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PRIORITIZING REGIONAL AGRICULTURAL R&D INVESTMENTS IN AFRICA

Incorporating R&D Spillovers and Economywide Effects

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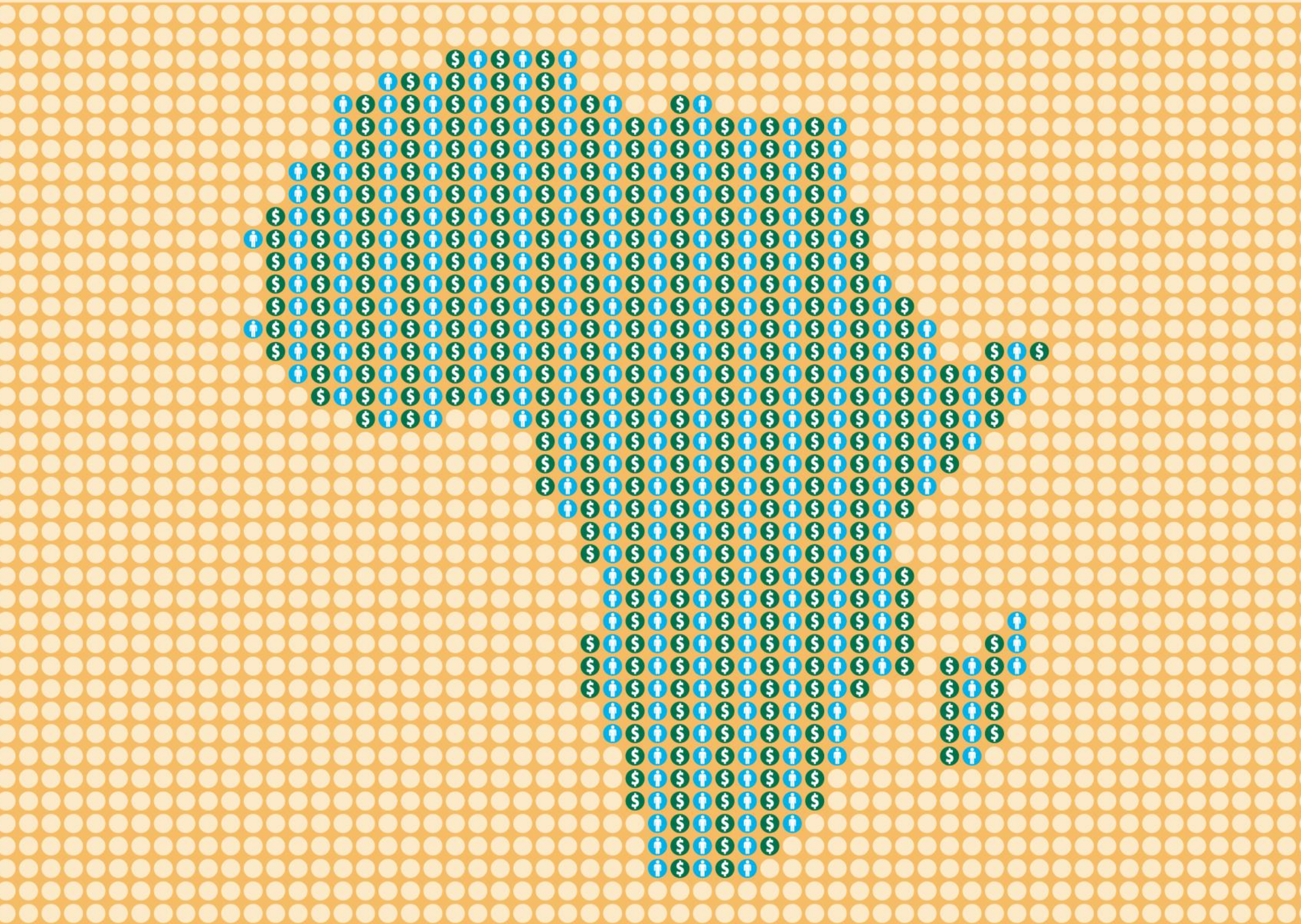
AGRICULTURAL R&D: INVESTING IN AFRICA'S FUTURE
Analyzing Trends, Challenges, and Opportunities



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Acronyms and Abbreviations

ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
ASTI	Agriculture Science and Technology Indicators
CIMMYT	International Maize and Wheat Improvement Center
CORAF/WECARD	West and Central African Council for Agricultural Research and Development
DRC	Democratic Republic of Congo
DREAM	Dynamic Research Evaluation for Management
EMM	economywide multimarket (model)
FARA	Forum for Agriculture Research in Africa
GDP	gross domestic product
IFPRI	International Food Policy Research Institute
MDGs	Millennium Development Goals
mt	metric tons
NARS(s)	national agricultural research system(s)
R&D	research and development
ROR	rate of return
SADC	Southern Africa Development Community
SPAM	Spatial Production Allocation Model

