the projected growth in population and income (and other factors) when estimating the benefits from research. We also made explicit the international trade aspects of the respective crops 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 is 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 zones that we have reported here.

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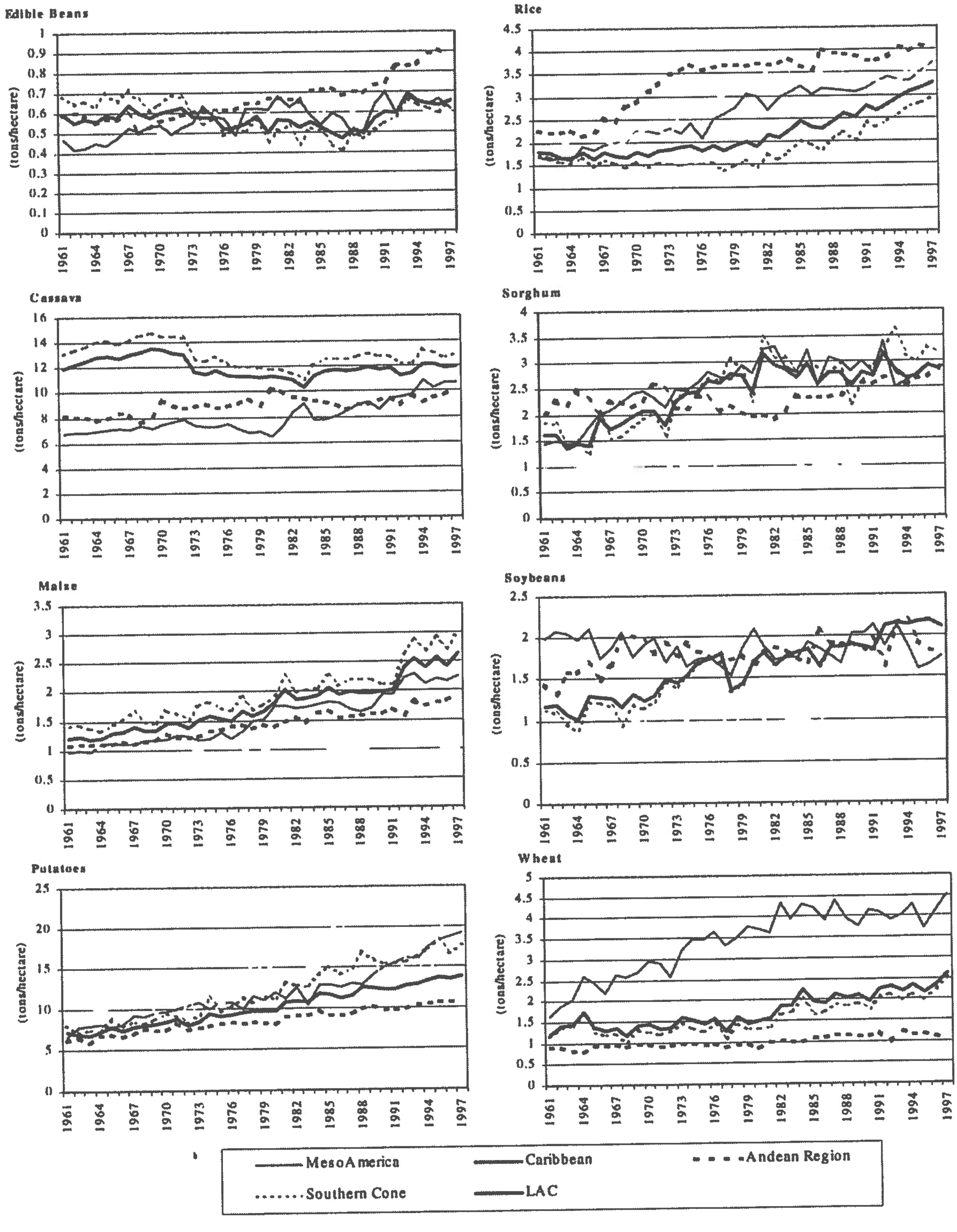
Table 1: *Spatial Pattern of Crop Production in Latin America, 1997*

	Soybeans		Maize		Rice		Wheat		Beans		Cassava		Potatoes		Sorghum	
Rank	Country	Share	Country	Share	Country	Share	Country	Share	Country	Share	Country	Share	Country	Share	Country	Share
		(%)		(%)		(%)		(%)		(%)		(%)		(%)		(%)
1	Brazil	63.6	Brazil	44.8	Brazil	46.1	Argentina	62.3	Brazil	59.2	Brazil	75.5	Colombia	18.2	Mexico	55.7
2	Argentina	26.5	Mexico	22.9	Colombia	8.9	Mexico	15.5	Mexico	19.1	Paraguay	9.8	Brazil	17.8	Argentina	24.4
3	Paraguay	6.4	Argentina	20.1	Peru	7.2	Brazil	10.3	Argentina	5.6	Colombia	5.7	Peru	15.4	Brazil	4.5
4	Bolivia	2.5	Venezuela	1.6	Argentina	6.0	Chile	6.6	Colombia	2.8	Peru	2.4	Argentina	15.4	Venezuela	4.1
5	Mexico	0.4	Guatemala	1.5	Ecuador	5.3	Uruguay	2.1	Nicaragua	1.8	Venezuela	1.3	Mexico	8.5	Colombia	3.3
6	Colombia	0.2	Paraguay	1.4	Uruguay	5.1	Paraguay	1.7	Guatemala	1.6	Haiti	1.1	Chile	8.4	El Salvador	1.9
7	Guatemala	0.1	Colombia	1.3	Venezuela	3.9	Bolivia	0.6	Paraguay	1.3	Bolivia	1.1	Bolivia	5.4	Uruguay	1.3
8	Nicaragua	0.1	Peru	1.1	Guyana	2.8	Peru	0.5	El Salvador	1.3	Cuba	0.8	Ecuador	3.9	Bolivia	1.0
9	Uruguay	0.0	Chile	1.0	Dom. Rep.	2.6	Colombia	0.2	Peru	1.2	Argentina	0.5	Cuba	2.4	Nicaragua	1.0
10	Honduras	0.0	Ecuador	0.9	Mexico	2.4	Guatemala	0.1	Honduras	1.1	Costa Rica	0.5	Venezuela	2.1	Honduras	0.9
	Top five	99.5		90.9		73.6		96.8		88.5		94.7		75.4		92.0
	Top ten	99.9		96.5		90.6		99.9		95.0		98.6		97.6		98.0
							(millions international 1989-91 dollars)									
	Total value															
		9,727		9,596		3,825		3,404		2,722		2,184		1,708		1,272
								(percentage)								
	Share of total crop production															
		12.3		12.1		4.8		4.3		3.4		2.8		2.2		1.6

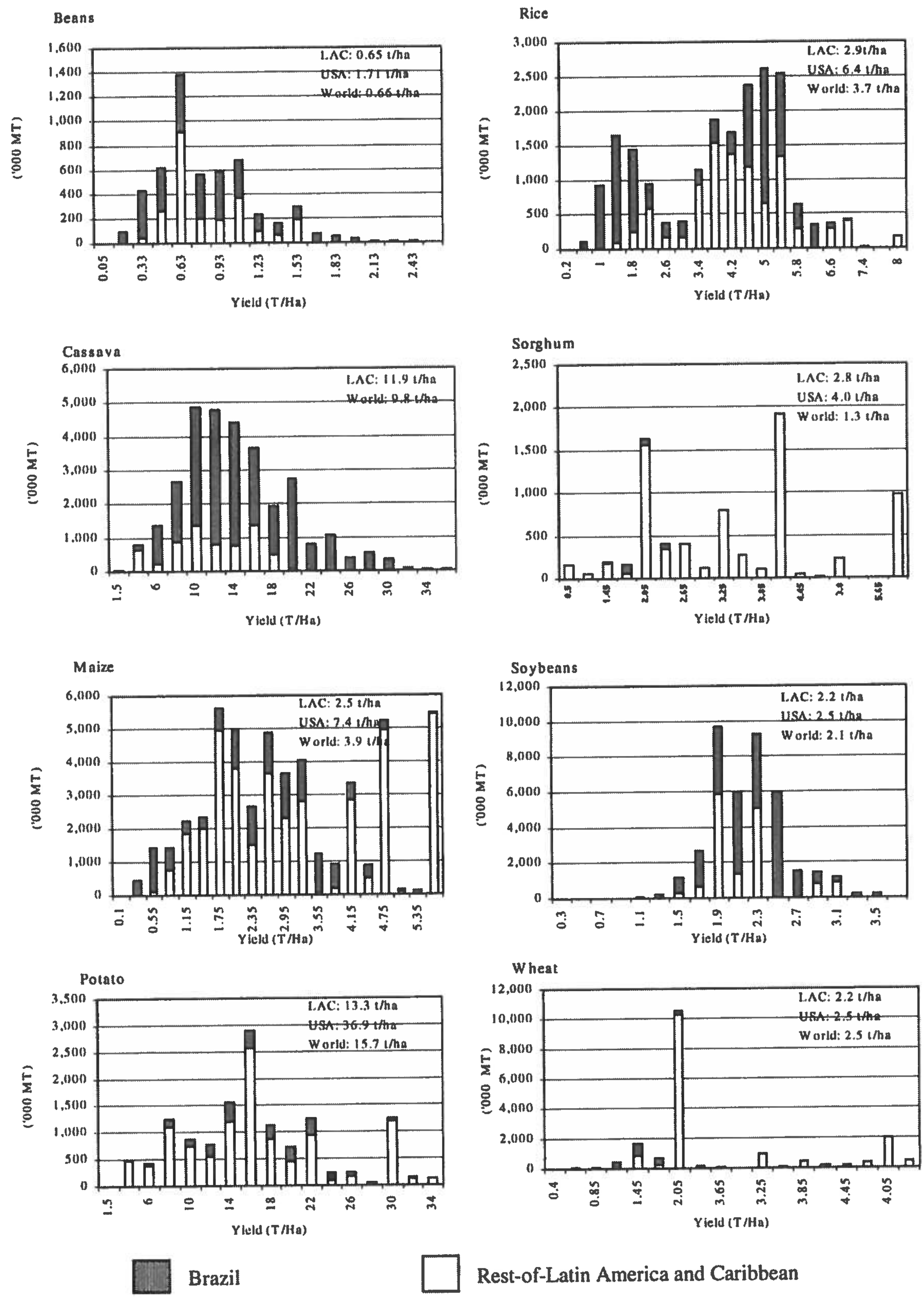
Source: Compiled by authors from FAOSTAT (1999).
Note: Percentages in the main body of the table represent 1997 quantity of production weighted by the respective 1989-91 international agricultural prices received by farmers.

Figure 1: *Yield Trend in Latin America, 1961-97*



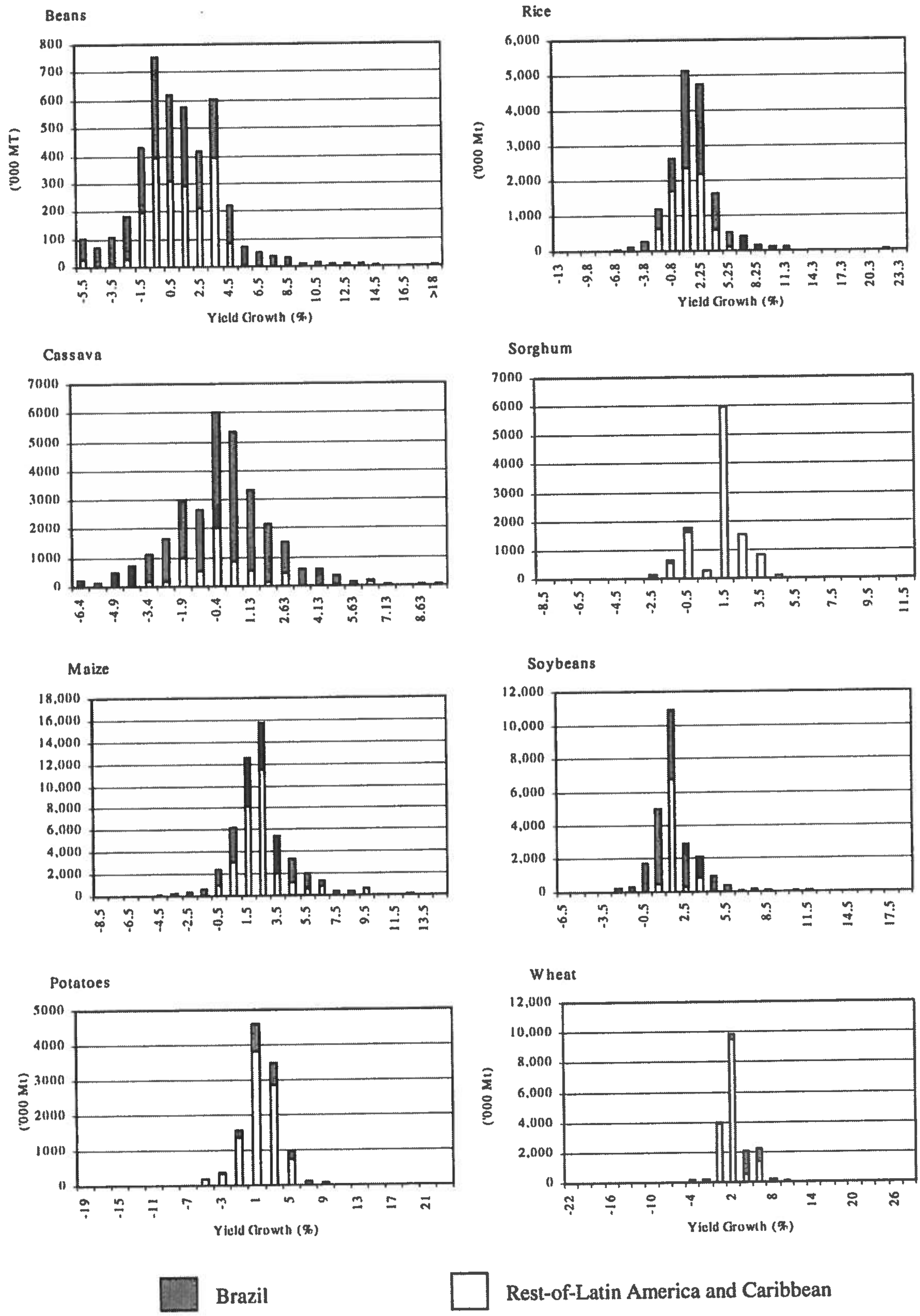
Source: FAOSTAT (1999).

Figure 2: *Distribution of 1993-95 crop production by yield levels*



Source: Pardey, Chan-Kang, and Wood (2000) using data from IFPRI (1999).

Figure 3: *Distribution of 1993-95 crop production by yield growth rates over 1975-95 period*



Source: Pardey, Chan-Kang, and Wood (2000) using data from IFPRI (1999).

Table 2: *Area Harvested Stratified by Various Yield Level and Growth Rate Classes*

	Bean	Cassava	Maize	Rice	Potato	Sorghum	Soybean	Wheat
Yield level				*(percentage)*				
Very low	12.9	1.2	14.1	12.6	16.0	2.6	0.0	26.9
Low	45.9	27.0	32.1	38.9	31.1	35.6	0.3	32.4
Medium	20.1	39.4	27.9	12.8	34.0	17.7	12.7	27.9
High	14.7	22.4	15.7	19.8	11.1	26.9	64.0	4.9
Very high	6.4	10.0	10.1	14.0	7.6	17.2	23.0	7.8
Yield growth								
High negative	14.2	14.0	4.4	0.8	7.3	4.1	0.7	1.8
Negative	26.2	31.9	7.2	25.6	15.7	27.6	4.8	22.2
Marginal	2.6	6.1	1.7	5.2	2.5	38.4	2.2	0.2
Positive	22.1	32.9	33.5	32.3	40.8	28.1	57.9	47.6
High positive	34.9	15.1	53.2	34.1	33.5	1.9	34.5	28.3
Missing data	0.0	0.0	0.1	1.9	0.2	0.0	0.0	0.0

Source: Pardey, Chan-Kang, and Wood (2000).
Note: Percentage indicates share of area harvested in respective yield classes.

Table 3: *Distribution of Area by Yield Level and Growth Intersection Class, Hectares*

Yield level/Yield growth	Bean	Cassava	Maize	Potato	Rice	Sorghum	Soybean	Wheat
				(1,000 hectares)				
Very low								
High negative	550.78	20.49	1,045.13	32.47	5.71	60.91	3.41	32.15
Negative	262.44	3.97	1,034.25	79.35	565.21	0.43	1.55	1.449.48
Marginal	9.37	0	115.26	21.16	30.95	0.20	0.01	.06
Positive	131.19	0	809.08	25.41	139.02			616.75
High positive	101.04	3.61	938.36	0.74	106.57	0.13	0.01	78.86
Low								
High negative	520.54	156.37	115.80	18.52	20.76	16.96	21.69	108.17
Negative	1,242.10	241.81	598.51	13.68	763.83	626.31	14.45	340.38
Marginal	97.51	28.56	192.22	0.23	120.58	1.60	1.32	12.87
Positive	703.33	163.10	4,505.67	231.37	737.95	161.97	5.10	732.29
High positive	1,205.19	61.03	3,562.41	45.03	980.37	43.48	4.10	1.428.14
Medium								
High negative	76.10	143.98	65.30	18.37	2.12	0.66	91.38	0
Negative	434.63	370.56	304.93	53.97	255.01	32.96	294.15	0
Marginal	57.92	52.47	139.95	1.10	56.21	294.65	73.06	0.06
Positive	429.96	301.10	2,042.46	118.92	291.15	94.66	1.425.05	1.909.20
High positive	653.12	82.65	5,225.45	145.29	257.53		514.75	346.14
High								
High negative	16.97	16.13	0	17	22.00	19.12	7.68	0.27
Negative	182.10	131.85	30.41	8.97	144.39		413.23	0.34
Marginal	26.88	39. 90	15.25	2.15	118.01	459.72	251.13	0
Positive	453.53	238.76	908.89	19.08	500.87	164.16	8.560.24	97.78
High positive	528.89	114.060	3,416.81	79.94	553.48	0.65	2.849.82	299.30
Very High								
High negative	1.53	1.32	0	3.46	0		6.42	5.53
Negative	25.73	19.52	38.40	0.31	1.08		174.95	0
Marginal	19.39	25.85	0	0	26.45	160.48	84.94	0
Positive	96.84	89.77	1.078.03	10.50	513.07	250.11	927.26	492.84
High positive	378.49	103.61	1.705.86	61.59	404.84		3.140.54	131.18
Missing data	0.07	0.23	35.23	2.10	130.10	0.46	0.04	0.01
Total area per crop	*8,205.65*	*2,410.70*	*27,923.65*	*993,85*	*6,747.25*	*2,389.00*	*18,866.26*	*8,081.61*

Source: Pardey, Chan-Kang, and Wood (2000).

Table 4: *Distribution of Area by Yield Level and Growth Intersection Class, Percentage*

Yield level/Yield growth	Bean	Cassava	Maize	Potato	Rice	Sorghum	Soybean	Wheat
				(percentage)				
Very low								
High negative	6.7	0.9	3.7	3.3	0.1	2.6	0.0	0.4
Negative	3.2	0.2	3.7	8.0	8.4	0.0	0.0	17.9
Marginal	0.1	0.0	0.4	2.1	0.5	0.0	0.0	0.0
Positive	1.6	0.0	2.9	2.6	2.1	0.0	0.0	7.6
High positive	1.2	0.2	3.4	0.1	1.6	0.0	0.0	1.0
Low								
High negative	6.3	6.5	0.4	1.9	0.3	0.7	0.1	1.3
Negative	15.1	10.0	2.1	1.4	11.3	26.2	0.1	4.2
Marginal	1.2	1.2	0.7	0.0	1.8	0.1	0.0	0.2
Positive	8.6	6.8	16.1	23.3	10.9	6.8	0.0	9.1
High positive	14.7	2.5	12.8	4.5	14.5	1.8	0.0	17.7
Medium								
High negative	0.9	6.0	0.2	1.9	0.0	0.0	0.5	0.0
Negative	5.3	15.4	1.1	5.4	3.8	1.4	1.6	0.0
Marginal	0.7	2.2	0.5	0.1	0.8	12.3	0.4	0.0
Positive	5.2	12.5	7.3	12.0	4.3	4.0	7.6	23.6
High positive	8.0	3.4	18.7	14.6	3.8	0.0	2.7	4.3
High								
High negative	0.2	0.7	0.0	0.0	0.3	0.8	0.0	0.0
Negative	2.2	5.5	0.1	0.9	2.1	0.0	2.2	0.0
Marginal	0.3	1.7	0.1	0.2	1.8	19.2	1.3	0.0
Positive	5.5	9.9	3.3	1.9	7.4	6.9	45.4	1.2
High positive	6.5	4.7	12.2	8.0	8.2	0.0	15.1	3.7
Very high								
High negative	0.0	0.1	0.0	0.4	0.0	0.0	0.0	0.1
Negative	0.3	0.8	0.1	0.0	0.0	0.0	0.9	0.0
Marginal	0.2	1.1	0.0	0.0	0.4	6.7	0.5	0.0
Positive	1.2	3.7	3.9	1.1	7.6	10.5	4.9	6.1
High Positive	4.6	4.3	6.1	6.2	6.0	0.0	16.7	1.6
Missing data	0.0	0.0	0.1	0.2	1.9	0.0	0.0	0.0
Total area per crop	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*

Source: Pardey, Chan-Kang, and Wood (2000).