Abstract

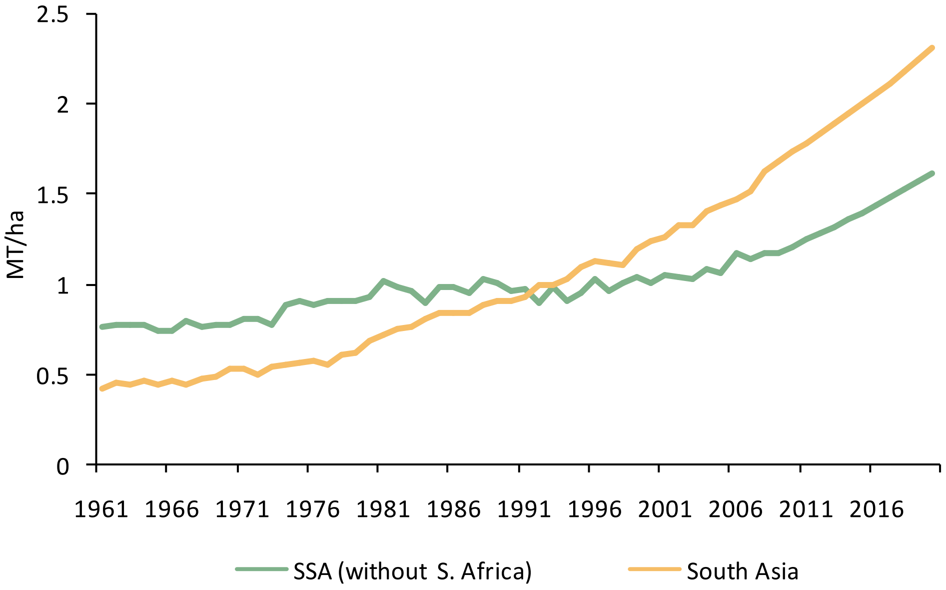
To achieve the first of the United Nations' Millennium Development Goals (MDGs), halving poverty and hunger by 2015, African countries have set a target of 6 percent agricultural GDP growth. Whether, and to what extent, this target can be achieved depends a great deal on the rate at which agricultural productivity can be accelerated, given current low levels in most countries. Because many countries in Africa have small economies and limited capacities and resources for effective R&D, focusing on a regional agricultural R&D strategy can help fill these gaps and facilitate scale economies. While the need for regional cooperation in R&D is well known, as is evident from the efforts of organizations such as the Forum for Agriculture Research in Africa (FARA), the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), and the West and Central African Council for Agricultural Research and Development (CORAF/WECARD), a key challenge is having empirically sound evidence and methods for setting regional R&D priorities that are also consistent with the resource constraints and development objectives of the individual countries.

The aim of this study, therefore, is to review a number of methods that have been applied in the African context and at the regional level. More specifically, the study reviews both the empirical methods and results from three regional studies undertaken by the international Food Policy Research Institute (IFPRI) to assess regional agricultural R&D priorities for ASARECA in East and Central Africa (Omamo et al. 2006), CORAF/WECARD in West and Central Africa (Nin Pratt et al. 2011) and the Southern African Development Community (SADC) in Southern Africa (SADC 2012, forthcoming). Although the studies were undertaken at different times, they built a lot on each others' work, beginning with the work for ASARECA in 2003/04, then for CORAF/WECARD in 2006, and more recently for SADC in 2010. Comparing and contrasting all three, therefore, offers an opportunity to review the methods used, data limitations and relevance for the Agricultural Science and Technology Indicators (ASTI) initiative, the kinds of policy implications that emerge from the results, and ultimately their translation into policy action within each region.

1. INTRODUCTION

To achieve the first of the United Nations' Millennium Development Goals (MDGs), halving poverty and hunger by 2015, African countries have set a target of 6 percent agricultural GDP growth. Whether, and to what extent, this target can be achieved depends a great deal on the rate at which agricultural productivity can be accelerated given current low levels in most countries. As a key driver of agricultural output growth, productivity has grown little in the region; cereal yield levels, for example, have not kept pace with the steady growth achieved in South Asia (Figure 1).

Figure 1. Aggregate cereal yields in Sub-Saharan Africa and South Asia, 1961–2009



Source: FAO 2011.
Note: mt/ha indicates metric tons per hectare.

For Africa, increasing cereal yields at comparable rates to those of South Asia would require significant investments in agricultural research and development (R&D), as well as other complementary investments in areas such as irrigation, market infrastructure, and institutions (Diao, Headey, and Johnson 2008;von Braun et al. 2008). In particular, local research infrastructure and capacities in Africa have been eroded over time through years of neglect, primarily from lack of public funding for agricultural R&D (Beintema and Stads 2006, 2011). There is therefore a desperate need to strengthen agricultural R&D systems in Africa, ensuring they become more cost-effective.

Many African countries have small economies and limited capacities and resources to undertake their own basic research, so greater regional cooperation in R&D offers opportunities for achieving valuable scale and scope economies. This is possible in the African context because many countries share similar agroecological and socioeconomic conditions, and hence have higher potential for successful research and technology transfer.

Fortunately, the need for greater regionalization of R&D is well recognized among national R&D systems, as is evident in the establishment of the Forum for Agriculture Research in Africa (FARA), the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), and the West and Central African Council for Agricultural Research and Development (CORAF/WECARD).

The agricultural challenges facing each major subregion are in some respects similar with regard to the need to increase investment in agricultural R&D to increase the yields of many basic food staples. The differences, and hence scope for regional approaches, occur in the range of key food staples, agricultural production systems, and constraints; the characteristics of individual economies; the current performance; and the degree of integration through trade.

Focusing on the Eastern subregion, ASARECA has 10 member countries: Burundi, the Democratic Republic of Congo (DRC), Eritrea, Ethiopia, Kenya, Madagascar, Rwanda, Sudan, Tanzania, and Uganda. Agriculture contributes about 40 percent of the subregion's gross domestic product (GDP), and all 10 members are classified as low-income countries. Those with the largest economies are DRC, Ethiopia, Kenya, Madagascar, Tanzania, and Uganda. Generally, the subregion's agricultural sectors have a poor record of productivity growth, as is evident in the very low rates of yield growth for cereals in past decades (Table 1). As a result, many ASARECA countries have become net importers of most agricultural commodities, including cereals. With a growing need to import food staples for a growing population that lacks sufficient purchasing power, poverty and hunger remains a serious threat in the region. Making matters worse, periodic droughts and violent conflicts have occurred in both the Horn of Africa and DRC.

Table 1.Rates of cereal yield growth in Sub-Saharan Africa by subregion, 1961–2009

Region/subregion	1960s	1970s	1980s	1990s	2000s	1961–2009
	Average annual growth rate (%)					
Eastern Africa	0.3	2.1	0.4	–0.5	1.1	0.6
Southern Africa	0.2	1.8	0.7	3.5	1.3	1.0
West and Central Africa	–0.3	2.0	0.2	1.2	2.4	1.2
Southern Africa excluding South Africa	–0.8	4.0	6.5	–2.2	0.9	0.8
West and Central Africa excluding Nigeria	1.0	0.5	0.6	1.6	2.3	0.8
Sub-Saharan Africa excluding South Africa	0.1	1.8	0.1	1.0	1.9	0.9
Southern Asia	1.6	2.7	2.7	2.8	3.5	3.0
World	1.9	0.6	4.3	2.5	2.9	2.3

Source: Calculated from FAO 2011.

Notes: Eastern Africa comprises the 10 member countries of the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA); Southern Africa comprises the 15 member countries of the Southern African Development Community (SADC); and West and Central Africa comprises the 22 countries of the West and Central African Council for Agricultural Research and Development (CORAF/WECARD). A few countries are members of more than one of these organizations. DRC is a member of all three, whereas Madagascar and Tanzania are members of both ASARECA and SADC.

West and Central Africa has fared a little better than Eastern Africa in recent decades. CORAF/WECARD has 22 member countries in this subregion: Benin, Burkina Faso, Cameroon, Cape Verde, Central African Republic, Chad, Congo, Côte d'Ivoire, DRC, Gabon, Gambia, Ghana, Guinea Bissau, Guinea Conakry, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, and Togo. Aggregate cereal yields grew at about 1.6 and 2.3 percent per year, respectively, in the 1990s and 2000s (Table 1). Agriculture dominates most of the economies, accounting for almost 30 percent of the subregion's aggregated GDP. This varies at the country level, however. At one extreme, agriculture accounts for 71 percent of GDP in Liberia and 57 percent in Guinea Bissau, but the share is much lower in oil-rich, middle-income countries like Gabon, the Republic of Congo, and Equatorial Guinea.

Southern Africa, the SADC region, comprises a mix of low-income countries together with a few middle-income countries. The low-income countries are DRC, Lesotho, Madagascar, Malawi, Mozambique, Tanzania, Zambia, and Zimbabwe. The middle-income countries are Angola, Botswana, Mauritius, Namibia, Seychelles, South Africa, and Swaziland. Among these, South Africa alone accounts for about two-thirds of the subregion's aggregated GDP; if the other six middle-income countries are included, the combined share rises to 82 percent of the subregion's combined GDP. Although agriculture dominates among the lower income countries, as in the other two subregions, the bulk of Southern Africa's cereals, livestock products, and fruits and vegetables are produced by the subregion's middle-income countries. These seven countries produce almost 65 percent of the subregion's cereals, 80 percent of its beef and poultry meat, and 80 percent of its fruits and vegetables. Nonetheless, the complementarities offered by this combination of low- and middle-income countries offers potential for broader dynamics and linkages for growth in trade and investment (Nin Pratt and Diao2008). Unfortunately, few among the low-income countries are poised to take advantage of such opportunities due to their low and stagnant levels of agricultural productivity and growth.