Figure 4: *Size and distribution of research benefits for a traded good (exporter innovates, no technology spillovers, large country)*

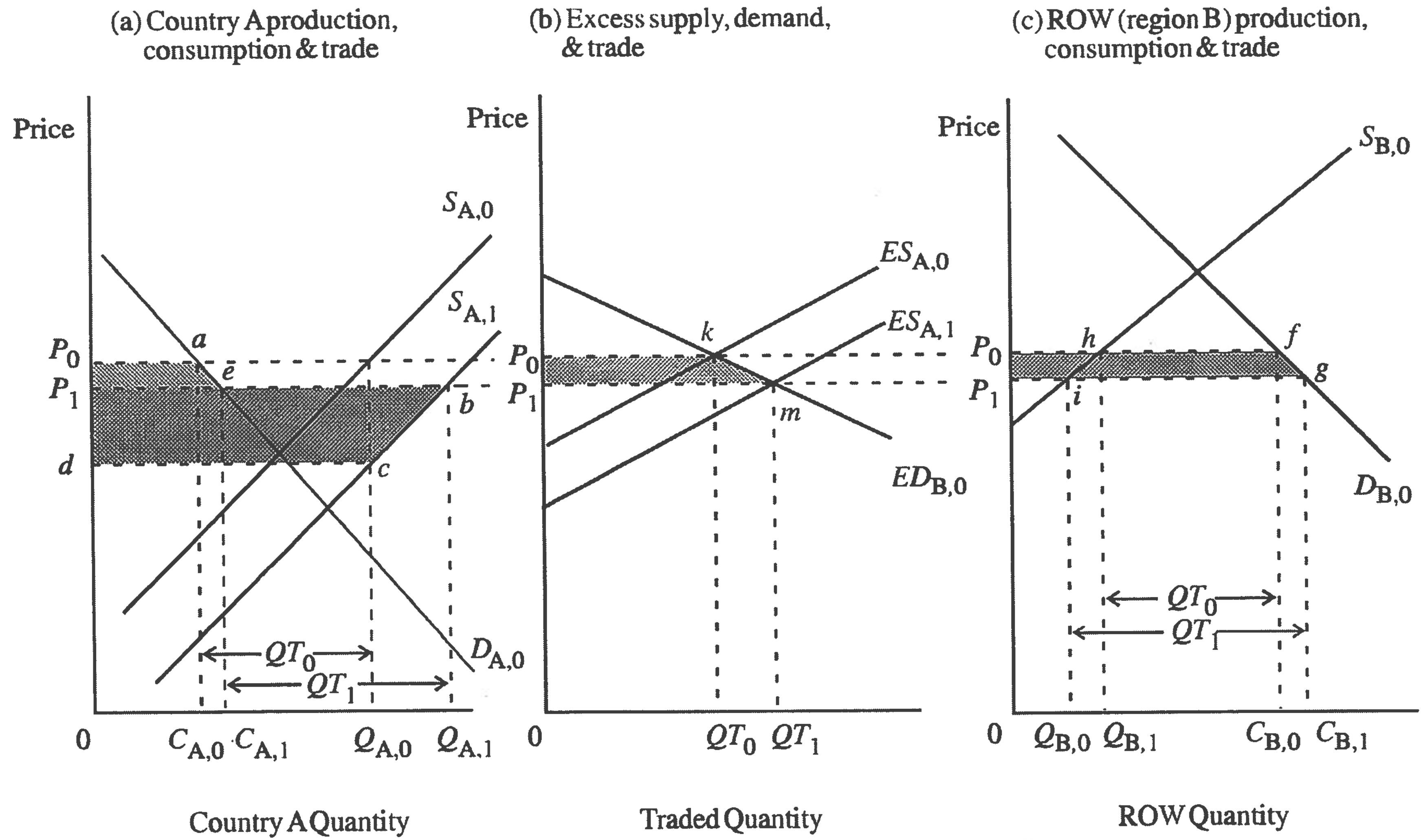


Figure 5: *Size and distribution of research benefits for a traded good (importer innovates, no technology spillovers, large country)*

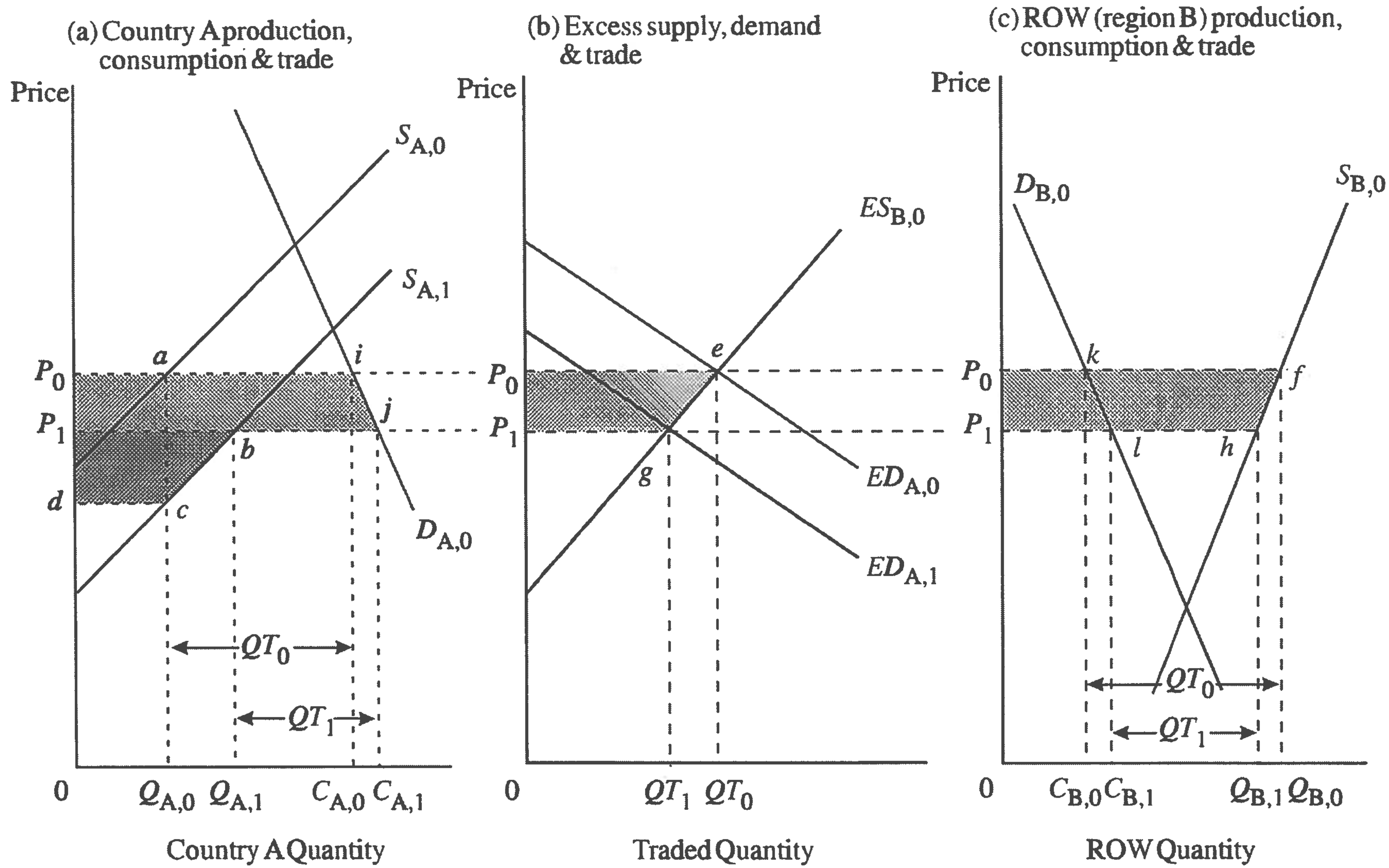


Table 5: *Overall Structure of Simulations*

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/annum	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
Disadoption		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	

Table 6a: *Base Data for DREAM Simulation—Beans*

Regions/Countries	Quantities		Price[b]	Price Elasticities		Exogenous Demand Shift Variables		
	Demand	Supply		Demand	Supply	Feed Share	Derived Income Elasticities[c]	Per Capita GDP Growth[d]
	(tons)		*(US $/ton)*	*(percent)*		*(percent)*		*(percent p.a.)*
Mesoamerica	*1,565,708*	*1,486,211*						
Costa Rica	33,869	33,101	646.19	0.5	1.0	0	0.5	1.86
El Salvador	65,114	59,000	646.19	0.5	1.0	0	0.5	3.33
Guatemala	101,526	98,944	646.19	0.5	1.0	0	0.5	1.41
Honduras	59,398	53,277	646.19	0.5	1.0	0	0.5	0.34
Mexico	1,231,899	1,160,326	646.19	0.5	1.0	0	0.5	0.37
Nicaragua	68,196	75,615	646.19	0.5	1.0	0	0.5	0.27
Panama	5,706	5,949	646.19	0.5	1.0	0	0.5	2.89
Caribbean/other	*147,231*	*108,509*						
Cuba	17,500	18,250	646.19	0.5	1.0	0	0.5	1.66
Dominican Rep.	48,066	37,566	646.19	0.5	1.0	0	0.5	3.20
Haiti	75,525	49,275	646.19	0.5	1.0	0	0.5	0.00
Other[a]	6,140	3,418	646.19	0.5	1.0	0	0.5	1.66
Andean	*340,259*	*266,136*						
Bolivia	5,686	10,100	646.19	0.5	1.0	0	0.5	1.63
Colombia	148,745	134,145	646.19	0.5	1.0	0	0.5	1.56
Ecuador	36,923	37,301	646.19	0.5	1.0	0	0.5	0.89
Peru	52,237	52,557	646.19	0.5	1.0	0	0.5	4.34
Venezuela	96,668	32,033	646.19	0.5	1.0	0	0.5	0.00
Southern Cone	*3,087,436*	*3,218,157*						
Argentina	23,424	203,468	646.19	0.5	1.0	0	0.5	1.99
Brasil	2,989,491	2,898,375	646.19	0.5	1.0	0	0.5	1.95
Chile	23,575	63,782	646.19	0.5	1.0	0	0.5	3.24
Paraguay	46,659	49,532	646.19	0.5	1.0	0	0.5	0.41
Uruguay	4,288	3,000	646.19	0.5	1.0	0	0.5	2.35
United States	*924,408*	*1,183,575*	*646.19*	*0.5*	*1.0*	*0.0005*	*0.50*	*1.95*
Rest of world	*10,438,222*	*10,240,676*	*646.19*	*0.5*	*1.0*	*0.08*	*0.54*	*0.59*
World total	*16,503,263*	*16,503,263*						

Table 6b: *Base Data for DREAM Simulations—Cassava*

Regions/Countries	Quantities		Price[b]	Price Elasticities		Exogenous Demand Shift Variables		
	Demand	Supply		Demand	Supply	Feed Share	Derived Income Elasticities[c]	Per Capita GDP Growth[d]
	(tons)		*(US $/ton)*	*(percent)*		*(percent)*		*(percent p.a.)*
Mesoamerica	*162,903*	*243,491*						
Costa Rica	7,128	93,141	180.7	0.5	1.0	0	0.5	1.86
El Salvador	41,743	41,826	180.7	0.5	1.0	0	0.5	3.33
Guatemala	15,106	15,185	180.7	0.5	1.0	0	0.5	1.41
Honduras	4,056	8,680	180.7	0.5	1.0	0	0.5	0.34
Mexico	8,312	1,941	180.7	0.5	1.0	0	0.5	0.37
Nicaragua	51,127	51,375	180.7	0.5	1.0	0.34	0.67	0.27
Panama	35,432	31,343	180.7	0.5	1.0	0.17	0.59	2.89
Caribbean/other	*773,835*	*823,062*						
Cuba	280,000	280,000	180.7	0.5	1.0	0.23	0.61	1.66
Dominican Rep.	115,940	118,327	180.7	0.5	1.0	0	0.5	3.20
Haiti	317,900	342,900	180.7	0.5	1.0	0.12	0.56	0.00
Other[a]	59,995	81,835	180.7	0.5	1.0	0.18	0.59	1.66
Andean	*3,052,748*	*2,960,264*						
Bolivia	330,550	330,229	180.7	0.5	1.0	0.48	0.74	1.63
Colombia	1,801,830	1,774,415	180.7	0.5	1.0	0.18	0.59	1.56
Ecuador	74,751	76,442	180.7	0.5	1.0	0	0.5	0.89
Peru	471,912	471,203	180.7	0.5	1.0	0	0.5	4.34
Venezuela	373,706	307,975	180.7	0.5	1.0	0.13	0.56	0.00
Southern Cone	*26,199,600*	*26,244,949*						
Argentina	164,498	152,500	180.7	0.5	1.0	0.51	0.76	1.99
Brasil	23,324,305	23,387,543	180.7	0.5	1.0	0.60	0.80	1.95
Chile	38		180.7	0.5	1.0	0	0.5	3.24
Paraguay	2,705,876	2,704,906	180.7	0.5	1.0	0.72	0.86	0.41
Uruguay	4,883		180.7	0.5	1.0	0	0.5	2.35
United States	*307,109*		*180.7*	*0.5*	*1.0*	*0.61*	*0.80*	*1.95*
Rest of world	*131,503,805*	*131,728,235*	*180.7*	*0.5*	*1.0*	*0.22*	*0.61*	*0.59*
World total	*162,000,000*	*162,000,000*						

Table 6c: *Base Data for DREAM Simulations—Maize*

Regions/Countries	Quantities			Price Elasticities		Exogenous Demand Shift Variables		
	Demand	Supply	Price[b]	Demand	Supply	Feed Share	Derived Income Elasticities[c]	Per Capita GDP Growth[d]
	(tons)		*(US $/ton)*	*(percent)*		*(percent)*		*(percent p.a.)*
Mesoamerica	*22,580,074*	*20,773,322*						
Costa Rica	318,913	33,895	113.38	0.5	1.0	0.83	0.91	1.86
El Salvador	731,550	613,993	113.38	0.5	1.0	0.28	0.64	3.33
Guatemala	1,359,872	1,227,609	113.38	0.5	1.0	0.13	0.56	1.41
Honduras	638,578	601,399	113.38	0.5	1.0	0.16	0.58	0.34
Mexico	18,981,533	17,910,825	113.38	0.5	1.0	0.29	0.65	0.37
Nicaragua	302,212	277,130	113.38	0.5	1.0	0.13	0.56	0.27
Panama	247,417	108,473	113.38	0.5	1.0	0.65	0.82	2.89
Caribbean/other	*1,473,921*	*353,722*						
Cuba	195,133	65,633	113.38	0.5	1.0	1.00	1.00	1.66
Dominican Rep.	675,270	39,236	113.38	0.5	1.0	0.89	0.95	3.20
Haiti	220,555	206,580	113.38	0.5	1.0	0.05	0.53	0.00
Other[a]	382,964	42,274	113.38	0.5	1.0	0.61	0.81	1.66
Andean	*6,645,840*	*3,863,268*						
Bolivia	423,780	497,818	113.38	0.5	1.0	0.30	0.65	1.63
Colombia	1,917,102	1,095,139	113.38	0.5	1.0	0.33	0.66	1.56
Ecuador	557,233	563,828	113.38	0.5	1.0	0.57	0.78	0.89
Peru	1,435,936	683,156	113.38	0.5	1.0	0.78	0.89	4.34
Venezuela	2,311,790	1,023,328	113.38	0.5	1.0	0.42	0.71	0.00
Southern Cone	*40,368,904*	*44,745,243*						
Argentina	5,558,472	10,841,375	113.38	0.5	1.0	0.95	0.97	1.99
Brasil	32,851,550	32,330,775	113.38	0.5	1.0	0.89	0.94	1.95
Chile	1,318,564	922,506	113.38	0.5	1.0	0.09	0.55	3.24
Paraguay	450,721	541,669	113.38	0.5	1.0	0.46	0.73	0.41
Uruguay	189,598	108,918	113.38	0.5	1.0	0.63	0.81	2.35
United States	*169,000,000*	*211,000,000*	*113.38*	*0.5*	*1.0*	*0.97*	*0.98*	*1.95*
Rest of world	*284,931,261*	*244,264,444*	*113.38*	*0.5*	*1.0*	*0.71*	*0.86*	*0.59*
World total	*525,000,000*	*525,000,000*						

Table 6d: *Base Data for DREAM Simulations—Potatoes*

Regions/Countries	Quantities		Price[b]	Price Elasticities		Exogenous Demand Shift Variables		
	Demand	Supply		Demand	Supply	Feed Share	Derived Income Elasticities[c]	Per Capita GDP Growth[d]
	(tons)		*(US $/ton)*	*(percent)*		*(percent)*		*(percent p.a.)*
Mesoamerica	*1,538,434*	*1,373,719*						
Costa Rica	52,187	51,045	158.83	0.5	1.0	0.05	0.52	1.86
El Salvador	16,702	7,650	158.83	0.5	1.0	0	0.5	3.33
Guatemala	38,675	55,905	158.83	0.5	1.0	0	0.5	1.41
Honduras	18,104	18,218	158.83	0.5	1.0	0	0.5	0.34
Mexico	1,354,169	1,195,709	158.83	0.5	1.0	0	0.5	0.37
Nicaragua	39,402	26,875	158.83	0.5	1.0	0	0.5	0.27
Panama	19,195	18,319	158.83	0.5	1.0	0	0.5	2.89
Caribbean/other	*405,168*	*289,641*						
Cuba	279,176	242,431	158.83	0.5	1.0	0	0.5	1.66
Dominican Rep.	28,027	28,046	158.83	0.5	1.0	0	0.5	3.20
Haiti	7,375	7,375	158.83	0.5	1.0	0	0.5	0.00
Other[a]	90,591	11,790	158.83	0.5	1.0	0	0.5	1.66
Andean	*5,898,451*	*5,798,146*						
Bolivia	670,314	669,843	158.83	0.5	1.0	0.13	0.57	1.63
Colombia	2,703,180	2,744,766	158.83	0.5	1.0	0.12	0.56	1.56
Ecuador	482,251	482,544	158.83	0.5	1.0	0.01	0.51	0.89
Peru	1,683,336	1,656,494	158.83	0.5	1.0	0	0.5	4.34
Venezuela	359,370	244,499	158.83	0.5	1.0	0	0.5	0.00
Southern Cone	*5,828,337*	*5,688,970*						
Argentina	2,115,018	2,148,458	158.83	0.5	1.0	0	0.5	1.99
Brasil	2,618,257	2,484,424	158.83	0.5	1.0	0	0.5	1.95
Chile	934,571	929,599	158.83	0.5	1.0	0.06	0.53	3.24
Paraguay	2,755	1,639	158.83	0.5	1.0	0	0.5	0.41
Uruguay	157,736	124,850	158.83	0.5	1.0	0.12	0.56	2.35
United States	*19,940,218*	*20,011,500*	*158.83*	*0.5*	*1.0*	*0.01*	*0.51*	*1.95*
Rest of world	*249,389,393*	*249,838,024*	*158.83*	*0.5*	*1.0*	*0.30*	*0.65*	*0.59*
World total	*283,000,000*	*283,000,000*						

Table 6e: *Base Data for DREAM Simulations—Rice*

Regions/Countries	Quantities		Price[b]	Price Elasticities		Exogenous Demand Shift Variables		
	Demand	Supply		Demand	Supply	Feed Share	Derived Income Elasticities[c]	Per Capita GDP Growth[d]
	(tons)		*(US $/ton)*	*(percent)*		*(percent)*		*(percent p.a.)*
Mesoamerica	*1,737,742*	*1,082,268*						
Costa Rica	267,515	188,621	336.3	0.5	1.0	0	0.5	1.86
El Salvador	87,401	65,543	336.3	0.5	1.0	0	0.5	3.33
Guatemala	74,878	39,369	336.3	0.5	1.0	0	0.5	1.41
Honduras	67,196	34,592	336.3	0.5	1.0	0	0.5	0.34
Mexico	748,849	355,462	336.3	0.5	1.0	0	0.5	0.37
Nicaragua	264,480	194,178	336.3	0.5	1.0	0.01	0.50	0.27
Panama	227,423	204,503	336.3	0.5	1.0	0	0.5	2.89
Caribbean/other	*2,116,276*	*897,787*						
Cuba	803,718	246,028	336.3	0.5	1.0	0.01	0.51	1.66
Dominican Rep.	474,068	467,683	336.3	0.5	1.0	0	0.5	3.20
Haiti	339,596	110,120	336.3	0.5	1.0	0	0.5	0.00
Other[a]	498,894	73,956	336.3	0.5	1.0	0.01	0.51	1.66
Andean	*5,358,770*	*4,905,031*						
Bolivia	232,739	232,186	336.3	0.5	1.0	0.001	0.50	1.63
Colombia	1,865,095	1,681,193	336.3	0.5	1.0	0.13	0.56	1.56
Ecuador	1,218,085	1,245,077	336.3	0.5	1.0	0	0.5	0.89
Peru	1,464,805	1,084,986	336.3	0.5	1.0	0	0.5	4.34
Venezuela	578,046	661,589	336.3	0.5	1.0	0	0.5	0.00
Southern Cone	*11,937,716*	*12,173,026*						
Argentina	320,657	805,250	336.3	0.5	1.0	0	0.5	1.99
Brasil	11,194,015	10,457,582	336.3	0.5	1.0	0	0.5	1.95
Chile	206,440	135,785	336.3	0.5	1.0	0.06	0.53	3.24
Paraguay	113,556	103,842	336.3	0.5	1.0	0	0.5	0.41
Uruguay	103,049	670,568	336.3	0.5	1.0	0.12	0.56	2.35
United States	*4,725,116*	*8,022,525*	*336.3*	*0.5*	*1.0*	*0*	*0.5*	*1.95*
Rest of world	*511,124,380*	*509,919,363*	*336.3*	*0.5*	*1.0*	*0.02*	*0.51*	*0.59*
World total	*537,000,000*	*537,000,000*						