In all three regions, improved agricultural R&D systems are fundamental to increasing productivity and stimulating overall income growth. As stated earlier, however, many of Africa's national agricultural research systems (NARSs), particularly those in the smaller and poorer countries, lack sufficient staff, technical skills, and other resources as a result of decades of general neglect. Greater regional cooperation and pooling of resources provide a cost-effective way of tackling this challenge.

Arguments for Regionalization of Agricultural R&D in Africa

A regional approach to agricultural R&D offers a number of potential benefits, especially for subregions with a mix of small and large countries, similar patterns of natural resource endowments and development constraints, and scarce public resources (Eicher 2003; Abdulai, Johnson, and Diao 2006; Pardey et al. 2007; You and Johnson 2010). Whenever research and technologies are shown to be easily transferrable or have large potential spillovers across countries, pooling resources has the potential to reduce R&D costs for individual countries, while helping to improve systemwide efficiency by reducing duplication of effort, encouraging greater specialization, and exploiting existing complementarities in research capacities (Gijsbers and Contant 1996). Additionally, a regional approach can offer greater scope and scale economies than is achievable by individual countries, thereby allowing coverage of a broader range of research topics and generation of the critical mass of human resource capacity needed for success (You and Johnson 2010).

A regional approach brings added opportunities, but it also increases the complexity of R&D planning. To rank and prioritize investments at country and regional levels, planners must know where the potential for cross-country R&D spillovers is greatest. The magnitude of such spillovers—and thus the benefits of regional cooperation—is often difficult to measure. Early efforts to measure agricultural research spillovers are evident in the seminal work of Evenson (1989), which showed how larger research systems in the United States benefited smaller ones. More recently, Pardey et al. (2007) measured the potential extent of intercontinental research spillovers; Johnson, Masters, and Preckel (2006) and Nweke, Spencer, and Lynam (2002) examine research spillovers for cassava in Africa; and Ahmed, Sanders, and Nell (2000) did the same for sorghum and millet. Byerlee and Eicher (1997) found large research spillovers for improved maize varieties across African countries, and Maredia and Byerlee (2000) found spillovers for improved wheat in a range of developing countries. Gabre-Madhin and Haggblade (2004) reviewed evidence on the transfer and adaptation of technologies across Africa and found significant spillovers especially for cotton and rice in West Africa, maize in East and Southern Africa, and cassava in West and Central Africa.

Numerous biophysical and socioeconomic factors influence the extent to which research benefits can spillover to regions other than those targeted. These many factors make measuring spillover potential difficult. Davis, Oram, and Ryan (1987) and Alston, Norton and Pardey (1995) suggested using agroecological and socioeconomic similarities to estimate environmental "proximity" between and across countries. To this end, Pardey et al. (2007) constructed a distance metric at the global level based on similarities in production systems and agroecological zones. They found that countries can have a high research proximity despite being separated by large geographical distances (South Africa and Mexico are an example of such countries). In fact, an important finding of their analysis was that a majority of countries in Sub-Saharan Africa have greater research proximities with countries outside the region than with those within it, emphasizing a critical role of internationally focused research efforts. Nevertheless, this does not negate research proximity among countries within the region and, therefore, the value of subregional R&D among African countries.

Other studies have used more direct measures of research proximity. Pardey (1986) and Thorpe and Pardey (1990), for example, constructed indexes of research proximity based on the type of research undertaken between research centers and across countries. Another technique, when sufficient data exists, is to directly calculate spill-in coefficients, for example, using data on the yield performance of improved varieties derived from germplasm developed elsewhere. Taking this approach, Maredia and Byerlee (2000) found significant spillovers of wheat varieties developed by the International Maize and Wheat Improvement Center (CIMMYT) in Mexico to many developing countries. Their results suggest a greater emphasis on adaptive, rather than basic, research among African countries, which is not surprising.

Evidence of research or technology spillovers emphasizes the advantages of allocating more resources to adaptive R&D, especially for countries that could benefit from the spill-ins of research and technologies developed elsewhere. For planners, knowledge of what types of research and technology have the greatest spillover potential can improve resource allocation within and across countries, thus maximizing the rate of return to investment. Ignoring spillovers not only leads to an underestimation of the benefits of agricultural research, but also—more importantly—to underinvestment in research. Spillovers have been shown to account for at least half of the total benefits of research (Alston, Norton, and Pardey 1995; Alston 2002).

All told, harmonizing country-level R&D efforts with regional initiatives requires, priority setting, which in turn depends on sufficient empirical evidence on which types of research and technologies show greater potential for spillovers, can contribute to the subregion’s targeted development goals, and maximize the input of the national systems involved while aligning with national and subregional resource and capacity constraints and comparative advantages.

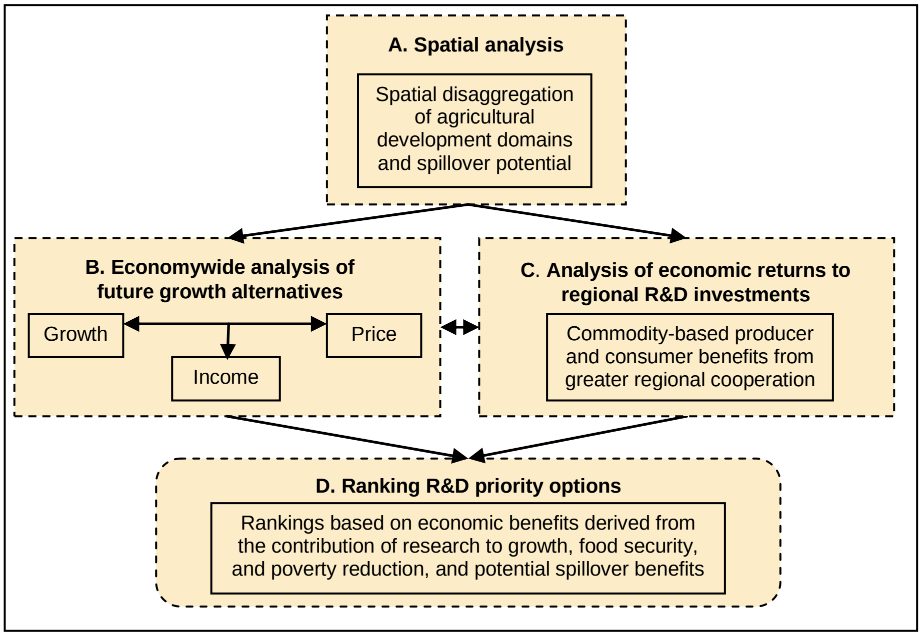
2. METHODOLOGY: COMBINING SPATIAL AND ECONOMIC TOOLS UNDER A COMMON FRAMEWORK

The unifying objective for the empirical economic analysis undertaken in the three subregional studies conducted by IFPRI for ASARECA, CORAF/WECARD, and SADC was to help each subregion and its national and subregional partners determine their agricultural research priorities based on credible analytical evidence. To this end, the studies relied on three distinct, but integrated approaches: spatial analysis, economywide modeling, and analysis of the returns to R&D investments (including a consideration of spillovers). The extent to which these approaches were successfully integrated varied across the different subregions based on the availability of data and the sequencing of the studies, given that improvements were incorporated into each successive study. See Box 1 for a description of the conceptual framework that underpinned the three studies.

Box 1. A common analytical framework

All three regional studies utilized a common framework that began with a highly disaggregated spatial analysis based on key biophysical and socioeconomic factors of geographic areas sharing similar characteristics and endowments and, in turn, their degree of agricultural suitability, type of production systems and commodities, and available technology options (Figure B1, part A). The resulting distinctive agricultural development domains, which are not limited by political boundaries, provided a measure of the technological proximity of different countries and hence the potential for technology spillovers among them. Second, more detailed economic analysis was undertaken using a regional economywide multimarket (EMM) model (Figure B1, part B) and IFPRI's Dynamic Research Evaluation for Management (DREAM) model (Figure B1, part C). The DREAM model was typically used to measure the potential magnitude of economic benefits derived from different commodity-based R&D investment options that rely on the distributional pattern of each development domain across countries. The EMM was developed to capture economywide implications of the same investments, including the potential benefits from technology spillovers on overall sector growth, incomes, prices, and consumption. Results from the economic analyses were then used to derive alternative rankings of R&D investments based on weighted criteria of a commodity-specific R&D investment's potential to contribute to overall sector growth, generate greater spillover benefits, and provide larger welfare outcomes in terms of regional food security and poverty reduction objectives (Figure B1, part D).

Figure B1. A common integrated analytical framework for assessing future regional R&D priorities in East Africa, Southern Africa, and West and Central Africa



Source: Adapted by authors from the framework developed in SADC (2012, forthcoming).

A number of key premises for setting regional R&D priorities underlie this framework: (1) the importance of accounting for and measuring the spatial patterns of production and socioeconomic conditions within and across countries; (2) the need to consider R&D spillovers; (3) the need for a dynamic, forward-looking perspective; and (4) the importance of a broad economic perspective when considering the effects of alternative R&D interventions on overall growth and welfare outcomes (including, for example, incomes, consumption, and production). It is reasonable to expect different patterns of investments within agricultural sectors to have different impacts on overall growth in the sector, in the wider economy, and on food security and poverty reduction (see Diao et al. 2007). Additionally, in Africa the potential for agricultural research spillovers is assumed to be high, given the biophysical and socioeconomic similarities between many countries. Although it seems reasonable to assume that there will be spillover benefits, these may not always occur in practice. For example, if a country has little capacity to undertake adaptive research, it may be unable to take advantage of technology spill-ins.