Table 6f: *Base Data for DREAM Simulations—Sorghum*

Regions/Countries	Quantities			Price Elasticities		Exogenous Demand Shift Variables		
	Demand	Supply	Price[b]	Demand	Supply	Feed Share	Derived Income Elasticities[c]	Per Capita GDP Growth[d]
	(tons)		*(US $/ton)*	*(percent)*		*(percent)*		*(percent p.a.)*
Mesoamerica	*7,897,675*	*4,385,802*						
Costa Rica	12		92.56	0.5	1.0	1	1	1.86
El Salvador	206,626	199,843	92.56	0.5	1.0	0.36	0.68	3.33
Guatemala	61,990	62,423	92.56	0.5	1.0	0.74	0.87	1.41
Honduras	69,134	68,501	92.56	0.5	1.0	0.85	0.93	0.34
Mexico	7,461,073	3,951,328	92.56	0.5	1.0	1	1	0.37
Nicaragua	80,793	85,815	92.56	0.5	1.0	0.38	0.69	0.27
Panama	18,047	17,892	92.56	0.5	1.0	1	1	2.89
Caribbean/other	*115,850*	*112,181*						
Cuba	1,075	1,075	92.56	0.5	1.0	1	1	1.66
Dominican Rep.	17,381	16,106	92.56	0.5	1.0	1	1	3.20
Haiti	95,000	95,000	92.56	0.5	1.0	0.31	0.66	0.00
Other[a]	2,394	0	92.56	0.5	1.0	1	1	1.66
Andean	*1,242,689*	*1,218,412*						
Bolivia	79,524	79,300	92.56	0.5	1.0	1	1	1.63
Colombia	674,420	646,823	92.56	0.5	1.0	1	1	1.56
Ecuador	9,383	1,616	92.56	0.5	1.0	1	1	0.89
Peru	16,934	7,135	92.56	0.5	1.0	1	1	4.34
Venezuela	462,429	483,538	92.56	0.5	1.0	1	1	0.00
Southern Cone	*2,132,683*	*2,756,863*						
Argentina	1,677,536	2,356,175	92.56	0.5	1.0	1	1	1.99
Brasil	276,273	267,950	92.56	0.5	1.0	1	1	1.95
Chile	41,332	0	92.56	0.5	1.0	1	1	3.24
Paraguay	23,092	22,946	92.56	0.5	1.0	1	1	0.41
Uruguay	114,449	109,792	92.56	0.5	1.0	1	1	2.35
United States	*10,533,800*	*15,994,950*	*92.56*	*0.5*	*1.0*	*0.996*	*0.998*	*1.95*
Rest of world	*39,315,923*	*36,770,412*	*92.56*	*0.5*	*1.0*	*0.27*	*0.64*	*0.59*
World total	*61,238,620*	*61,238,620*						

Table 6g: *Base Data for DREAM Simulations—Soybeans*

Regions/Countries	Quantities		Price[b]	Price Elasticities		Exogenous Demand Shift Variables		
	Demand	Supply		Demand	Supply	Feed Share	Derived Income Elasticities[c]	Per Capita GDP Growth[d]
	(tons)		*(US $/ton)*	*(percent)*		*(percent)*		*(percent p.a.)*
Mesoamerica	*2,887,574*	*514,351*						
Costa Rica	116,010	5	230.35	0.5	1.0	0.78	0.89	1.86
El Salvador	2,035	1,970	230.35	0.5	1.0	0.94	0.97	3.33
Guatemala	40,512	41,074	230.35	0.5	1.0	0.80	0.90	1.41
Honduras	12,952	6,778	230.35	0.5	1.0	0.96	0.98	0.34
Mexico	2,701,577	450,866	230.35	0.5	1.0	0.84	0.92	0.37
Nicaragua	13,987	13,558	230.35	0.5	1.0	0.62	0.81	0.27
Panama	502	100	230.35	0.5	1.0	0.75	0.88	2.89
Caribbean/other	*180,413*	*48*						
Cuba	7,425		230.35	0.5	1.0	0.84	0.92	1.66
Dominican Rep.	18,200		230.35	0.5	1.0	0.76	0.88	3.20
Haiti			230.35	0.5	1.0	0	0.5	0.00
Other[a]	154,788	48	230.35	0.5	1.0	0.48	0.74	1.66
Andean	*1,024,579*	*851,905*						
Bolivia	470,286	603,540	230.35	0.5	1.0	0.92	0.96	1.63
Colombia	258,071	103,029	230.35	0.5	1.0	0.78	0.89	1.56
Ecuador	143,541	141,367	230.35	0.5	1.0	0.75	0.87	0.89
Peru	2,478	856	230.35	0.5	1.0	0.63	0.81	4.34
Venezuela	150,204	3,113	230.35	0.5	1.0	0.83	0.91	0.00
Southern Cone	*28,984,063*	*36,501,103*						
Argentina	9,051,583	11,552,150	230.35	0.5	1.0	0.78	0.89	1.99
Brasil	19,211,055	23,076,733	230.35	0.5	1.0	0.72	0.86	1.95
Chile	2,160		230.35	0.5	1.0	0.63	0.82	3.24
Paraguay	706,179	1,854,845	230.35	0.5	1.0	0.94	0.97	0.41
Uruguay	13,087	17,375	230.35	0.5	1.0	0.89	0.94	2.35
United States	*40,449,767*	*59,569,250*	*230.35*	*0.5*	*1.0*	*0.82*	*0.91*	*1.95*
Rest of world	*49,473,604*	*25,563,343*	*230.35*	*0.5*	*1.0*	*0.77*	*0.88*	*0.59*
World total	*123,000,000*	*123,000,000*						

Table 6h: *Base Data for DREAM Simulations—Wheat*

Regions/Countries	Quantities			Price Elasticities		Exogenous Demand Shift Variables		
	Demand	Supply	Price[b]	Demand	Supply	Feed Share	Derived Income Elasticities[c]	Per Capita GDP Growth[d]
	(tons)		*(US $/ton)*	*(percent)*		*(percent)*		*(percent p.a.)*
Mesoamerica	*5,954,595*	*3,731,099*						
Costa Rica	120,903		135.37	0.5	1.0	0	0.5	1.86
El Salvador	201,927		135.37	0.5	1.0	0	0.5	3.33
Guatemala	289,239	24,739	135.37	0.5	1.0	0	0.5	1.41
Honduras	173,330	838	135.37	0.5	1.0	0.18	0.59	0.34
Mexico	4,980,772	3,705,523	135.37	0.5	1.0	0.17	0.59	0.37
Nicaragua	90,692		135.37	0.5	1.0	0	0.5	0.27
Panama	97,734		135.37	0.5	1.0	0	0.5	2.89
Caribbean/other	*1,894,024*	*0*						
Cuba	970,499		135.37	0.5	1.0	0.14	0.57	1.66
Dominican Rep.	257,038		135.37	0.5	1.0	0.20	0.60	3.20
Haiti	197,037		135.37	0.5	1.0	0	0.5	0.00
Other[a]	469,451		135.37	0.5	1.0	0	0.5	1.66
Andean	*4,266,613*	*328,721*						
Bolivia	498,478	110,053	135.37	0.5	1.0	0	0.5	1.63
Colombia	980,662	87,708	135.37	0.5	1.0	0	0.5	1.56
Ecuador	310,146	22,281	135.37	0.5	1.0	0.002	0.50	0.89
Peru	1,371,005	108,318	135.37	0.5	1.0	0	0.5	4.34
Venezuela	1,106,322	362	135.37	0.5	1.0	0	0.5	0.00
Southern Cone	*15,773,399*	*14,321,117*						
Argentina	5,028,689	10,071,100	135.37	0.5	1.0	0.06	0.53	1.99
Brasil	8,029,231	2,143,827	135.37	0.5	1.0	0.04	0.52	1.95
Chile	1,933,630	1,383,812	135.37	0.5	1.0	0.07	0.54	3.24
Paraguay	358,859	334,531	135.37	0.5	1.0	0.68	0.84	0.41
Uruguay	422,991	387,847	135.37	0.5	1.0	0.24	0.62	2.35
United States	*31,735,101*	*63,731,500*	*135.37*	*0.5*	*1.0*	*0.23*	*0.62*	*1.95*
Rest of world	*490,776,268*	*468,287,563*	*135.37*	*0.5*	*1.0*	*0.20*	*0.60*	*0.59*
World total	*550,400,000*	*550,400,000*						

Notes for Table 6a–h:

[a] "Other" includes the following 25 countries: Anguilla, Antigua and Barbuda, the Bahamas, Barbados, Belize, British Virgin Islands, Cayman Islands, Dominica, French Guiana, Grenada, Guadeloupe, Guyana, Jamaica, Martinique, Montserrat, Netherlands Antilles, Puerto Rico, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Suriname, Trinidad and Tobago, Turks and Caicos, Falkland Islands, U.S. Virgin Islands.

[b] Prices are based on 1993-95 average export unit values (export value/export quantity) for the largest exporting country in LAC. The prices are based on the following crops and country combinations: Beans—Argentina; Cassava—Costa Rica; Maize—Argentina; Potatoes—Argentina; Rice—Uruguay; Sorghum—Argentina; Soybeans—Brazil; and Wheat—Argentina.

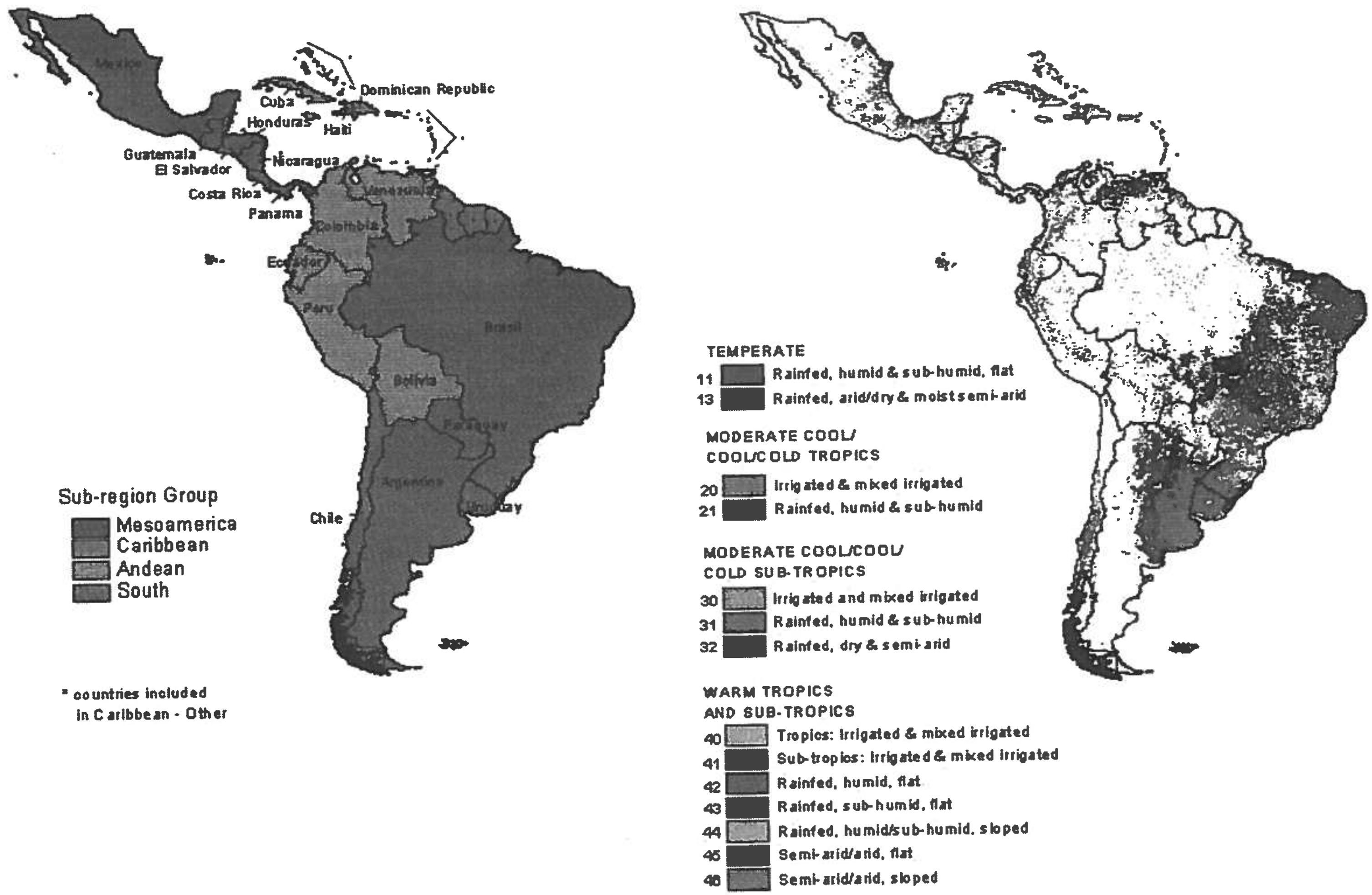
[c] See text for details of derivation.

[d] GDP/cap growth for Argentina, Chile, Colombia, Uruguay: implicit GDP cap growth for year 2000, obtained by subtracting GDP growth from FMI World Economic Outlook (May 1999) to population growth projection from Economic Research Service of USDA; for all other countries GDP/cap growth is proxied with the 1990-97 growth rates from regression estimates; Cuba's GDP growth is taken to be equal to that of "Caribbean and other;" GDP/cap growth is assumed to be zero for the Bahamas, Haiti, Jamaica, Netherlands Antilles, and Venezuela because negative growth was found over the 1990-97 period.

Figure 6: *Spatial configurations for ex ante agricultural technology assessments*

Panel a: Countries

Panel b. Agroecological Zones



Source: Wood, Sebastian, and Scherr (2000).

Table 7: *Agricultural Land by Agroecological Zone*

Region/ Country	Area per Agroecological Zone within the Extent of Agriculture												Area Outside Agriculture	Total Land Area
	20	21	30	31	32	40	41	42	43	44	45	46		
							(millions of hectares)							
Andean	**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	0	2.8	0	0	0	0	0	1.5	4.1	0.5	4.3	0.1	94.6	108.0
Colombia	0.8	6.3	0	0	0	1.1	1.5	6.4	1.9	5.0	0	0	89.3	112.3
Ecuador	0	2.6	0	0	0	0	0.3	0.5	0.5	0.9	1.4	0.9	16.6	23.6
Peru	1.6	9.9	0.4	0	0	0	0.1	1.7	0	0.9	0.3	0.2	108.0	123.1
Venezuela	0	2.0	0	0	0	0.3	0.1	2.6	15.9	6.2	0.3	0.2	62.0	89.5
Caribbean	**0.5**	**0.2**	**0**	**0**	**0**	**4.0**	**1.5**	**0.4**	**3.5**	**2.8**	**0**	**0**	**47.9**	**60.9**
Bahamas, The	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.1
Cuba	0	0	0	0	0	1.7	0.4	0.2	1.7	0.5	0	0	2.8	7.2
Dominican Republic	0.3	0.1	0	0	0	0.3	0.1	0	0	0.3	0	0	2.6	3.7
Haiti	0	0	0	0	0	0.1	0.2	0	0	0.5	0	0	0.9	1.8
Caribbean - Other	0.3	0.1	0	0	0	2.0	0.7	0.2	1.7	1.4	0	0	41.6	48.1
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	0	0	0.4	0	0	0.1	0.5	0	0	2.7	3.9
El Salvador	0	0	0	0	0	0.2	0	0	0.1	0.8	0	0	0.4	1.5
Guatemala	0	1.2	0	0	0	0	0.2	0.3	0.1	1.4	0	0	6.8	10.1
Honduras	0	0.5	0	0	0	0	0.1	0.3	0.1	2.9	0	0	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	0.1	0	0	0	0.2	0	0.6	0.3	2.2	0	0	7.7	11.1
Panama	0	0	0	0	0	0	0	0.1	0.2	1.3	0	0	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	0.9	4.6	11.0	0.8	17.5	6.3	161.5	274.6
Brasil	0.1	15.8	2.5	29.8	0	0.5	3.2	39.9	119.4	57.0	52.9	1.2	519.6	842.0
Chile	0.2	0	2.7	7.4	0.8	0	0	0	0	0	0	0	52.9	63.9
Paraguay	0	1.3	0	0.1	0	0	0.2	2.3	0.2	2.4	3.0	0	30.4	39.9
Uruguay	0	0	0	16.4	0	0	0	0	0	0	0	0	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*
							(percentage)							
Andean	**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	0	2.6	0	0	0	0	0	1.4	3.8	0.4	4.0	0.1	87.6	100.0
Colombia	0.7	5.6	0	0	0	0.9	1.3	5.7	1.7	4.5	0	0	79.5	100.0
Ecuador	0	11.1	0	0	0	0	1.2	2.0	2.1	3.9	5.8	3.8	70.1	100.0
Peru	1.3	8.1	0.4	0	0	0	0.1	1.4	0	0.7	0.2	0.2	87.7	100.0
Venezuela	0	2.2	0	0	0	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	0	0	0	0	0	0	0	0	30.7	0	0	0	69.3	100.0
Cuba	0	0.3	0	0	0	23.1	5.2	2.6	23.0	7.6	0	0	38.2	100.0
Dominican Republic	7.2	1.8	0	0	0	7.5	3.5	0.4	0.9	8.6	0	0	70.1	100.0
Haiti	0	0.5	0	0	0	4.1	13.1	0.9	0.9	29.4	0	0	51.1	100.0
Caribbean - Other	0	0.2	0	0	0	0	1.0	6.3	1.0	1.9	0	0	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	0	0	0	10.9	0	1.1	3.2	13.9	0	0	67.2	100.0
El Salvador	0	0	0	0	0	14.7	0	0	3.8	55.4	0	0	26.1	100.0
Guatemala	0	12.3	0	0	0	0	1.6	2.9	1.1	14.4	0	0	67.8	100.0
Honduras	0	4.7	0	0	0	0	0.8	2.7	0.8	26.0	0	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	0	1.0	0	0	0	1.8	0	5.8	2.3	19.6	0	0	69.3	100.0
Panama	0	0.7	0	0	0	0	0	2.1	4.0	22.7	0	0	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	0.3	1.7	4.0	0.3	6.4	2.3	58.8	100.0
Brasil	0	1.9	0.3	3.5	0	0.1	0.4	4.7	14.2	6.8	6.3	0.1	61.7	100.0
Chile	0.3	0	4.2	11.6	1.2	0	0	0	0	0	0	0	82.7	100.0
Paraguay	0	3.3	0	0.4	0	0	0.6	5.7	0.5	5.9	7.5	0	76.1	100.0
Uruguay	0	0	0	96.1	0	0	0	0	0	0	0	0	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*

Source: Wood and Sebastian (2000).

Table 8: *Crop Area and Production by Agroecological Zones*

Agroecological Zone	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*
				(thousand 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

Source: Calculated by authors.

Table 9: *Chronology of Selected Ex Ante R&D Evaluation Studies for Latin America*

Study Number	Year Published	Authors	Evaluation Approach	Spatial Focus	
				National & sub-National	Other
1	1986	ISA	Scoring	Dominican Republic	
2	1986	Espinosa, et al	Scoring	Ecuador	
3	1987	CIAAB	Scoring	Uruguay	
4	1987	Davis, Oram, & Ryan	Economic surplus		LAC/World
5	1987	Norton, Ganoza, & Pomaredo	Economic surplus	Perú	
6	1991	CIAT	Hybrid		Countries within LAC[a]
7	1992	Palamino & Norton	Scoring	Ecuador	
8	1992	TAC	Scoring		LAC/World
9	1993	Lima & Norton	Scoring	Venezuela	
10	1995	IICA	Scoring		TAC/LAC
11	1995	Medina	Scoring	Central America (6 countries)	
12	1997	Fontagro	Hybrid		Countries including LAC[b]
13	1998	IICA/IFPRI	Hybrid	Caribbean (8 countries)	
14	1998	IICA/IFPRI	Economic surplus	----------------Andean region------------------	
15	1998	IICA/IFPRI	Economic surplus	-----------------Mesoamerica------------------	
16	2000	Present study	Economic surplus	--	

Notes:
[a] The CIAT study excluded non-tropical areas (such as Argentina and Chile) that lay beyond its ecoregional mandate area.
[b] The Fontagro study included the southern United States to highlight importance of potential knowledge and technology spillovers between the U.S. and LAC.