Spatial Analysis of Development Domains and Technology Spillover Potential

Spatial analysis tools using geographic information systems provided information on the biophysical and socioeconomic endowments within and across countries. In particular, overlays of agroecological and climatic information, population densities, and market access were used to map agricultural "development domains," which are distinct areas similarly endowed in these three attributes. Length of growing period provided the basis for measuring agricultural potential. Market access reflects physical accessibility to output markets in terms of expected travel times, for example, to cities, major trade corridors, regional trading centers, and seaports. Population density was measured as the number of persons per square kilometer. Each of the three studies selected appropriate cut-off points to categorize areas as "low,""medium," or "high" in terms of each key attribute. Together, the three attributes influence the choice of agricultural production systems and resource allocation, and the degree of commercialization feasible.

In addition to identifying commodity-based economic livelihood zones, the spatial analysis also high lighted places where agricultural activities may be encroaching on fragile ecological domains, therefore requiring technologies to safeguard environmental sustainability (Wood et al. 1999; Wood and Chamberlin 2003). For example, locations where economic goals compete with natural resource conservation may require tailored resource management technologies that enable sustainable use while protecting fragile environments.

By defining the production systems and constraints observed in the field, the spatial analysis provided an initial indication of the technology options available and yield performance potential. However, calculating total production and yields within the different development domains proved to be a major challenge, as the required disaggregated household-level data were not readily available everywhere. To fill such data gaps, the CORAF/WECARD study combined existing district-level data with plausible estimates of crop production derived using satellite imagery of land cover and vegetation (You et al. 2007). Using this method, referred to as the "Spatial Production Allocation Model" (SPAM), average and maximum potential yields could be calculated within the defined development domains. Inputs were the local agroecological and climatic characteristics, the known production area and output, and yield performance under different farming systems (for example, irrigated versus rainfed). Information on potential maximum yields was introduced as well, derived from the types of technologies suitable for areas with specific agroecological and climatic attributes. (For further details on the data and methods employed, see Nin Pratt et al. 2011.

Using the results of the yield gap analysis, estimates could be made of the growth rates required to close the yield gaps over a given period of time. Because the yield gap information is comparable across countries within the same development domain, it also provides an approximate measure of spillover potential. For example, if yields under similar conditions are lower in one country than in another, spillover potential is said to be high.

The SADC study investigated spillover potential more directly, constructing "spillover matrixes" for each crop using yield gap information and other factors. The matrixes drew on three dimensions: similarity in production environment (based on similar endowments in terms of agroecology and climate), probability of successful "spill-ins" of research and technologies (based on the capacity for adaptive research in the receiving country), and probability of successful "spill-outs" of research and technologies (based on the size of the yield gaps). Construction of the spillover matrixes followed Jaffe (1986, 1989); Davis, Oram, and Ryan (1987); and, most recently, Pardey et al. (2007). For details on the approach, see the appendix and SADC (2012, forthcoming).

The spillover matrixes enabled the SADC study to better integrate the results of the spatial analysis with the subsequent economic analysis. The growth and welfare implications of closing yield gaps for the different key crops could be decomposed based on a country's own research and capturing research spill-ins through adaptive research. This was quite different from the analysis of benefits from regional R&D cooperation in the ASARECA and CORAF/WECARD regions (described further below).

Economywide Analysis of Future Growth Alternatives

Founded on neoclassical microeconomic theory, EMM models—which as previously stated were developed for all three studies (see Box 1)—are useful for assessing and quantifying the implications of alternative policy scenarios. The analysis utilizes disaggregated data by sector and subsector (or commodity) and thus allows the incorporation of yield growth rates resulting from R&D investments and successful adoption. The model can be designed to represent any desired geographic arrangement of production and market areas—as long as sufficient data is available on production, consumption, and prices, for example, at the development domain level. For further details on the model, see Omamo et al. (2006) and Nin Pratt et al. (2011).

The basic structure of the EMM models was similar across the three regional studies. The main differences were whether domestic markets were broken down into smaller units and the extent to which the EMM analysis corresponded to the spatial analysis done earlier. In the ASARECA study, 12 development domains were drawn based on the spatial analysis but with particular focus on combinations of agricultural potential (“high” or “low”), the presence or absence of irrigation, and farmland size (“small,”“medium,” or “large”). The supply side of the model draws on subnational production data for 32 commodities important in the ASARECA region. On the demand side, national information on commodity demand was derived from population and income figures and broken down for rural and urban inhabitants.

The CORAF/WECARD study also identified 12 development domains, again based on the spatial analysis and similarities in terms of the presence or absence of irrigation, market access conditions (access to ports and domestic markets), and population density (“high” and “low”). Twenty West and Central African countries were included in the model, classified into three major agroclimatic regions (“coastal,”“central,” and “Sahelian”). The study included 40 commodities. Demand was determined at the national level only, unlike the ASARECA study, but this time regression analysis was used to estimate income elasticities where possible.