Table 10: *Changes in Baseline Prices and Quantities in the Absence of Technical Change*

Year	Region	Bean	Cassava	Maize	Potato	Rice	Sorghum	Soybean	Wheat
Price (US$/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)									
	LAC	5,079	30,272	69,736	13,150	19,058	8,473	37,867	18,381
1994	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
	LAC	8,222	56,133	130,893	23,644	32,253	15,357	71,138	30,820
2020	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)									
	LAC	5,141	30,189	71,069	13,670	21,150	11,389	33,077	27,894
1994	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
	LAC	8,338	55,949	136,477	24,461	35,802	20,293	64,204	47,710
2020	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

Table 11: *Total, Producer, and Regional Benefits—One-Percent, Regionwide, Commodity-Specific Shifts*

	Southern Cone	Mesoamerica	Andean	Caribbean	LAC
			(1,000 U.S. dollars)		
Total benefits					
Bean	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
Potato	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
Soybean	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					
Bean	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
Potato	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
Soybean	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*
Sub-regional share of total regional benefits					
Bean	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
Potato	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
Soybean	0.95	0.03	0.03	0.00	1.00
Wheat	0.78	0.20	0.02	0.00	1.00

Table 12: *Ranking and Supply-shift Relativities—One Percent, Regionwide, Commodity-specific Shifts*

	Caribbean			Southern Cone			Mesoamerica			Andean			LAC		
Rank	Crop	SSR[a]	Benefit	Crop	SSR[a]	Benefit	Crop	SSR[a]	Benefit	Crop	SSR[a]	Benefit	Crop	SSR[a]	Benefit
			(1,000$)			*(1,000$)*			*(1,000$)*			*(1,000$)*			*(1,000$)*
1	Rice	1.0	70,870	Soybean	1.0	1,880.270	Maize	1.0	518,498	Rice	1.0	387,860	Soybean	1.0	1,989,380
2	Cassava	2.3	31,096	Maize	1.5	1,213,463	Bean	2.4	212,474	Potato	1.7	222,374	Maize	1.1	1,859,466
3	Bean	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	Potato	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	Bean	4.2	443,362	Rice	6.0	86,052	Soybean	7.4	52,182	Bean	2.8	714,568
6	Sorghum	31.4	2,259	Wheat	4.3	432,791	Potato	9.5	54,719	Bean	9.2	42,168	Wheat	3.6	557,517
7	Soybean	32.1	2,209	Potato	9.4	200,793	Soybean	10.9	47,467	Sorghum	14.7	26,403	Potato	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

[a] SSR—Supply Shift Relatives.

Table 13: *Total and Producer Benefits—One-Percent, Regionwide, Commodity-specific Shifts, with ROW Spillovers*

	Latin America and Caribbean							
	Southern Cone	Mesoamerica	Andean	Caribbean	Total	United States	ROW	LAC share of world
			(1,000 U.S. dollars)					*(proportion)*
Total benefits								
Bean	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
Potato	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
Soybean	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*	
				(proportion)				
Producer share of total benefits								
Bean	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	-	-	-
Potato	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	-	-	-
Soybean	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*	-	-	-

Table 14: *Total Benefits—One-Percent, Area-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		24,247.1		387.7		129.2		682.6	6,217.6	5,690.5	893.8
Southern		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		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		5,584.3		2,393.7				3,180.5	27,096.0	14,832.1	6,268.5
Southern		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	6,809.2	203,044.8		26.2		1.6				9,190.3	
Southern	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		100,845.1	106.4	286.0		17,708.3		29,360.8	37,412.0	46,618.0	
Southern		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		5,929.3		14.5	10.0				10,977.4	2,962.3	2,184.1
Southern		-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				760.3	108.8			1,032.7	13,836.0	7,284.8	22,767.8
Southern				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	1,180.7	7,422.4		1,428.9	6,651.6					510.6	
Southern	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*

Figure 7: *Total, producer and consumer benefits—one-percent, country and commodity specific shifts, without spillover*

Panel (a) Benefits to the innovating country

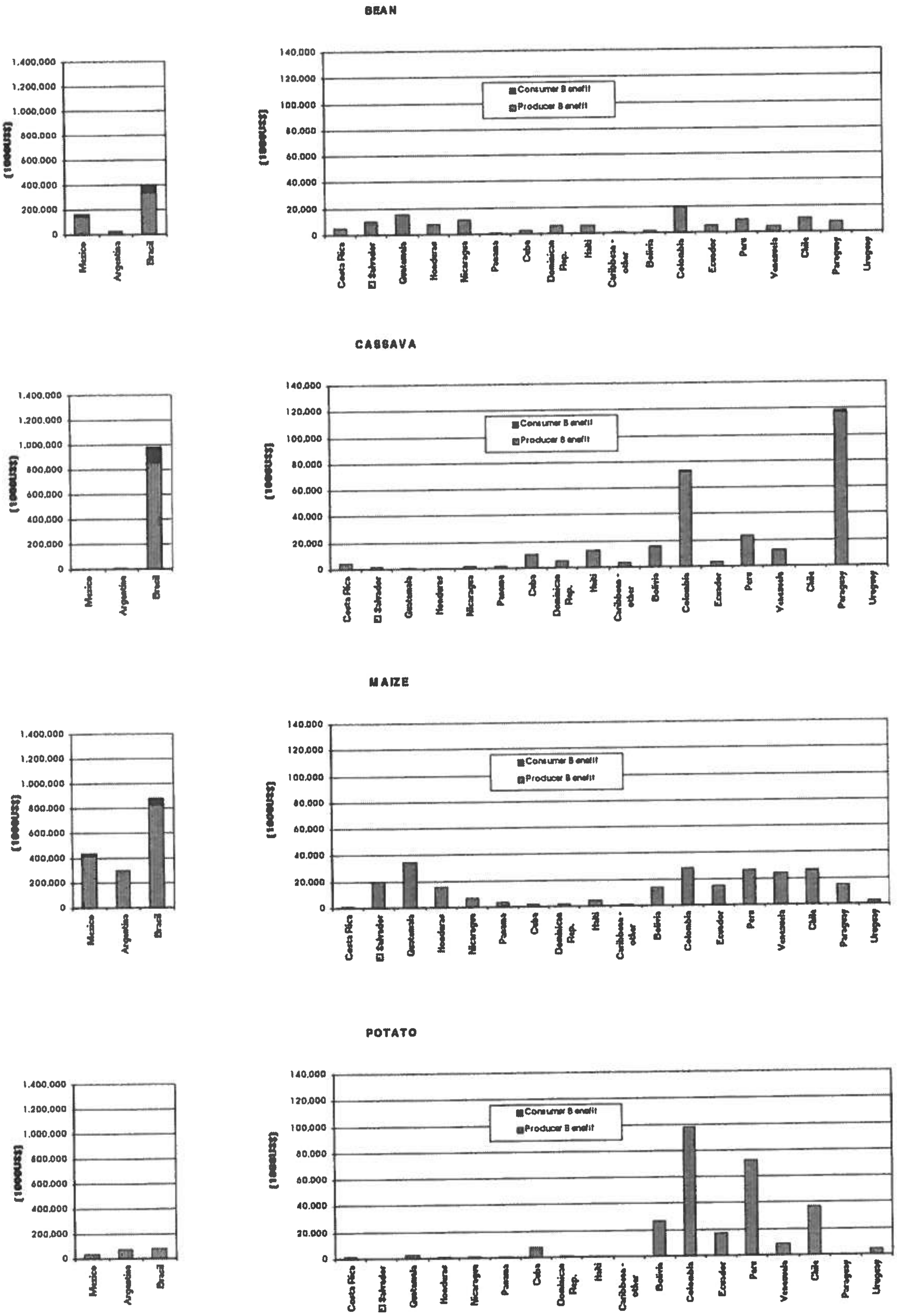
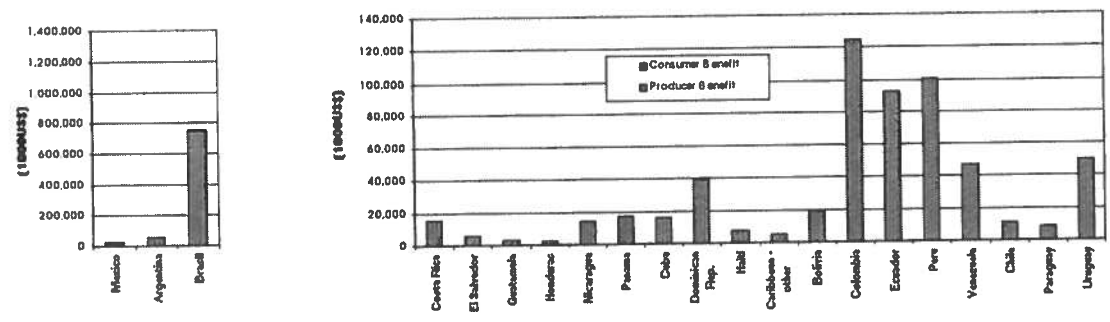


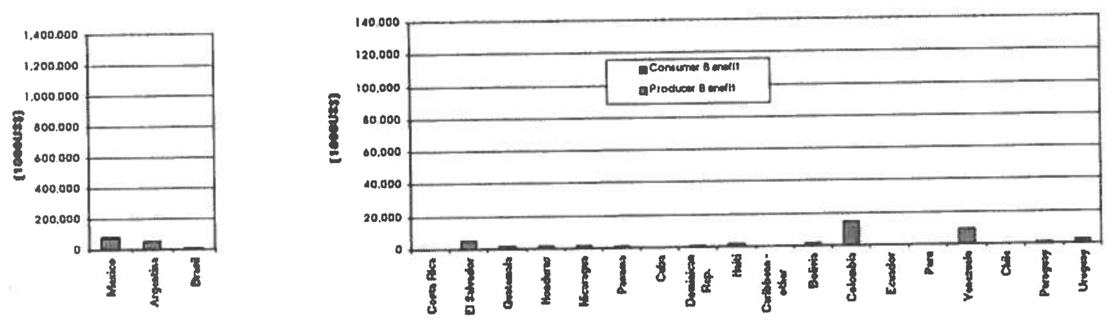
Figure 7: *Total, producer and consumer benefits—one-percent, country and commodity specific shifts, without spillover (continued)*

Panel (a) Benefits to the innovating country (continued)

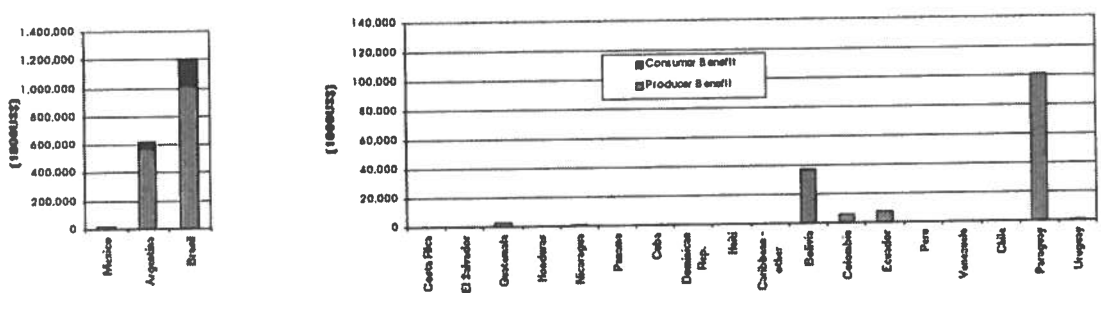
RICE



SORGHUM



SOYBEAN



WHEAT

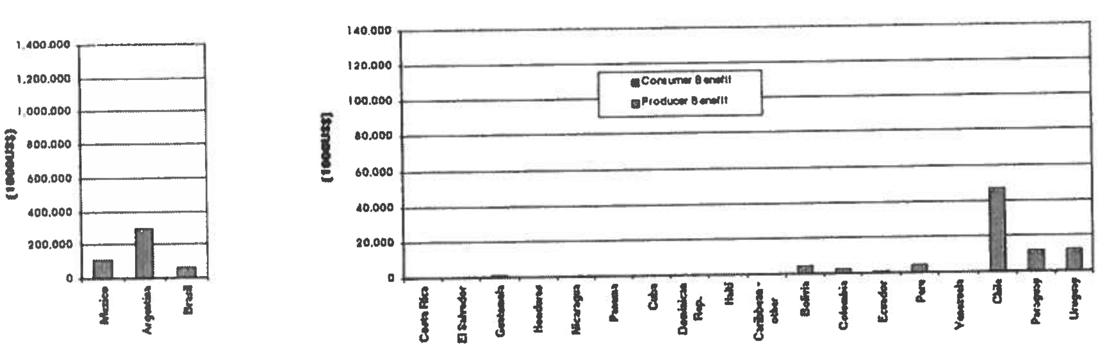
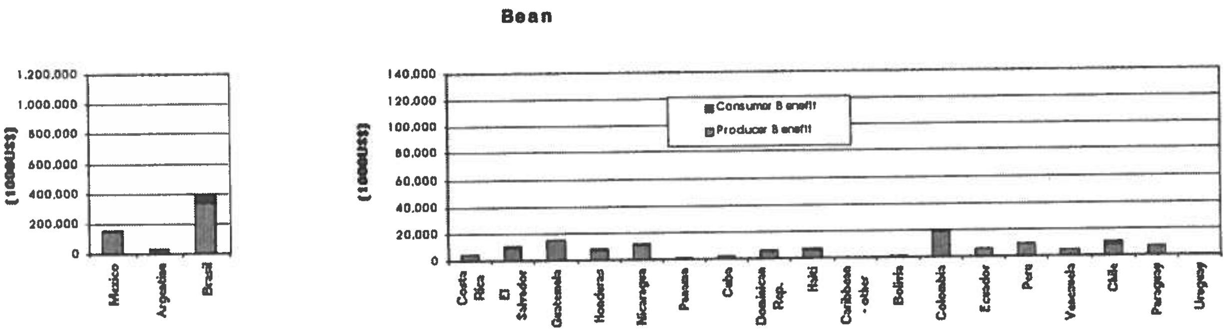
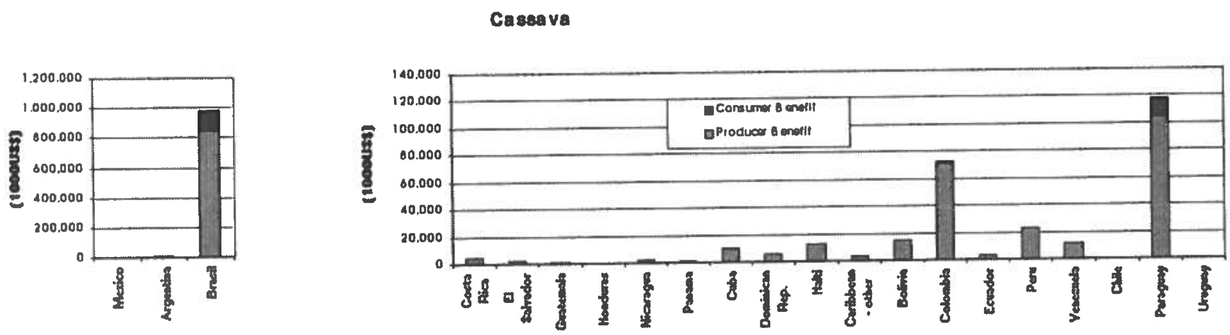
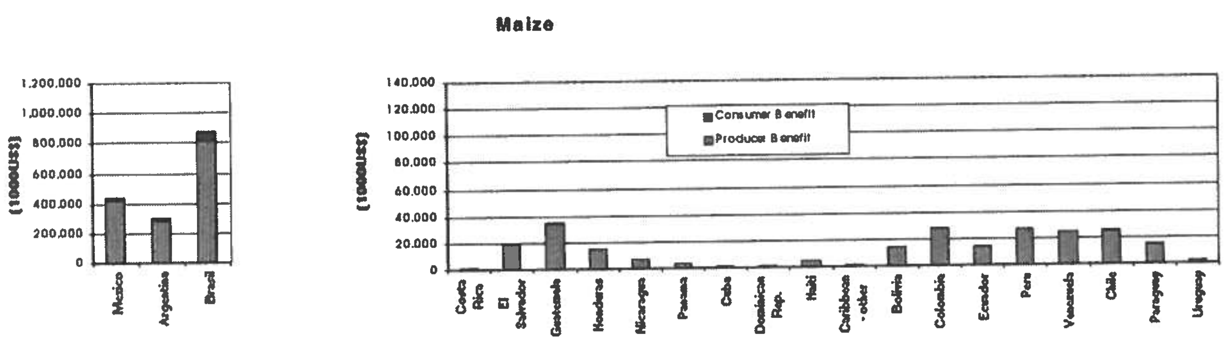


Figure 7: *Total, producer and consumer benefits—one-percent, country and commodity specific shifts, without spillover (continued)*

Panel (b) Benefits to the sub-region







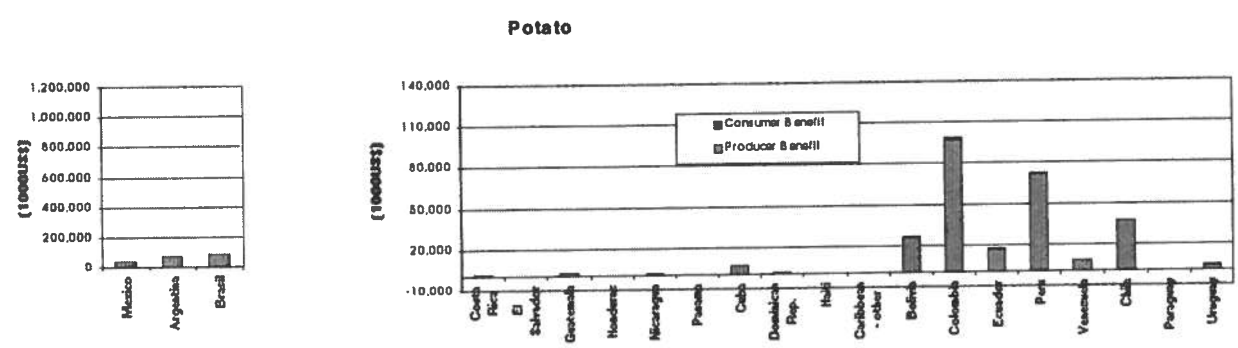
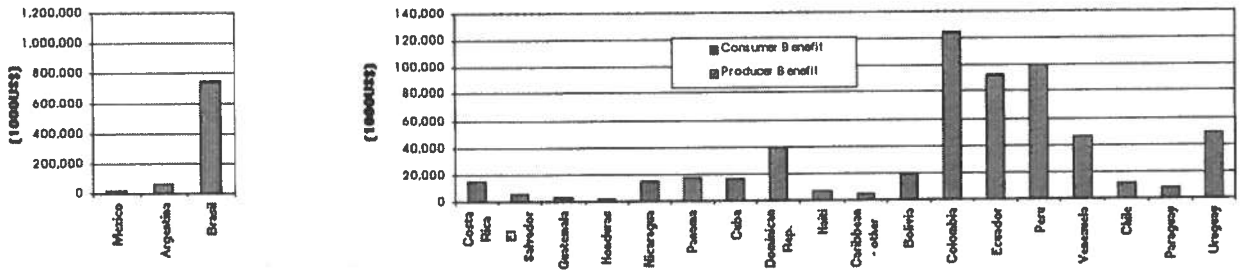


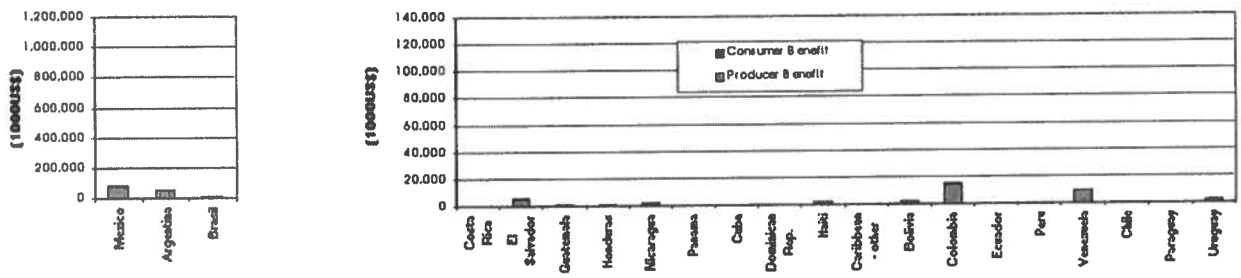
Figure 7: *Total, producer and consumer benefits—one-percent, country and commodity specific shifts, without spillover (continued)*

Panel (b) Benefits to the sub-region (continued)

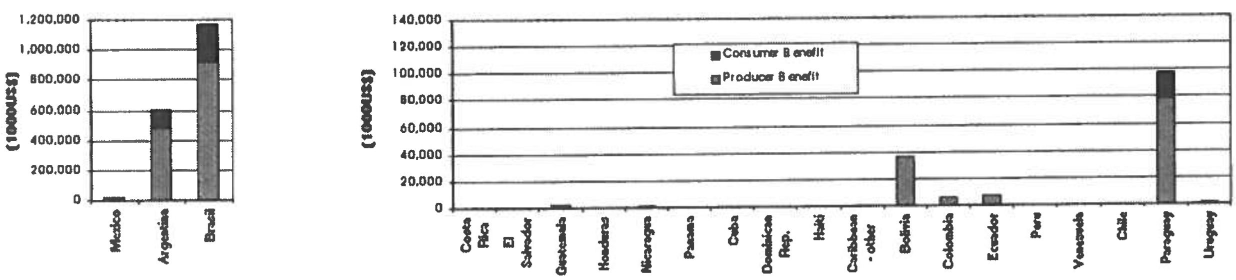
Rice



Sorghum



Soybean



Wheat

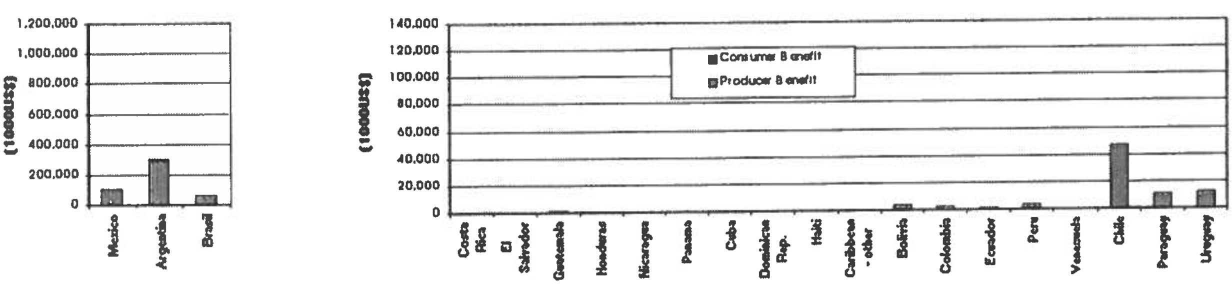


Figure 7: *Total, producer and consumer benefits—one-percent, country and commodity specific shifts, without spillover (continued)*

Panel (c) Benefits to Latin America

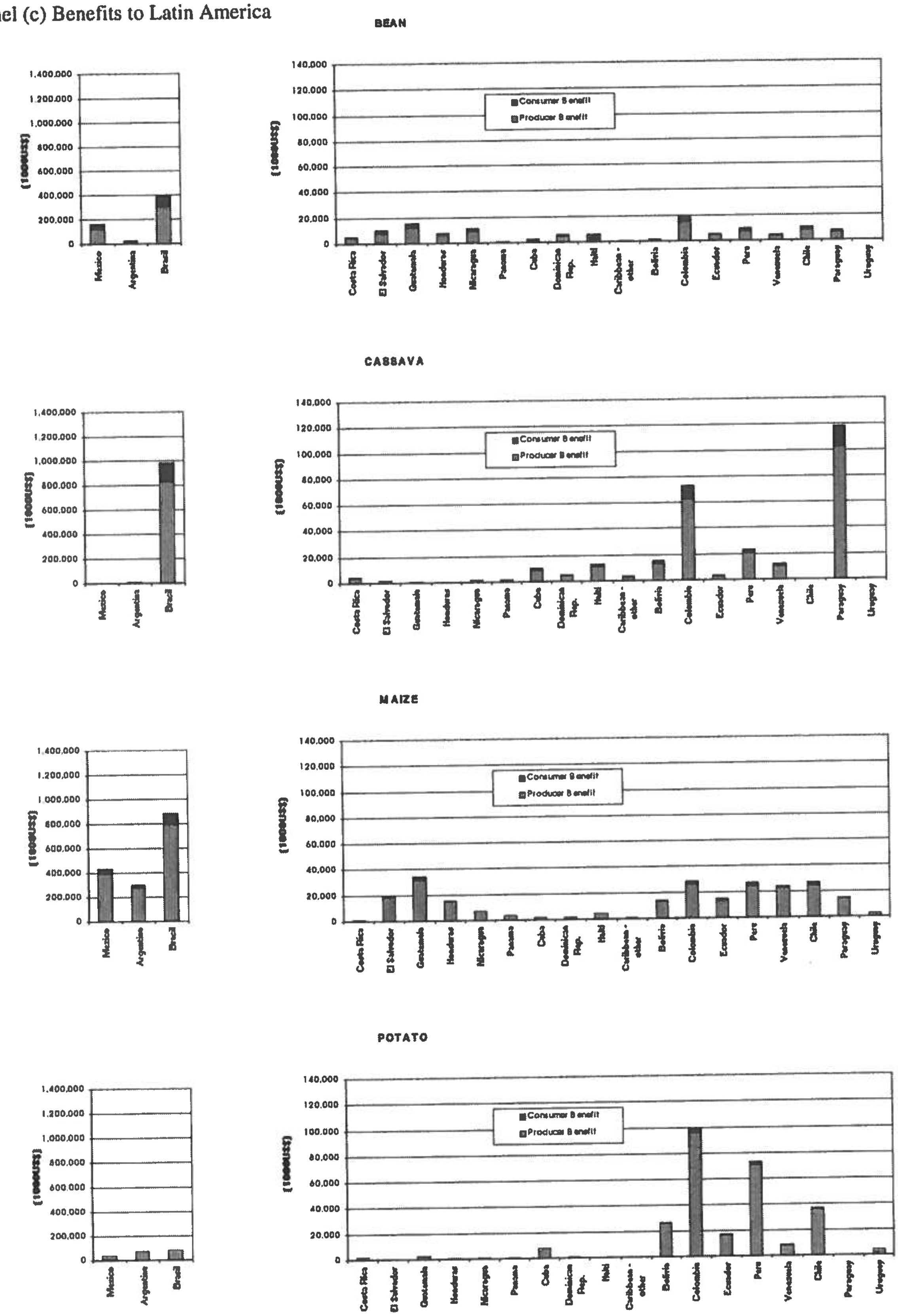
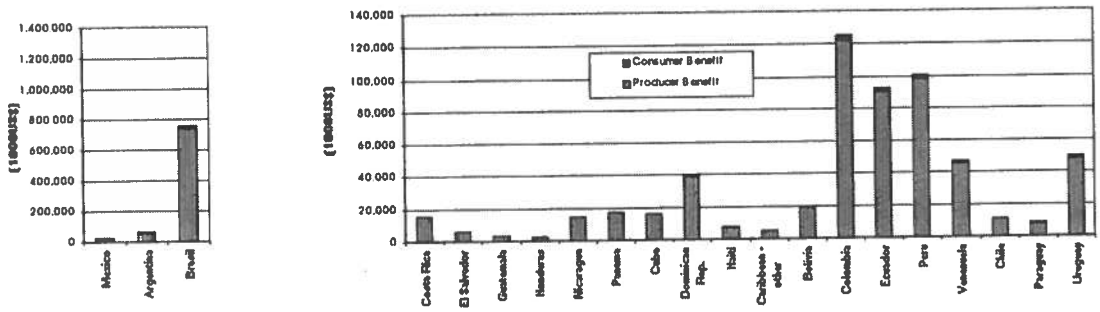


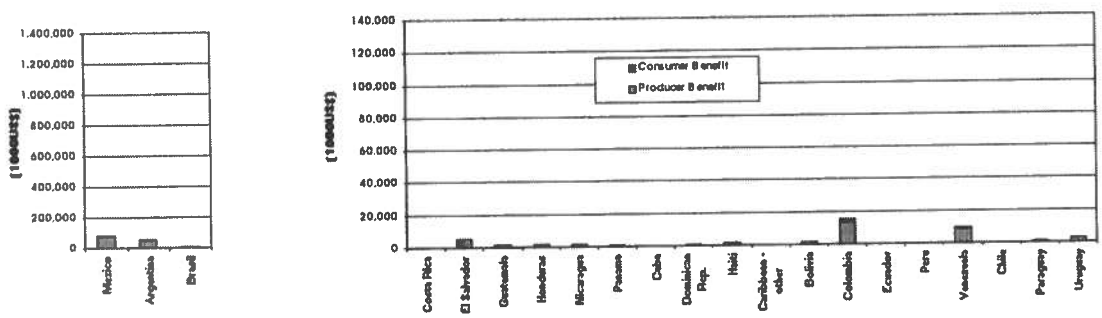
Figure 7: *Total, producer and consumer benefits—one-percent, country and commodity specific shifts, without spillover (continued)*

Panel (c) Benefits to Latin America (continued)

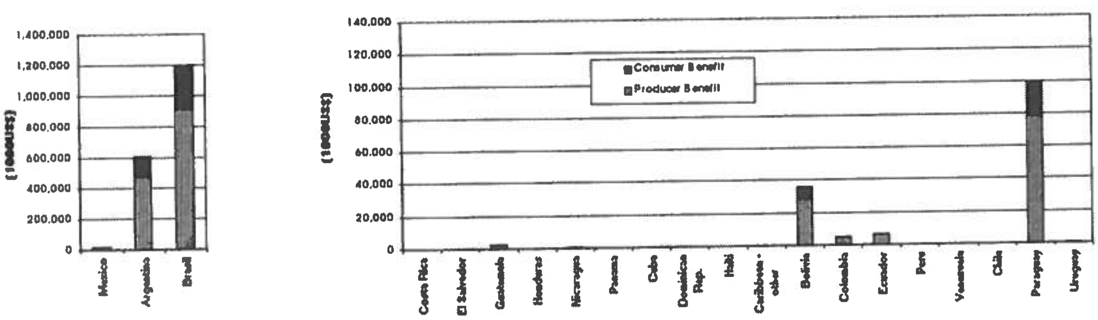
RICE



SORGHUM



SOYBEAN



WHEAT

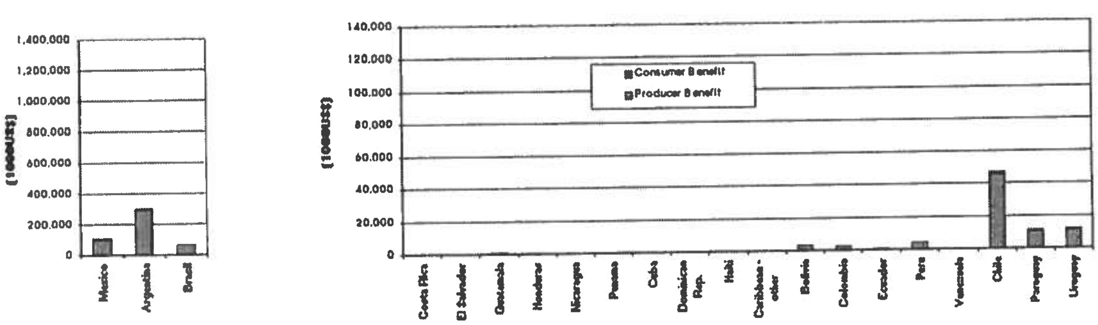


Figure 8: *Total, producer and consumer benefits—one percent, country-specific shifts, with spillover*

Panel (a) Benefits to the innovating country

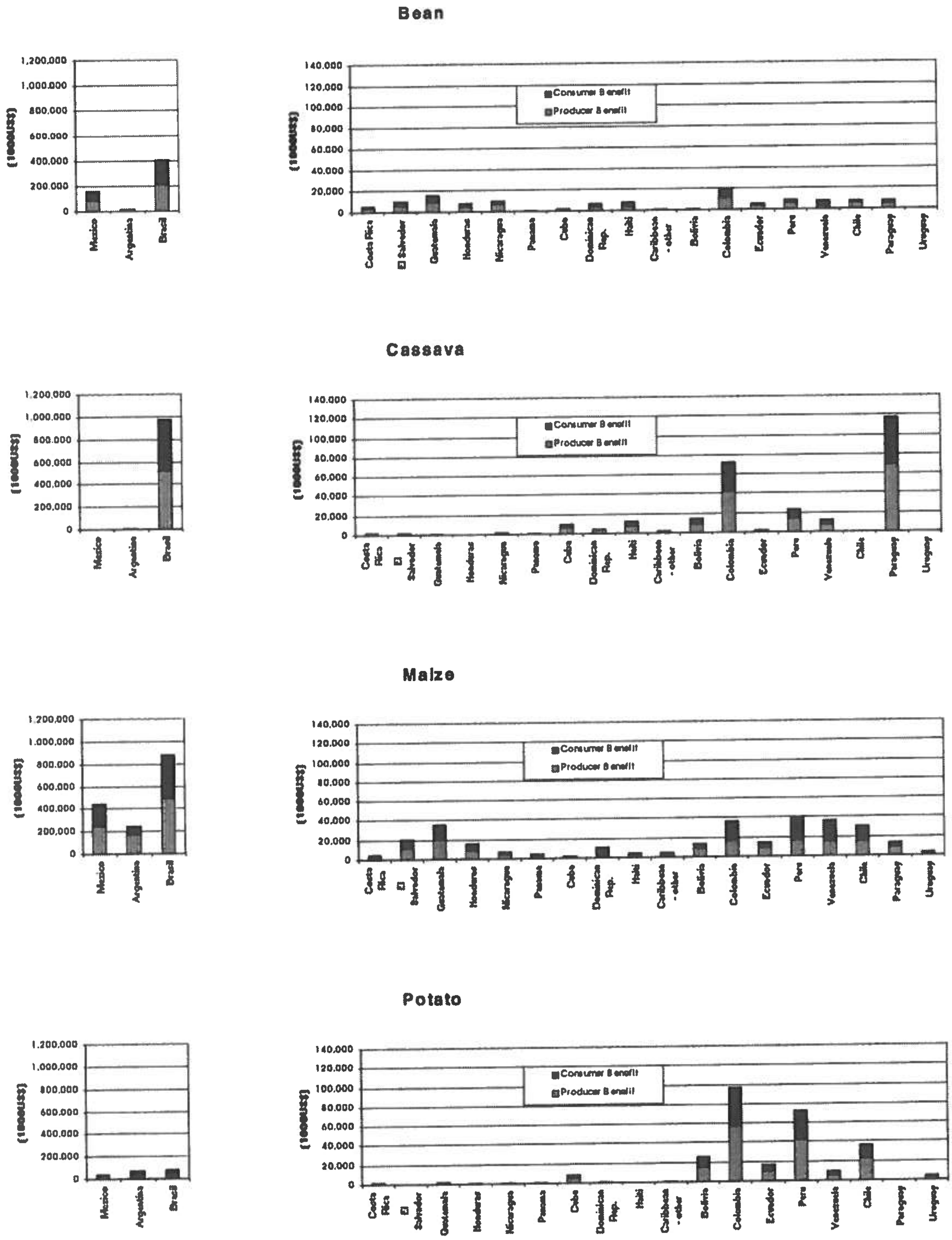
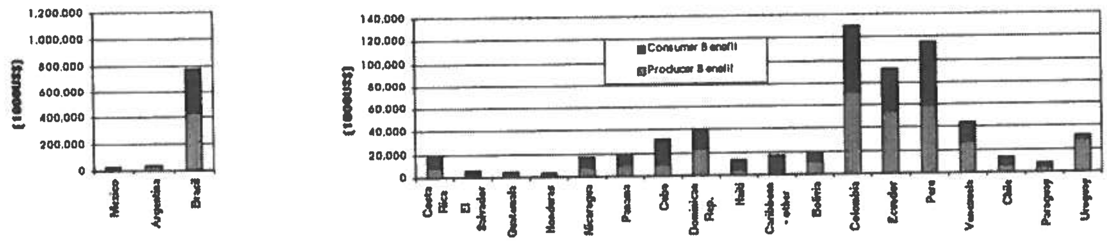


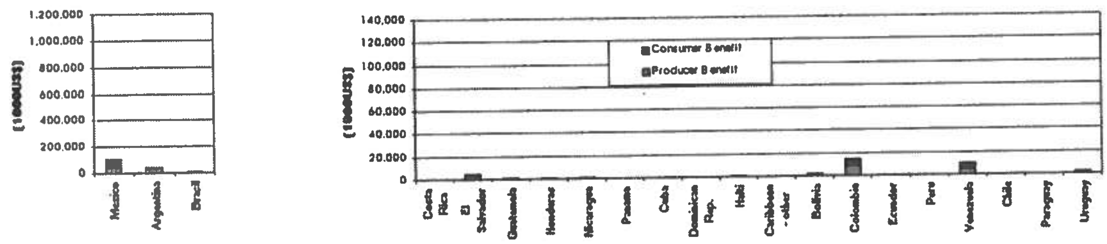
Figure 8: *Total, producer and consumer benefits—one percent, country-specific shifts, with spillover (continued)*

Panel (a) Benefits to the innovating country (continued)

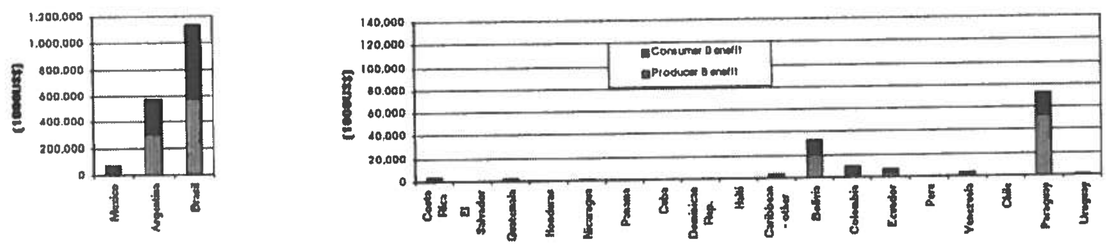
Rice



Sorghum



Soybean



Wheat

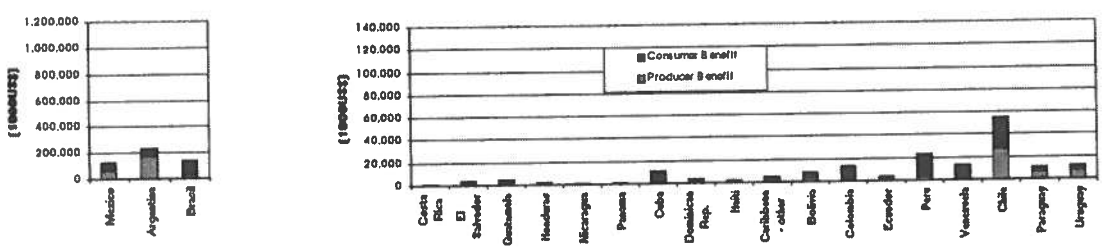


Figure 8: *Total, producer and consumer benefits—one percent, country-specific shifts, with spillover (continued)*