Finally, the SADC study used a simplified EMM model. This time, production was aggregated at the national level rather than at the domain level, mainly because it was expected that a link with the potential spillover analysis (through yields) would only be possible at this higher level of aggregation. The assumption was that the spillover matrixes had already captured the diversity in production environments, the variability in yield gaps, and therefore the yield growth potential in each country. A modification was also made to separate aggregate demand and household income into rural and urban sectors. The intention here was to capture the dynamics of urbanization in the region, as consumption structure and behavior differs between the two household types.

Analysis of the Economic Returns to R&D Investments and Spillovers

Agricultural R&D can take up to a decade to produce technologies that farmers can use in their fields. After that, adoption is typically very slow at first, then rises steeply before leveling off again (a sigmoid growth curve). The dynamics of these processes cannot be captured in an EMM model. For this reason, two of the three studies (ASARECA and CORAF/WECARD) also utilized IFPRI’s DREAM model because it explicitly incorporates characteristics such as the unit costs of research, time lags, technology-induced supply shifts, and diffusion over time (Alston, Norton, and Pardey 1995; Wood, You, and Baitx 2000).[1]

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[1] For details on the approach, see Alston, Norton, and Pardey (1995); You and Johnson (2010) looks at its application in detail for the ASARECA case.

A major challenge in using the two models to assess regional agricultural research priorities is ensuring that the DREAM analysis is consistent with the broader EMM model simulations. The CORAF/WECARD study did the best job of linking the DREAM and EMM models, employing common parameters and adopting similar underlying assumptions and yield-enhancing investment scenarios. Both models were calibrated to common parameter values and used the development domain configuration as the basic unit of analysis. Common values included crop production and consumption, crop prices, demand, supply, and income elasticities. Additionally, both models used the same growth scenarios and demand-side projections based on initial simulations in the EMM model.

Such integration did not occur in the ASARECA study, which took its DREAM analysis primarily from Abdulai, Johnson, and Diao (2006). Because in this case the modeling results were not easily comparable, the DREAM conclusions were included mainly as a stylized complement to the EMM results. Comparing the spillover benefits found using the DREAM model with the EMM results nonetheless provided useful insights into the implications of greater regional cooperation in R&D.

In both the ASARECA and CORAF studies, a major drawback of the application of the DREAM model was lack of sufficient data on time lags, potential diffusion, and the expected unit cost of research per commodity. As a result, the rankings were based on gross economic surplus benefits, which implicitly assume that the R&D cost of achieving one unit of gain from adoption (for example, one dollar) would be similar across all crops and regions (You and Johnson 2010). Due to this serious limitation, the SADC study did not use the DREAM model. Instead, it constructed spillover matrixes using the spatial analysis information and linked these directly with the EMM simulations. Essentially, the spillover matrixes were used to decompose the growth and welfare implications of closing yield gaps among the major crops using a country's own research and research spill-ins. Existing capacities for adaptive research and probability of adoption were therefore accounted for. Nevertheless, as in the first two studies, estimates of economic rates of return were not possible due to the lack of information on the expected unit cost of research per commodity.

Ranking R&D Priority Options

The final rankings resulted from three sets of key questions: (1) What investment and policy options, and what key commodity areas, offer the best potential for accelerating agricultural sector growth and raising incomes in order to reduce poverty and food insecurity in the relevant subregion? (2) Of the key commodity areas, which are most suitable for a subregional R&D program based on the potential for adaptation and direct transfer (or spillovers) across countries? (3) What other constraints and complementary or cross-cutting issues must be considered in order to enhance productivity growth among countries in the relevant subregion?

All components of the analysis provided useful criteria for ranking alternative R&D investments and tradeoffs. The first set of criteria was drawn from the spatial analysis: the scale and scope of a commodity's importance in the subregion in terms of its share in agricultural value-added, production, and consumption; demand growth potential given rural and urbanization trends; supply growth potential given past evidence of yield growth and existing yield gaps under current technologies or growth targets set by the region; and the share of smallholder production or participation in production of the commodity, as this was assumed to lead to larger growth multiplier effects and poverty reduction (Diao et al. 2007). Other criteria included potential contribution to future growth and regional spillovers based on a number of the scenarios introduced in the EMM and DREAM models.

In the CORAF/WECARD study, the detailed analysis of yield gaps served as the key source for defining growth scenarios for the different development domains. The first scenario represents the least ambitious policy alternative of simply reducing yield losses due to biotic stress. The second reflects the more ambitious strategy of closing current yield gaps to achieve the maximum attainable yields with existing technologies. The final and most optimistic scenario assumes the same accelerated yield growth rate as in the second scenario, but this time with improved access to markets. This emphasizes the importance of more fully integrated markets within and across countries.