Panel (b) Benefits to the sub-region

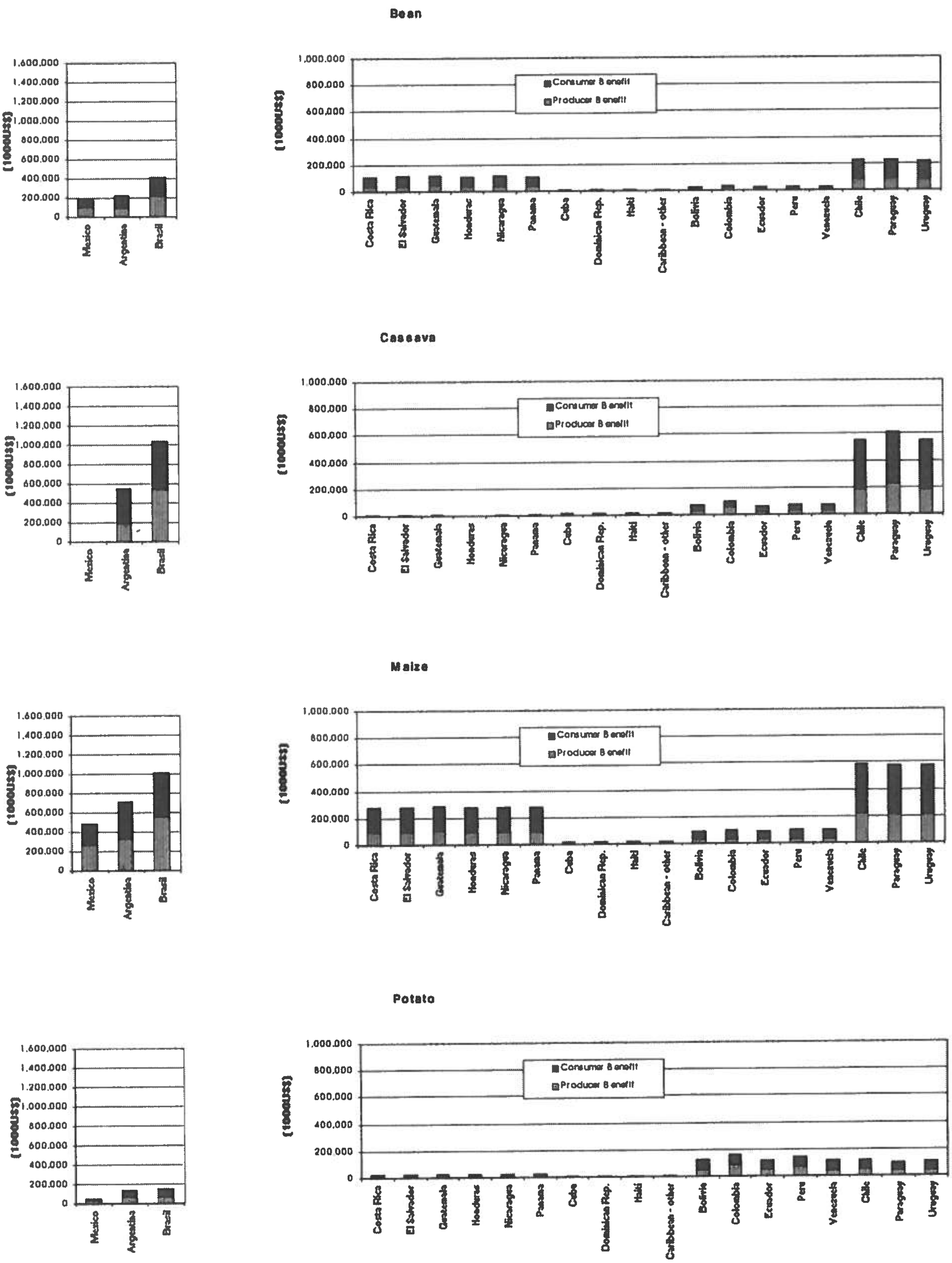
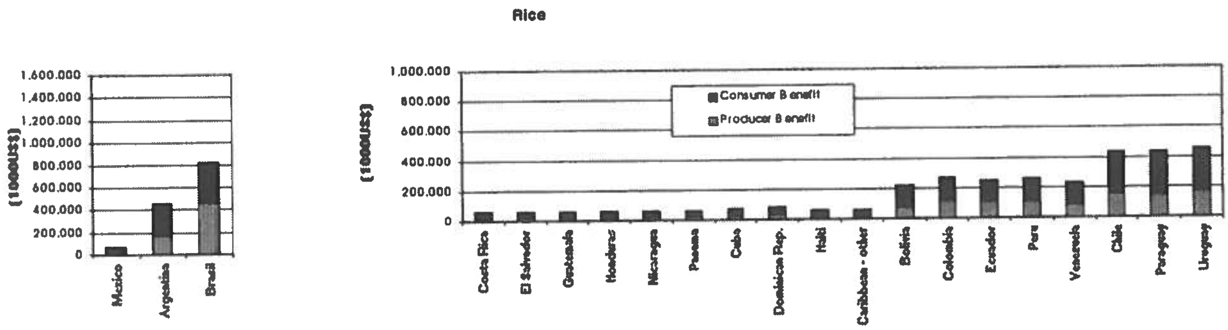
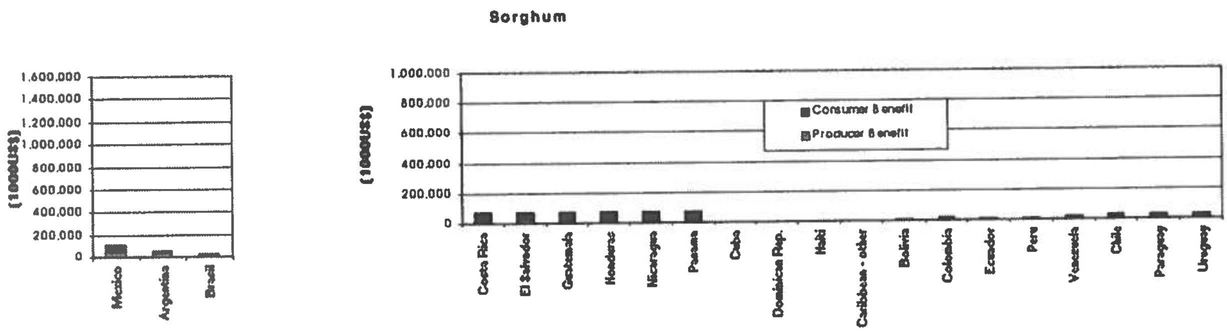
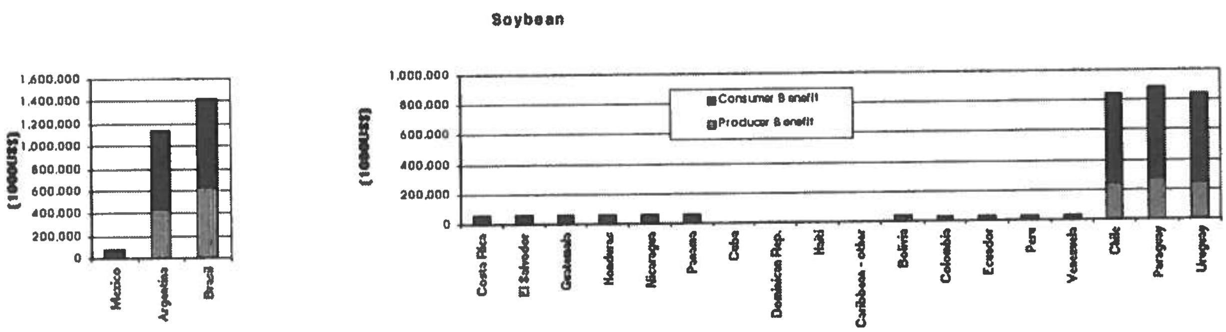


Figure 8: *Total, producer and consumer benefits—one percent, country-specific shifts, with spillover (continued)*

Panel (b) Benefits to the sub-region (continued)







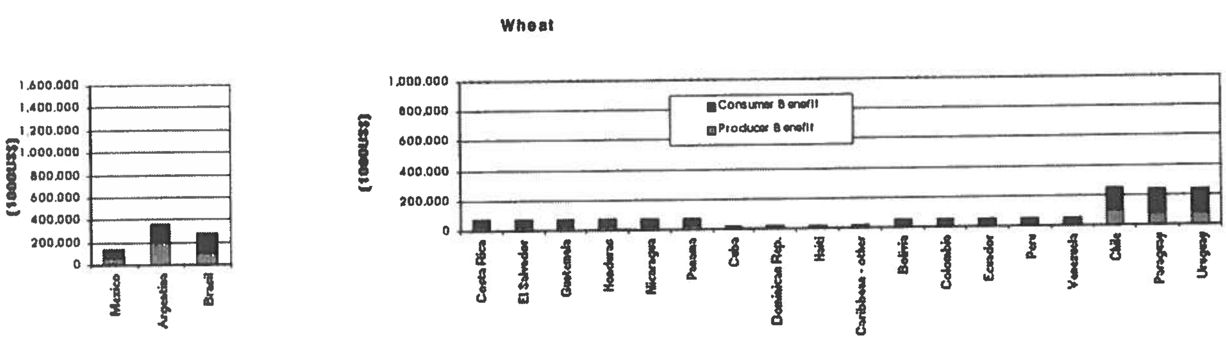
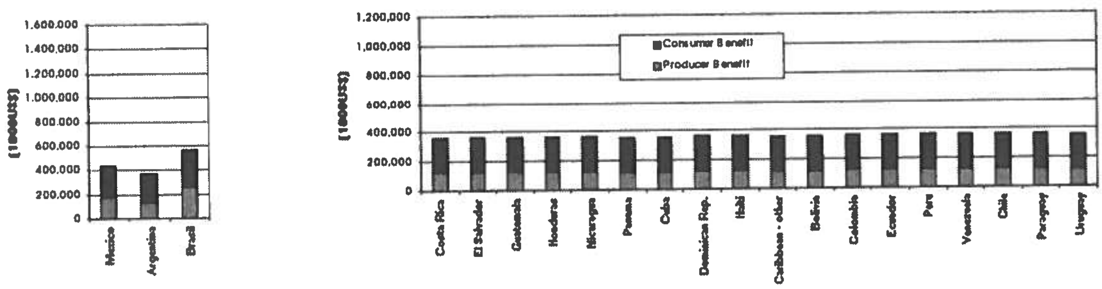


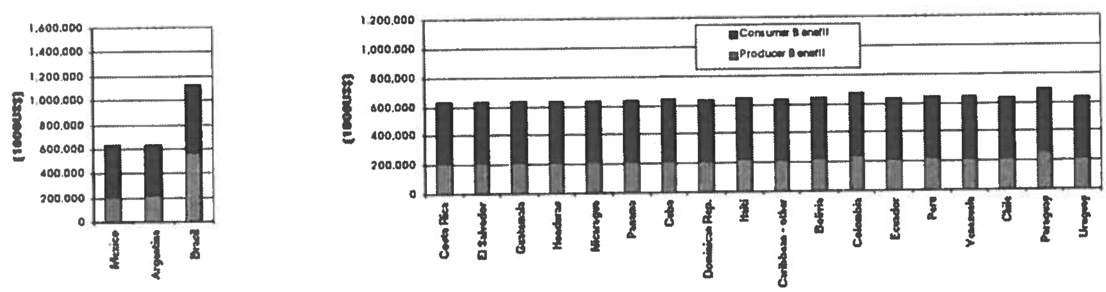
Figure 8: *Total, producer and consumer benefits—one percent, country-specific shifts, with spillover (continued)*

Panel (c) Benefits to Latin America

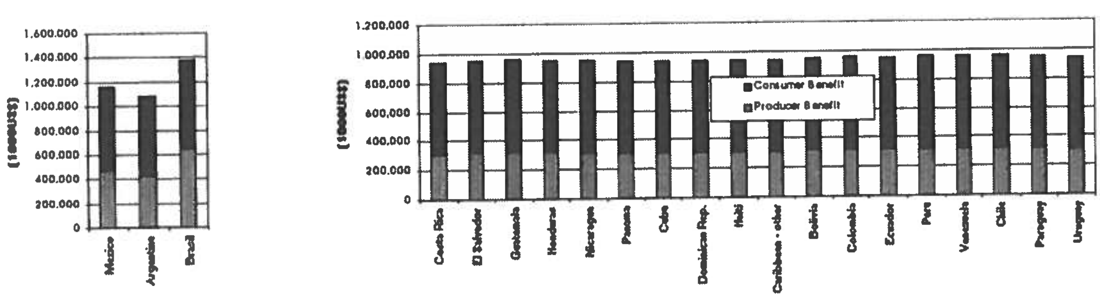
Bean



Cassava



Maize



Potato

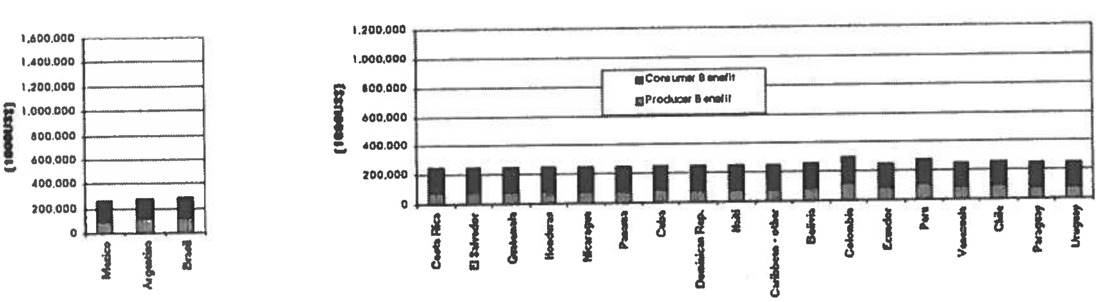
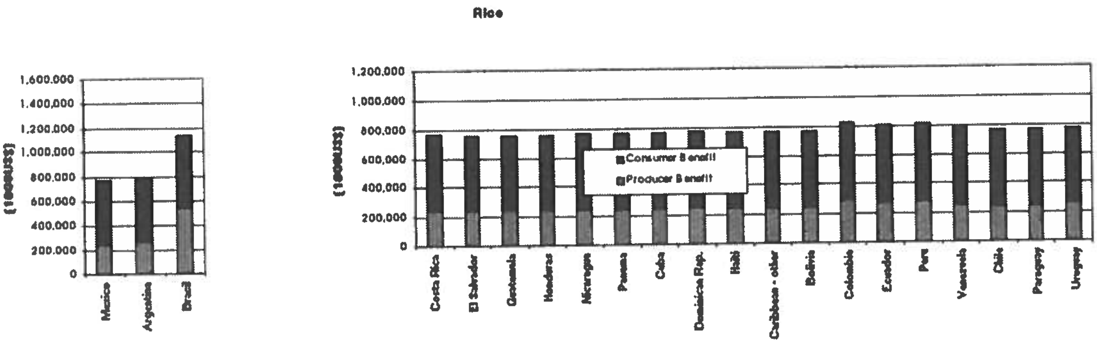
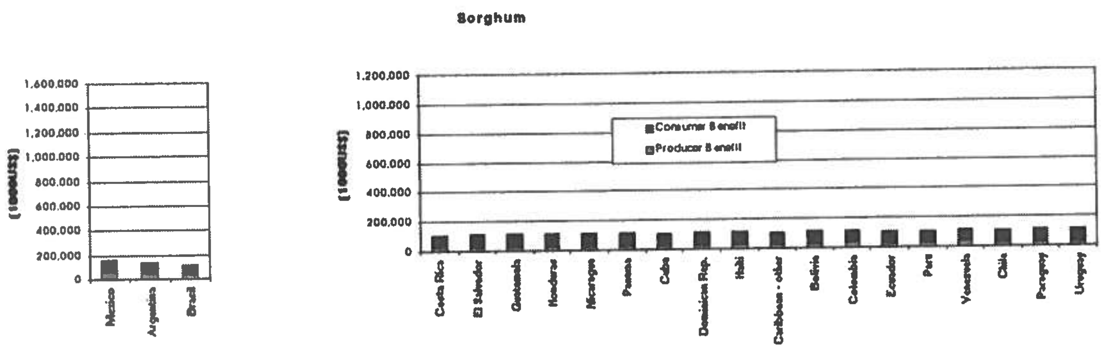
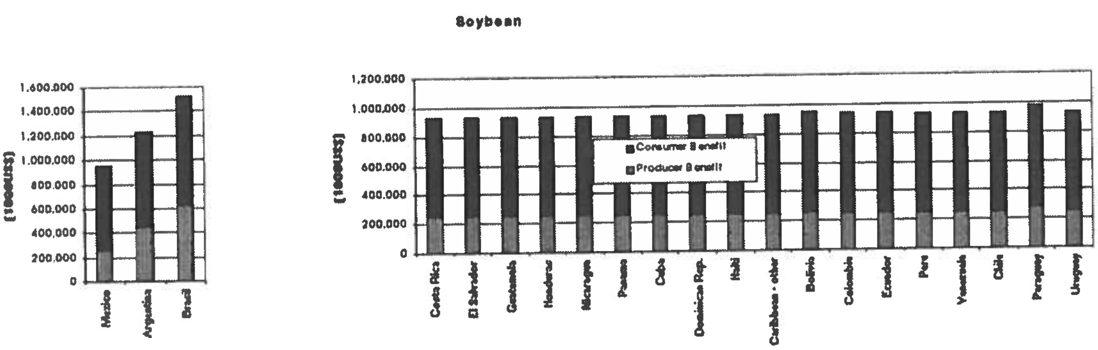


Figure 8: *Total, producer and consumer benefits—one percent, country-specific shifts, with spillover (continued)*

Panel (c) Benefits to Latin America (continued)







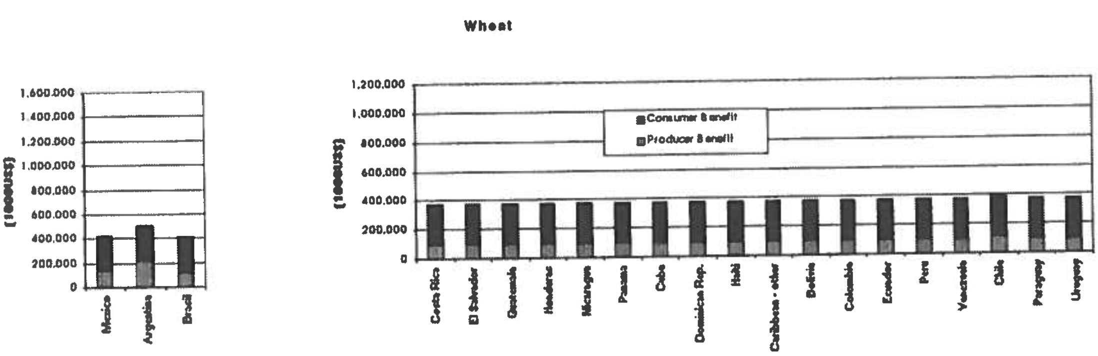


Figure 9: *Difference in producer and consumer benefits with and without spillovers—one percent, country-specific shifts*

Benefits to the innovating country

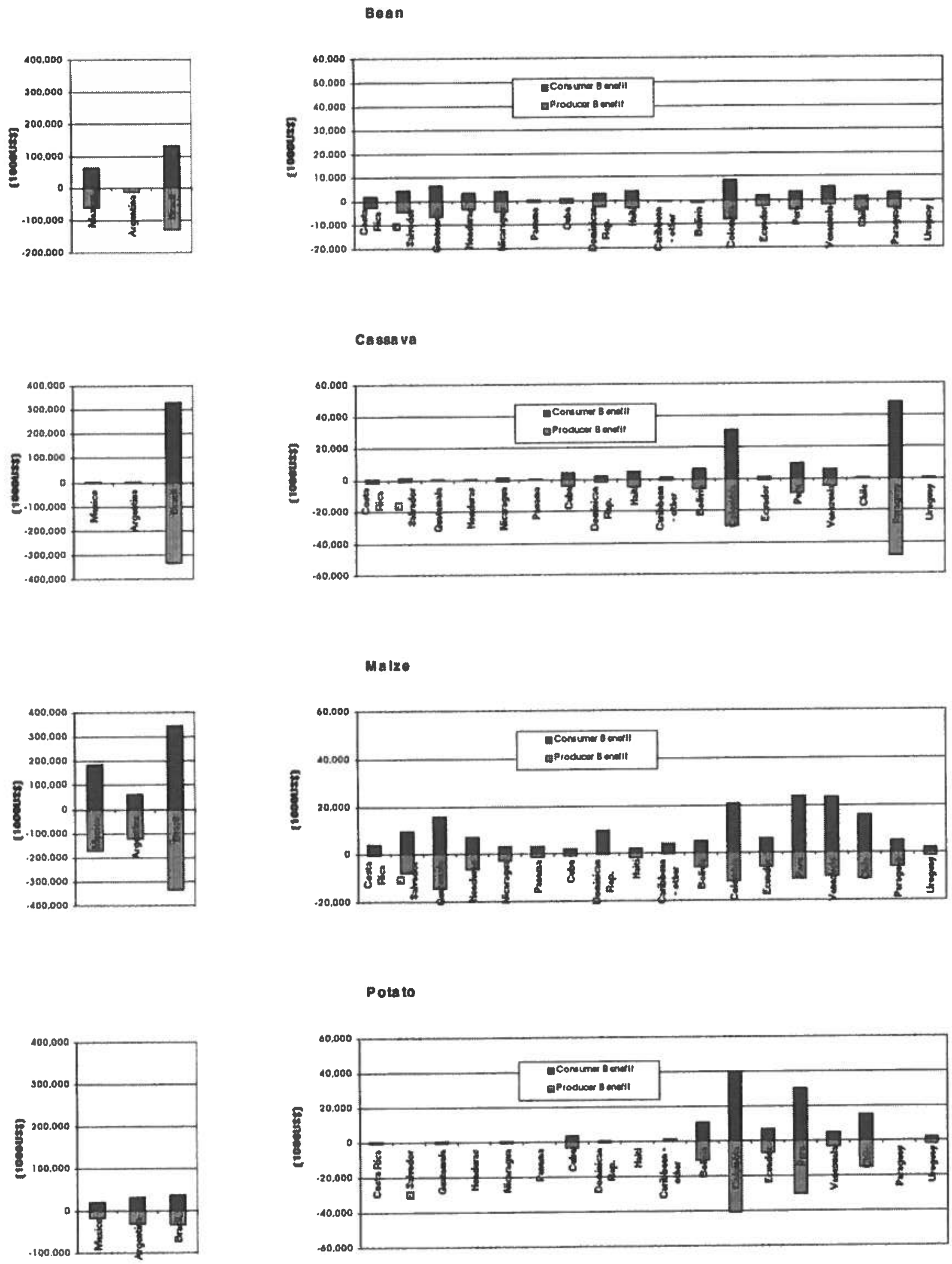
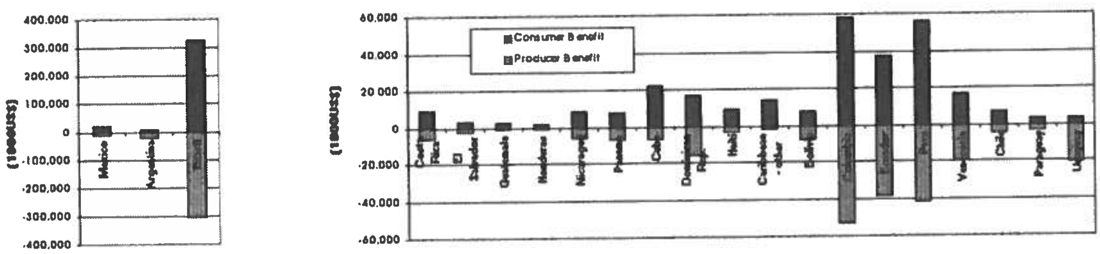
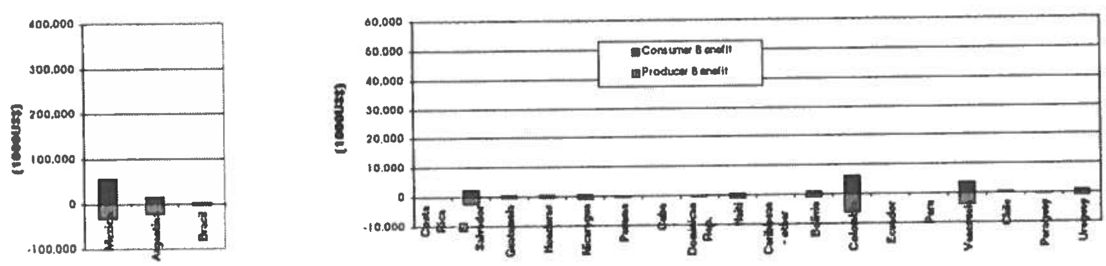


Figure 9: *Difference in producer and consumer benefits with and without spillovers—one percent, country-specific shifts (continued)*

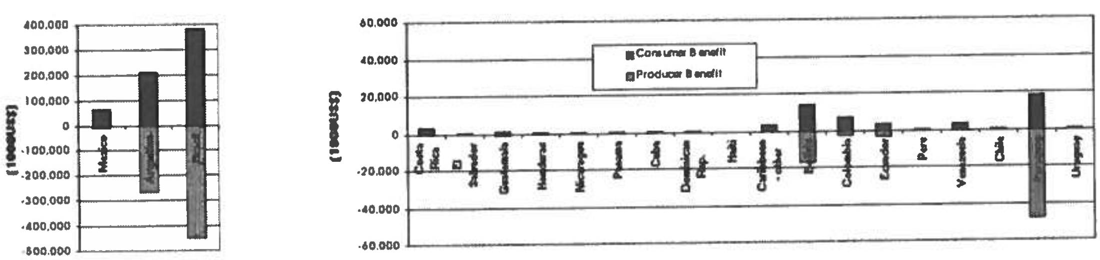
Rice



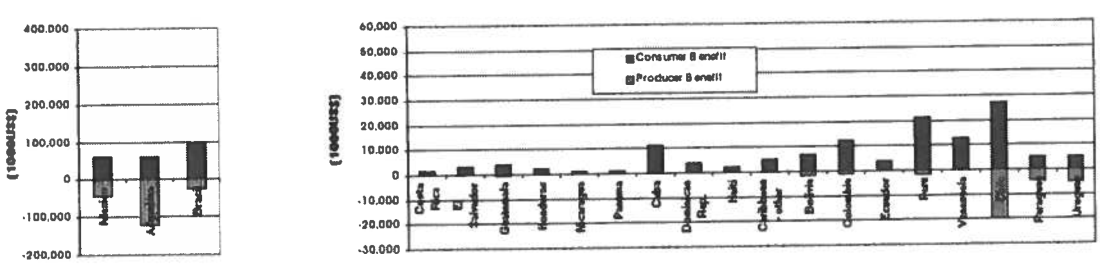
Sorghum



Soybean



Wheat



Appendix A. The Dream Model—As Revised for this Project

The Dream© *Approach*

In order to illustrate more clearly the economic surplus method in practice, this appendix presents a model that can be used to estimate the present value of research benefits in the following cases:

- multiple regions, i
- producing a homogeneous product
- with linear supply and demand in each region
- with exponential (parallel) exogenous growth of linear supply and demand
- with a parallel research-induced supply shift in one region (or multiple regions)
- with a consequent parallel research-induced supply shift in other regions
- with a range of market-distorting policies
- with zero transport costs (at least initially)
- with a research lag followed by a linear adoption curve up to a maximum
- with an eventual linear decline

This example for one commodity could be duplicated across a range of commodities (or research programs for a single commodity or several commodities) in a priority-setting study. It considers only the benefit side of the cost-benefit equation. Additional work would be needed, measuring the present value of the costs of achieving the supply shift, to complete the analysis.

The model, developed in detail below, is the conceptual basis for the *Dream*© computer program that has been developed for research priority setting and evaluation. In addition, at the end of this appendix, we present some shortcut methods and summary formulas that can be applied in the common situation where "back-of-the-envelope" estimates of benefits are desired, without going into the full analysis of growth over time, present-value calculations, multiple markets, or nontariff distortions in markets. For the archetypal cases of a small or large country in trade with and without a distortion at the border (i.e., a tariff or an export subsidy), a closed economy (with and without a commodity tax), and a large country in trade (with no distortions), we present summary formulas for the benefits to producers, consumers, taxpayers, and the economy as a whole from a given research-induced parallel supply shift.

General Form of Supply and Demand

For region i in year t, linear supply-and-demand equations for a particular commodity (subscript suppressed) are specified as

Supply: $Q_{i,t} = \alpha_{it} + \beta_i PP_{i,t}$ (1a)

Demand: $C_{i,t} = \gamma_{it} + \delta_i PC_{i,t}$ (1b)

The first subscript, i, refers to a region, and the second subscript, t, refers to years from the initial starting point of the evaluation. The slopes are assumed to be constant for each region for all time periods. The intercepts may grow over time to reflect underlying growth in supply or demand due to factors other than research (i.e., growth in productivity or income). All of the variables are expressed in real terms so that any growth is real growth. One important implication of this is that the discount rate used in subsequent analysis to compare costs and benefits of research over time must be a real rate.

Initial Parameterization

The parameters of the supply-and-demand equations are defined by beginning with initial (t=0) values of

- quantity consumed in each region – $C_{i,0}$
- quantity produced in each region – $Q_{i,0}$
- producer price in each region – $PP_{i,0}$
- consumer price in each region – $PC_{i,0}$
- elasticity of supply in each region - $\varepsilon_{i,0}$
- elasticity of demand in each region - $\eta_{i,0}$ (<0)

In many cases, the initial values of elasticities would be assumed to be equal among regions (a convenient, but not necessary, assumption). These initial values are sufficient to allow us to compute the slope and intercept of supply and demand in each region for the initial year:

$$\beta_{i0} = \varepsilon_{i0} Q_{i,0} / PP_{i,0} \quad (2a)$$

$$\alpha_{i0} = (1 - \varepsilon_{i0}) Q_{i,0} \quad (2b)$$

$$\delta_{i0} = \eta_{i0} C_{i,0} / PC_{i,0} \tag{2c}$$

$$\gamma_{i0} = (1 - \eta_{i0}) C_{i,0} \tag{2d}$$

Exogenous Growth in Supply and Demand

We incorporate average exponential growth rates to reflect growth in demand (due to growth in population and income) and supply (due to growth in productivity or an increase in area cropped) that is expected to occur regardless of whether the research program of interest is undertaken.

$$\alpha_{it} = \alpha_{it-1} + \pi_i^Q Q_{i,t} \text{ for } t > 0 \tag{3a}$$

$$\gamma_{it} = \gamma_{it-1} + \pi_i^C C_{i,t} \text{ for } t > 0 \tag{3b}$$

where

π_i^C = the growth rate of demand (e.g., population growth rate + income elasticity × income growth rate)

π_i^Q = is the growth rate of supply (e.g., area growth rate + yield growth rate not attributable to research)

Now we have sufficient information to parameterize the supply-and-demand equations for each region in each year under the no-research scenario.

Research-Induced Supply Shifts

Local effect of research: Let region i undertake a program of research with

- probability of success p_i, which, if the research is successful and the results are fully adopted, will yield
- a cost saving per unit of output equal to c_i percent of the initial price, $PP_{i,0}$ in region i, while
- a ceiling adoption rate of A_i^{MAX} percent holds in region i

Then it is *anticipated* that the supply function in region i will shift *down* (in the price direction), eventually, by an *amount per unit* equal to

$$k_i^{MAX} = p_i c_i A_i^{MAX} PP_{i,0} \geq 0 \qquad (4)$$

The *actual* supply shift in any particular year is some fraction of the eventual *maximum* supply shift, k_i^{MAX}, defined above. In order to define the actual supply shift, we can combine the maximum supply shift with other information about the shape of the time path of $k_{i,t}$ based on data about adoption and depreciation-cum-obsolescence factors. Assuming a trapezoidal shape for the adoption curve, in order to define the entire profile of supply shifts over time, we need to define the following parameters:

- research lag in years - λ_R
- adoption lag (years from initial adoption to maximum adoption) - λ_A
- maximum lag (years from maximum adoption to eventual decline) - λ_M
- decline lag (years from the beginning to the end of the decline) - λ_D

Then we can define the supply shifts (in the price direction) for region i in each year t as follows:

$$k_{i,t} = 0 \qquad (\text{for } 0 \leq t \leq \lambda_R)$$

$$k_{i,t} = k_i^{MAX}(t - \lambda_R)/\lambda_A \qquad (\text{for } \lambda_R < t \leq \lambda_R + \lambda_A)$$

$$k_{i,t} = k_i^{MAX} \qquad (\text{for } \lambda_R + \lambda_A < t \leq \lambda_R + \lambda_A + \lambda_M)$$

$$k_{i,t} = k_i^{MAX} \frac{\lambda_R + \lambda_A + \lambda_M + \lambda_D - t}{\lambda_D} \qquad (\text{for } \lambda_R + \lambda_A + \lambda_M < t \leq \lambda_R + \lambda_A + \lambda_M + \lambda_D)$$

$$k_{i,t} = 0 \qquad (\text{for } t > \lambda_R + \lambda_A + \lambda_M + \lambda_D)$$

Figure 1 shows the trapezoidal adoption curve and shows how the parameters above ($\lambda_R, \lambda_A, \lambda_M$, and λ_D) may be used to define the entire curve. Options for deriving S-shaped adoption curves are shown in Figure 2 from section 5.3.3 and appendix A5.4 of *Science Under Scarcity*.

Spillover effects of research:[1] The *spillover effects* from region i to other regions, j, are parameterized in relation to the supply shifts in region i, implicitly assuming the same adoption curve applies in every region.

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1 The spillover coefficients, θ_{ji}, are defined as if they were constant for all types of research-induced supply shifts and, for a given technological change, constant over time, implying that the relative shifts always occur in fixed proportion. These might not be reasonable restrictions for all problems. Between agroecological zones i and j, the

$k_{j,t} = \theta_{ji} k_{i,t}$ for all i and j (5)

where

θ_{ji} = supply shift in j due to research-induced supply shift in i ($\theta_{ii} = 1$)

With-Research Supply and Demand

To model the with-research case (denoted by superscript R on all relevant variables and parameters), we take the intercepts from the without-research case (but include the effects of exogenous supply growth), add the effect of the supply shift to them, and include the result in the supply equation:

$$\alpha^R_{j,t} = \alpha_{jt} + k_{jt}\beta_j \quad (6)$$

The models for supply and demand that reflect the local and spillover effects of research are

$$Q^R_{i,t} = \alpha^R_{it} + \beta_i PP^R_{i,t} \quad (7a)$$

$$C^R_{i,t} = \gamma_{it} + \delta_i PC^R_{i,t} \quad (7b)$$

The only substantive difference from the corresponding without-research equations (1a and 1b) is in the supply intercept, but as noted above, the prices and quantities are labeled differently (the R superscript) to distinguish them from the without–research values:

- quantity consumed in each region - $C^R_{i,t}$
- quantity produced in each region - $Q^R_{i,t}$
- producer price in each region - $PP^R_{i,t}$
- consumer price in each region - $PC^R_{i,t}$

Market-Clearing Rules

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spillover relationships are very likely to differ among commodities, among types of technological changes for a given commodity, and over time for a given technological change and a given commodity. For some problems, it might be necessary to redefine the spillover matrix for different types of technologies and different times after release of a technology.

For all of the scenarios to be considered, there is an overall quantity clearing rule to the effect that the sum of quantities supplied equals the sum of quantities demanded in each year. Considering n regions,

$$Q_t = Q_{1,t} + Q_{2,t} + \ldots + Q_{n,t}) = C_t = (C_{1,t} + C_{2,t} + \ldots + C_{n,t}) \tag{8}$$

All of the market-clearing rules express policies in terms of price wedges that permit differences between consumer and producer prices within and among regions consistent with clearing quantities produced and consumed.2

Free trade: The easiest case is that of free trade, where

- with-research prices: $PP^R_{i,t} = PC^R_{i,t} = PC^R_{j,t} = PP^R_{j,t} = P^R_t$
- without-research prices: $PP_{i,t} = PC_{i,t} = PC_{j,t} = PP_{j,t} = P_t$

are defined for all regions i and j and for any year t.

Making this substitution into each of the n regional supply-and-demand equations and then substituting them into equation 8 yields a solution for the equilibrium price for each year. To simplify, let us define the following aggregated parameters for each year, t:

- $\gamma_t = \gamma_{1t} + \gamma_{2t} + \ldots + \gamma_{nt}$
- $\alpha_t = \alpha_{1t} + \alpha_{2t} + \ldots + \alpha_{nt}$
- $\alpha^R_t = \alpha^R_{1t} + \alpha^R_{2t} + \ldots + \alpha^R_{nt}$
- $\delta_t = \delta = \delta_{10} + \delta_{20} + \ldots + \delta_{n0} < 0$
- $\beta_t = \beta = \beta_{10} + \beta_{20} + \ldots + \beta_{n0} > 0$

Then the without-research and the with-research market-clearing prices under free trade are given by

$$P_t = (\gamma_t - \alpha_t)/(\beta - \delta) \tag{9a}$$

$$P^R_t = (\gamma_t - \alpha^R_T)/(\beta - \delta) \tag{9b}$$

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2 Transportation costs influence trade among countries and should theoretically be incorporated into the analysis if possible. However, accurate calculation of these costs is often difficult because it requires knowing the transportation differentials for each commodity between the home country being studied and each of its major trading partners, as well as the pattern of commodity flows. If international research spillovers are included in the analysis, either (a) information should be collected on the likely destinations and transportation costs between the home country and each other country involved so that a relatively accurate assessment can be made of the price wedge to be driven between the excess-supply and excess-demand curves or (b) transportation costs should be ignored. When regional analyses within a country are being conducted, regional transportation costs also may be needed.

These are always positive numbers, with $P_t > P_t^R$, because the intercepts on the *quantity* axis satisfy $\gamma_t > \alpha_t^R > \alpha_t$ -unless we make a mistake such as letting supply grow too fast relative to demand.3

We can substitute the results for prices from equations 9a and 9b into the regional supply-and-demand equations to compute regional quantities produced and consumed with and without research and, as we shall see later, then calculate the regional consumer and producer welfare effects.

Generalized taxes and subsidies: We can define a general solution for a large variety of tax or subsidy regimes by setting out a general model in which a *per unit* tax is collected from consumers in every region and from producers in every region.

- T_i^C =per unit consumer tax in region *i*
- T_i^Q= per unit producer tax in region *i*

Different policies can be represented as different combinations of taxes and subsidies

- consumption tax in region *i* at T_i per unit: $T_i^C = T_i$; $T_i^Q = 0$
- production tax in region *i* at T_i per unit: $T_i^C = 0$; $T_i^Q = T_i$
- export tax in region *i* at T_i per unit: $T_i^C = -T_i$; $T_i^Q = T_i$
- import tariff in region *i* at T_i per unit: $T_i^C = T_i$; $T_i^Q = -T_i$

A subsidy is a negative tax, so it is also possible to use these to represent subsidies on output, consumption, imports, or exports. One way to think about this is to imagine a region with no taxes or subsidies in which the prices to producers and consumers are P_t=PC_t=PP_t and $P_t^R = PC_t^R = PP_t^R$. Thus, P_t (expressed in common currency units, either local currency or $US) is the border price for an exporter or an importer whose internal consumer or producer prices will be equal to that price in the absence of any domestic distortions. The arbitrage rules are that the prices in all regions are equal to

- $PP_{i,t} = P_t - T_i^Q$

3 For instance, we could violate this condition by setting the *autonomous* growth rate of supply so much greater than the *autonomous* growth rate of demand that in some set of future projections a point would be reached where supply and demand did not cross in the positive orthant – i.e., the *quantity* intercept of supply would become greater than the *quantity* intercept of demand in either the with- or without-research case.

- $PC_{i,t} = P_t + T_i^C$
- $PP_{i,t}^R = P_t^R - T_i^Q$
- $PC_{i,t}^R = P_t^R + T_i^C$

for all regions *i* and *j* and for any year *t*.

Making this substitution into each of the *n* regional supply-and-demand equations and substituting them into equation 9 yields a solution for the equilibrium price for each year. As for the case of free trade, let us define the following aggregated parameters for each year:

- $\gamma_t = \gamma_{1t} + \gamma_{2t} + \ldots + \gamma_{nt}$
- $\alpha_t = \alpha_{1t} + \alpha_{2t} + \ldots + \alpha_{nt}$
- $\alpha_t^R = \alpha_{1t}^R + \alpha_{2t}^R + \ldots + \alpha_{nt}^R$
- $\delta_t = \delta = \delta_{10} + \delta_{20} + \ldots + \delta_{n0} < 0$
- $\beta_t = \beta = \beta_{10} + \beta_{20} + \ldots + \beta_{n0} > 0$

In addition, we can define the following aggregated demand-and supply shifts in the quantity direction because of consumer and producer taxes:

- $T_t^C = T_{1t}^C \delta_{10} + T_{2t}^C \delta_{20} + \ldots + T_{nt}^C \delta_{n0}$
- $T_t^Q = T_{1t}^Q \beta_{10} + T_{2t}^Q \beta_{20} + \ldots + T_{nt}^Q \beta_{n0}$

$$P_t = (\gamma_t + T_t^Q + T_t^C - \alpha_t)/(\beta - \delta) \qquad 10a$$

$$P_t^R = (\gamma_t + T_t^Q + T_t^C - \alpha_t^R)/(\beta - \delta) \qquad 10b$$

To check the signs intuitively, taxes on production in all regions will raise the equilibrium world trading price P_t –which is equal to the producer price in any country or region with no producer taxes and the consumer price in any country or region with no consumer taxes. Taxes on consumption in all regions will lower it.4 Of course this hypothetical price, P_t, might not actually apply anywhere.

To compute the actual consumer and producer prices in any region, the results of equations 10a and 10b are substituted into the arbitrage (market-clearing) rules given above

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4 A positive value of T_i^Q for all *i* leads to a *positive* value of T_t^Q and thus a higher value of P_t. A positive value of T_i^C for all *i* leads to a *negative* value of T_t^C (because the demand slopes $\delta_{i,0}$ are negative numbers) and a lowering of the price, P_t.

(under the heading "generalized taxes and subsidies"). Then the individual prices can be used in the individual supply-and-demand equations (equations 1 and 7) to compute quantities with and without research, and from there to compute surplus effects. Notice that this set of results includes the free-trade model as a special case (i.e., when all of the taxes and subsidies are zero).

The small-country case: The small-country case can be represented in this model without modification. However, to do that requires getting information—that is not useful otherwise—on quantities produced and consumed in the rest of the world. The alternative is to define the market-clearing price for equations 10a and 10b as an exogenous parameter:

$$P_t = P_t^R = \overline{P}_t$$

It might require defining a growth rate for P_t, to obtain a series of exogenous world prices based on a starting value for P_0. Then corresponding quantities can be obtained by substituting into the relevant supply-and-demand equations.

Other policies: Quantitative restrictions on production or trade can be treated approximately as tax/subsidy equivalents with a little care to distribute "tax revenue" as quota rents. The approximation is somewhat unreliable in a dynamic model, but it might suffice for our purposes. A target price, deficiency-payment scheme might involve more work. Conceptually, the approach is to define target price and allow it to determine output in regions where it applies. Then, with that supply as exogenous, supply equations in the other regions and demand equations in all regions would interact to determine price.

Welfare Effects

The following equations for welfare effects should be correct for most (if not all) types of policies (i.e., market-clearing rules).

$$\Delta PS_{j,t} = k_{j,t} + PP_{j,t}^R - PP_{j,t})[Q_{j,t} + 0.5(Q_{j,t}^R - Q_{j,t})] \qquad \text{11a}$$

$$\Delta CD_{j,t} = (PC_{j,t} - PC_{j,t}^R)[C_{j,t} + 0.5(C_{j,t}^R - C_{j,t})] \qquad \text{11b}$$

$$\Delta GS_{j,t} = T_{jt}^C (C_{j,t}^R - C_{j,t}) + T_{jt}^Q (Q_{j,t}^R - Q_{j,t}) \qquad \text{11c}$$

where

$\Delta PS_{j,t}$ = producer research benefit in region j in year t

$\Delta CS_{j,t}$= consumer research benefit in region j in year t

$\Delta GS_{j,t}$=government research benefit in region j in year t

Aggregation over Time and Interest Groups

The model so far is capable of generating an indefinitely long time series of prices, quantities, and economic surplus measures for the regions of interest for a range of tax or subsidy policies. The remaining problem is to aggregate those measures into summary measures of research benefits. For a given policy scenario, we have the measure of benefits- $\Delta PS_{i,t}, \Delta CS_{i,t}, \Delta GS_{i,t}$ *- for each region in each time period.*

The *real* discount rate must be defined for the computation of the present value of the stream of benefits. A reasonable approach is to fix a single value for all regions, interest groups and years so that

$$r_{i,t} = r_{j,s} = r$$

We need to define a relevant planning horizon. Thirty years should be adequate for most purposes if we are using discount rates of 5% per year or greater. The *present values* of benefits to interest groups are then defined as

$$\begin{aligned} VPS_i &= \Sigma_{t=0}^{30} \Delta PS_{i,t} /(1+r)^t \\ &= \Delta PS_{i,0} + \Delta PS_{i,1}/(1+r) \qquad \text{12a} \\ &+ \Delta PS_{i,2}/(1+r)^2 + \ldots + \Delta PS_{i,30}/(1+r)^{30} \end{aligned}$$

$$\begin{aligned} VCS_i &= \Sigma_{t=0}^{30} \Delta CS_{i,t} /(1+r)^t \\ &= \Delta CS_{i,0} + \Delta CS_{i,1}/(1+r) \qquad \text{12b} \\ &+ \Delta CS_{i,2}/(1+r)^2 + \ldots + \Delta CS_{i,30}/(1+r)^{30} \end{aligned}$$

$$\begin{aligned} VGS_i &= \Sigma_{t=0}^{30} \Delta GS_{i,t} /(1+r)^t \\ &= \Delta GS_{i,0} + \Delta GS_{i,1}/(1+r) \qquad \text{12c} \\ &+ \Delta GS_{i,2}/(1+r)^2 + \ldots + \Delta GS_{i,30}/(1+r)^{30} \end{aligned}$$

If a longer planning horizon is appropriate we can either simply increase the number of years from 30 (probably the best way) or approximate the effects beyond 30 years using an infinite series (which is risky when the markets are growing and research effects are depreciating). Then we are free to add these present values up across the different producing and consuming groups in whatever fashion we find useful.

Appendix B. The Income Elasticity of Demand for a Factor of Production

Suppose a factor of production, K, is used to produce two consumer goods, X and Y. The demand for K is then the sum of the two demands $K(X)$, and $K(Y)$. Then,

$$dK = dK(X) + dK(Y)$$

Taking the derivative with respect to income (I) we get

$$dK/dI = dK(X)/dY + dK(Y)/dI$$

Using the chain rule

$$dK/dI = \{dK(X)/dX\}\{dX/dI\} + \{dK(Y)/dY\}\{dY/dI\}$$

Now, multiply and divide by I/K to convert to elasticities, where $E(K, I)$ is the elasticity of demand for the input, K, with respect to income

$$(dK/dI)(I/K) = E(K,I)$$

$$= [\ \{dK(X)/dX\}\ \{X/K(X)\}\ ]\ [\{dX/dI\}\ \{I/X\}\ ]\ \{K(X)/K\} + [\ \{dK(Y)/dY\}\ \{Y/K(Y)\}\ ]\ [\{dY/dI\}\{I/Y\}]\ \{K(Y)/K\}$$

Let us define:

$\{dK(X)/dX\}.\{X/K(X)\} = 1$ -- the elasticity of demand for K in the production of X with respect to total production of X, is a scale elasticity which we can assume is equal to 1 for present purposes [similarly for $\{dK(Y)/dY\}.\{Y/K(Y)\}$ 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

$\{K(X)/K\} = s(X) =$ the fraction of the total amount of the input, K, that is used to produce the final good, X

$\{K(Y)/K\} = s(Y)$ the fraction of the total amount of the input, K, that is used to produce the final good, Y

Then, $E(K,I) = s(X)E(X,I) + s(Y)E(Y,I)$

If we have many different uses of K, 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)

.i.e., $E(K,I) = \sum_{i=1}^{n} s(i)\, E(i,I)$

where the $s(i)$'s sum to 1

Note, also, that if the "input" were used as a "final" product in some use (e.g., 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 that goes 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 C. Detailed Simulation Results

Appendix Table 1: *Yield Level and Growth Rate in Latin America, 1961-97*

	1961	1971	1981	1991	1997	Growth Rate
			(tons per hectare)			*(percentage)*
Edible Beans						
Mexico	0.45	0.49	0.67	0.69	0.59	1.05
Mesoamerica (excluding Mexico)	0.58	0.54	0.74	0.71	0.67	0.43
Mesoamerica	0.47	0.49	0.68	0.70	0.61	0.99
Caribbean	0.48	0.50	0.63	0.57	0.61	0.93
Andean Countries	0.59	0.57	0.67	0.75	0.87	1.29
Brazil	0.68	0.68	0.47	0.51	0.62	-0.77
Southern Cone (excluding Brazil)	0.95	0.90	1.06	1.22	1.07	0.46
Southern Cone	0.69	0.69	0.51	0.55	0.65	-0.62
LAC	*0.59*	*0.62*	*0.56*	*0.60*	*0.65*	*0.03*
Cassava						
Mexico	20.00	20.00	13.64	7.88	7.72	-3.38
Mesoamerica (excluding Mexico)	5.25	6.06	6.45	9.45	10.64	2.16
Mesoamerica	6.77	7.63	7.15	9.44	10.62	1.17
Caribbean	4.23	4.48	4.61	4.71	4.46	0.18
Andean Countries	8.14	8.98	10.02	9.48	10.09	0.49
Brazil	13.07	14.59	11.86	12.62	12.73	-0.42
Southern Cone (excluding Brazil)	13.87	12.41	11.05	14.35	14.05	0.20
Southern Cone	13.12	14.47	11.79	12.78	12.87	-0.35
LAC	*11.90*	*13.13*	*11.16*	*11.81*	*11.95*	*-0.30*
Maize						
Mexico	0.99	1.27	1.81	2.05	2.36	2.54
Mesoamerica (excluding Mexico)	0.89	1.19	1.44	1.56	1.66	1.93
Mesoamerica	0.97	1.26	1.75	1.95	2.24	2.44
Caribbean	1.03	1.10	1.11	0.94	0.98	-0.35
Andean Countries	1.08	1.22	1.47	1.69	1.94	1.58
Brazil	1.31	1.34	1.83	1.81	2.55	1.95
Southern Cone (excluding Brazil)	1.67	2.35	3.60	3.91	4.45	2.86
Southern Cone	1.43	1.64	2.28	2.13	2.98	2.02
LAC	*1.21*	*1.47*	*2.02*	*2.02*	*2.64*	*2.16*
Potatoes						
Mexico	6.64	11.02	12.65	16.24	21.00	2.50
Mesoamerica (excluding Mexico)	6.51	6.08	5.87	11.31	12.04	2.35
Mesoamerica	6.62	10.04	11.15	15.42	19.18	2.46
Caribbean	10.38	6.53	15.64	13.12	23.17	2.14
Andean Countries	6.14	8.27	8.82	9.61	10.76	1.49
Brazil	5.65	7.60	11.18	14.07	15.19	3.04
Southern Cone (excluding Brazil)	9.50	10.41	15.01	17.03	20.13	2.65
Southern Cone	8.06	9.22	13.38	15.56	17.71	2.70
LAC	*7.19*	*8.76*	*10.76*	*12.24*	*13.87*	*2.03*

Appendix Table 1: *Yield Level and Growth Rate in Latin America, 1961-97 (continued)*

	1961	1971	1981	1991	1997	Growth Rate
			(tons per hectare)			*(percent)*
Paddy Rice						
Mexico	2.28	2.40	3.58	4.10	4.28	2.11
Mesoamerica (excluding Mexico)	1.26	2.12	2.58	2.84	3.41	2.63
Mesoamerica	1.69	2.24	2.98	3.16	3.70	2.23
Caribbean	1.78	2.30	3.30	3.40	3.82	2.09
Andean Countries	2.27	3.10	3.71	3.77	4.00	1.73
Brazil	1.70	1.38	1.35	2.30	2.60	1.41
Southern Cone (excluding Brazil)	3.02	3.31	3.83	4.13	5.62	1.41
Southern Cone	1.74	1.45	1.43	2.41	2.93	1.57
LAC	*1.80*	*1.71*	*1.91*	*2.77*	*3.27*	*1.81*
Sorghum						
Mexico	2.49	2.69	3.56	3.12	2.99	1.02
Mesoamerica (excluding Mexico)	0.91	1.10	1.40	1.27	1.57	1.22
Mesoamerica	1.45	2.33	3.25	2.77	2.80	1.69
Caribbean	0.96	1.03	0.85	0.90	0.87	-0.33
Andean Countries	2.03	2.59	1.97	2.55	2.87	0.53
Brazil	2.50	2.22	2.31	1.48	1.75	-1.15
Southern Cone (excluding Brazil)	1.87	2.00	3.52	3.27	3.62	2.58
Southern Cone	1.87	2.00	3.48	2.93	3.13	2.22
LAC	*1.62*	*2.06*	*3.15*	*2.71*	*2.83*	*1.91*
Soybeans						
Mexico	1.99	1.98	1.88	2.12	1.46	-0.48
Mesoamerica (excluding Mexico)	no data	1.47	1.39	2.31	2.70	2.29
Mesoamerica	1.99	1.98	1.88	2.13	1.75	-0.18
Caribbean	0.80	0.74	1.00	0.86	0.82	-1.06
Andean Countries	1.45	1.81	1.80	1.96	1.80	0.53
Brazil	1.13	1.21	1.77	1.55	2.30	2.19
Southern Cone (excluding Brazil)	1.20	1.47	1.98	2.30	1.86	1.70
Southern Cone	1.13	1.22	1.81	1.82	2.13	2.24
LAC	*1.18*	*1.29*	*1.81*	*1.83*	*2.11*	*1.93*
Wheat						
Mexico	1.68	2.98	3.70	4.13	4.56	2.09
Mesoamerica (excluding Mexico)	0.73	1.21	1.72	1.86	1.89	2.71
Mesoamerica	1.64	2.89	3.63	4.10	4.52	2.16
Andean Countries	0.89	0.90	1.00	1.20	1.04	0.85
Brazil	0.53	0.89	1.15	1.46	1.62	2.74
Southern Cone (excluding Brazil)	1.27	1.32	1.41	2.25	2.68	1.77
Southern Cone	1.15	1.19	1.35	2.04	2.48	1.77
LAC	*1.19*	*1.31*	*1.55*	*2.25*	*2.61*	*1.86*

Source: Compiled by authors from FAOSTAT (1999).

Appendix Table 2: *Total Benefits—One percent, Country-specific Shifts, without Spillovers*

Region/Country	Bean	Cassava	Maize	Potato	Rice	Sorghum	Soybean	Wheat
				(1,000 U.S. dollars)				
Mesoamerica								
Costa Rica	5,189	4,092	1,030	1,983	15,431	0	1	0
El Salvador	10,014	1,990	19,387	320	5,802	5,236	146	0
Guatemala	15,677	675	34,365	2,182	3,254	1,508	2,459	823
Honduras	7,811	361	15,634	666	2,679	1,472	360	26
Mexico	159,837	75	433,013	40,455	25,471	82,671	22,504	107,335
Nicaragua	11,125	2,133	7,136	975	14,916	1,807	707	0
Panama	965	1,475	3,493	733	17,316	503	7	0
Caribbean								
Cuba	2,360	10,406	1,653	7,727	16,639	22	0	0
Dominican Republic	6,113	5,394	1,358	1,124	39,675	464	0	0
Haiti	6,428	12,522	4,698	236	7,488	1,759	0	0
Other	447	3,054	1,031	379	5,052	0	2	0
Andean								
Bolivia	1,584	15,322	14,091	26,270	19,011	1,975	36,669	3,624
Colombia	19,271	72,782	28,418	98,319	124,919	14,646	5,624	2,644
Ecuador	5,322	3,058	14,517	16,976	92,686	35	7,383	667
Peru	9,338	23,471	26,897	72,526	100,659	245	65	4,047
Venezuela	4,385	11,781	24,415	8,220	47,078	9,371	149	10
Southern Cone								
Argentina	28,344	6,439	299,483	74,495	59,085	53,293	620,424	297,141
Brazil	402,983	979,814	877,674	84,782	756,170	6,003	1,198,290	63,103
Chile	10,150	0	26,221	37,022	11,453	0	0	47,074
Paraguay	7,598	118,640	14,688	62	8,313	514	101,339	10,971
Uruguay	417	0	2,914	4,352	49,449	2,536	972	11,736

Appendix Table 3: *Producer Benefits—One percent, Country-specific Shifts, without Spillovers*

Region/Country	Bean	Cassava	Maize	Potato	Rice	Sorghum	Soybean	Wheat
				(1,000 U.S. dollars)				
Mesoamerica								
Costa Rica	5,178	4,091	1,029	1,983	15,423	0	1	0
El Salvador	9,969	1,989	19,360	320	5,801	5,217	146	0
Guatemala	15,575	675	34,285	2,182	3,254	1,507	2,458	822
Honduras	7,784	361	15,618	666	2,679	1,471	360	26
Mexico	149,186	75	420,763	40,295	25,441	74,885	22,063	106,527
Nicaragua	11,080	2,133	7,133	975	14,910	1,805	707	0
Panama	965	1,475	3,491	733	17,309	503	7	0
Caribbean								
Cuba	2,358	10,392	1,652	7,721	16,619	22	0	0
Dominican Republic	6,093	5,390	1,356	1,124	39,641	464	0	0
Haiti	6,403	12,503	4,697	236	7,484	1,757	0	0
Other	447	3,053	1,031	379	5,048	0	2	0
Andean								
Bolivia	1,584	15,292	14,080	26,210	19,003	1,972	36,513	3,621
Colombia	19,106	72,079	28,330	97,498	124,534	14,497	5,613	2,640
Ecuador	5,311	3,057	14,504	16,952	92,503	35	7,375	667
Peru	9,302	23,399	26,802	72,064	100,361	245	65	4,036
Venezuela	4,362	11,759	24,331	8,212	47,036	9,315	149	10
Southern Cone								
Argentina	28,306	6,434	296,606	74,024	59,055	51,922	574,889	294,803
Brazil	339,156	858,672	830,205	84,128	742,916	5,978	1,019,317	62,336
Chile	10,134	0	26,160	36,903	11,448	0	0	46,913
Paraguay	7,576	116,805	14,677	62	8,311	514	100,746	10,964
Uruguay	417	0	2,913	4,350	49,441	2,531	972	11,728

Appendix Table 4: *Consumer Benefits—One percent, Country-specific Shifts, without Spillovers*

Region/Country	Bean	Cassava	Maize	Potato	Rice	Sorghum	Soybean	Wheat
				(1,000 U.S. dollars)				
Mesoamerica								
Costa Rica	11	0	1	0	7	0	0	0
El Salvador	45	1	28	0	1	19	0	0
Guatemala	102	0	81	0	0	2	1	0
Honduras	27	0	16	0	0	1	0	0
Mexico	10,651	0	12,250	160	30	7,785	442	809
Nicaragua	45	1	3	0	7	2	0	0
Panama	0	0	2	0	7	0	0	0
Caribbean								
Cuba	2	14	1	6	20	0	0	0
Dominican Republic	19	4	2	0	35	0	0	0
Haiti	25	19	1	0	4	2	0	0
Other	0	1	1	0	4	0	0	0
Andean								
Bolivia	1	31	10	60	8	3	156	3
Colombia	165	704	87	821	385	149	12	4
Ecuador	11	1	13	25	183	0	8	0
Peru	35	72	95	462	298	0	0	11
Venezuela	23	22	84	9	42	57	0	0
Southern Cone								
Argentina	38	6	2,877	472	30	1,370	45,535	2,338
Brazil	63,827	121,142	47,469	654	13,254	25	178,973	767
Chile	15	0	61	119	4	0	0	161
Paraguay	22	1,836	11	0	2	0	593	7
Uruguay	0	0	1	2	8	4	0	8

Appendix Table 5: *Total Benefits—One percent, Country-specific Shifts, with Spillovers*

Region/Country	Bean	Cassava	Maize	Potato	Rice	Sorghum	Soybean	Wheat
				(1,000 U.S. dollars)				
Mesoamerica								
Costa Rica	5,233	2,512	4,669	1,996	18,065	0	3,420	1,653
El Salvador	10,432	1,982	20,988	476	6,589	5,333	150	3,122
Guatemala	15,828	671	35,989	1,897	4,464	1,510	2,472	4,476
Honduras	8,174	280	16,072	663	3,719	1,484	524	2,267
Mexico	163,396	176	444,287	42,558	37,081	110,099	76,176	122,320
Nicaragua	10,660	2,123	7,422	1,161	17,115	1,769	726	1,164
Panama	948	1,551	5,380	745	18,073	507	19	1,383
Caribbean								
Cuba	2,317	10,377	3,025	8,191	32,223	22	179	11,107
Dominican Republic	6,814	5,334	10,594	1,120	39,791	482	596	3,810
Haiti	7,840	12,109	4,841	236	13,939	1,765	0	2,205
Other	594	2,708	4,521	1,431	17,073	21	3,633	5,347
Andean								
Bolivia	1,294	15,286	13,242	26,206	18,977	1,985	33,186	8,931
Colombia	20,111	73,045	37,396	97,446	130,342	14,964	9,798	13,814
Ecuador	5,293	3,020	14,476	16,926	91,599	105	7,523	4,248
Peru	9,304	23,422	39,366	72,816	114,950	388	125	23,598
Venezuela	8,042	12,789	37,311	9,799	44,484	9,235	3,570	13,166
Southern Cone								
Argentina	17,925	6,632	239,943	73,818	44,181	47,303	568,240	235,626
Brazil	406,812	977,109	884,973	86,428	775,703	6,105	1,132,050	133,953
Chile	7,482	1	30,992	37,003	13,893	495	68	54,723
Paraguay	7,406	118,343	13,685	79	8,612	517	72,274	11,281
Uruguay	491	79	3,826	4,816	31,954	2,591	866	12,154

Appendix Table 6: *Producer Benefits—One percent, Country-specific Shifts, with Spillovers*

Region/Country	Bean	Cassava	Maize	Potato	Rice	Sorghum	Soybean	Wheat
				(1,000 U.S. dollars)				
Mesoamerica								
Costa Rica	3,017	2,382	599	1,154	8,981	0	0	0
El Salvador	5,812	1,158	11,276	186	3,378	3,041	76	0
Guatemala	9,088	393	19,975	1,270	1,895	877	1,291	479
Honduras	4,537	210	9,096	388	1,559	856	189	15
Mexico	88,983	43	247,394	23,489	14,815	44,607	11,607	62,152
Nicaragua	6,461	1,242	4,153	568	8,682	1,051	371	0
Panama	562	858	2,033	426	10,079	293	3	0
Caribbean								
Cuba	1,373	6,052	962	4,496	9,678	13	0	0
Dominican Republic	3,551	3,138	789	654	23,086	270	0	0
Haiti	3,731	7,282	2,735	138	4,358	1,023	0	0
Other	260	1,778	600	221	2,939	0	1	0
Andean								
Bolivia	922	8,908	8,200	15,272	11,066	1,149	19,201	2,108
Colombia	11,155	42,103	16,505	56,936	71,470	8,470	2,947	1,537
Ecuador	3,094	1,779	8,447	9,874	53,895	20	3,872	388
Peru	5,423	13,636	15,615	42,051	58,481	143	34	2,350
Venezuela	2,541	6,849	14,174	4,782	27,394	5,435	78	6
Southern Cone								
Argentina	16,536	3,746	173,731	43,195	34,396	30,604	310,756	172,513
Brazil	210,502	525,368	493,094	49,109	435,171	3,485	569,114	36,357
Chile	5,908	0	15,239	21,509	6,666	0	0	27,338
Paraguay	4,415	68,379	8,547	36	4,839	299	53,095	6,384
Uruguay	243	0	1,696	2,533	28,794	1,475	510	6,829

Appendix Table 7: *Consumer Benefits—One percent, Country-specific Shifts, with Spillovers*

Region/Country	Bean	Cassava	Maize	Potato	Rice	Sorghum	Soybean	Wheat
				(1,000 U.S. dollars)				
Mesoamerica								
Costa Rica	2,217	130	4,069	842	9,085	0	3,420	1,653
El Salvador	4,620	824	9,712	290	3,212	2,292	73	3,122
Guatemala	6,740	279	16,014	627	2,569	633	1,181	3,997
Honduras	3,637	70	6,976	275	2,159	627	335	2,252
Mexico	74,413	133	196,893	19,069	22,266	65,492	64,569	60,168
Nicaragua	4,199	882	3,269	593	8,433	718	355	1,164
Panama	386	692	3,347	319	7,995	214	16	1,383
Caribbean								
Cuba	944	4,325	2,063	3,695	22,545	9	179	11,107
Dominican Republic	3,264	2,195	9,804	466	16,705	212	596	3,810
Haiti	4,108	4,827	2,106	98	9,581	742	0	2,205
Other	334	930	3,921	1,210	14,134	21	3,632	5,347
Andean								
Bolivia	372	6,379	5,043	10,935	7,912	837	13,984	6,823
Colombia	8,957	30,942	20,891	40,510	58,873	6,495	6,851	12,277
Ecuador	2,199	1,241	6,029	7,052	37,704	85	3,651	3,860
Peru	3,881	9,786	23,751	30,765	56,469	245	91	21,248
Venezuela	5,500	5,940	23,137	5,017	17,090	3,801	3,492	13,160
Southern Cone								
Argentina	1,389	2,886	66,213	30,623	9,785	16,699	257,484	63,114
Brazil	196,310	451,741	391,878	37,320	340,532	2,620	562,936	97,596
Chile	1,574	1	15,752	15,494	7,227	495	68	27,385
Paraguay	2,991	49,964	5,138	43	3,773	218	19,179	4,896
Uruguay	248	79	2,130	2,283	3,160	1,117	356	5,325