The SADC study introduced only one scenario with accelerated yield growth rates to 2015. Target growth rates for individual commodities were set to SADC's growth objectives. Combined, these produce an overall agricultural sector growth rate of at least a 6 percent per year. The individual target growth rates were compared with regionwide estimates of average yield gaps based on a detailed spatial analysis of actual and maximum yields, as in the CORAF/WECARD study. In contrast to that study, improved market access was not introduced as an alternative; the preference was to draw on the results of an earlier study on regional market opportunities and growth dynamics in the region (Nin Pratt and Diao 2008).

3. COMPARING THE RESULTS OF THE ANALYSISACROSS THE THREE SUBREGIONS

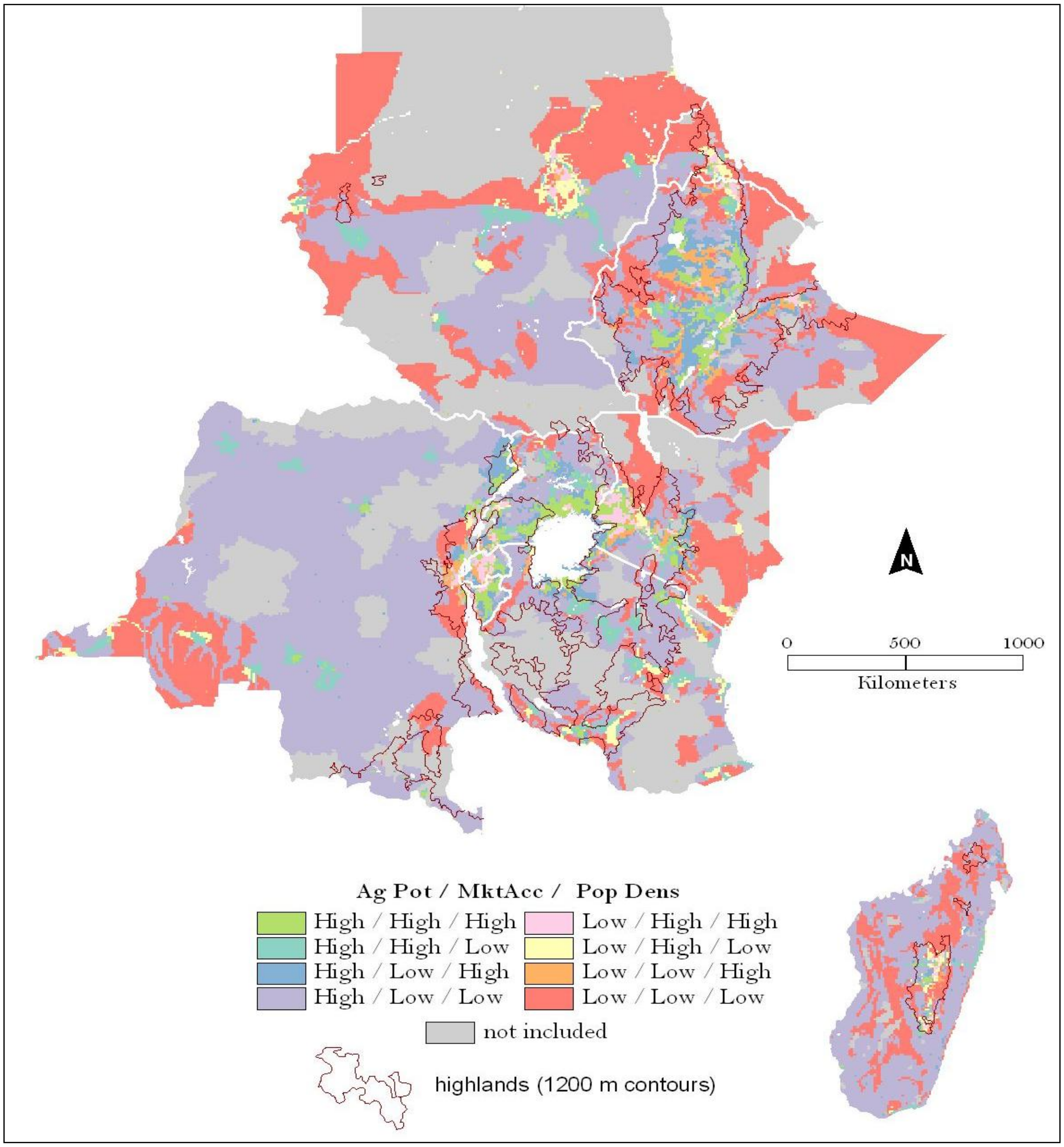
The loosely integrated analytical approaches adopted in the three studies produced valuable information on the potential effects of commodity-specific R&D on yield performance, technology spillovers, and economic growth within the agricultural sector and overall.

Development Domains and Spillover Potential

The spatial analysis for the ASARECA group of countries showed the highest agricultural potential in relatively densely populated areas close to water bodies and rivers, and where temperatures and rainfall tend to be higher. Typical crops grown include cassava, plantain, and maize. Fruits and vegetables, legumes and pulses are also common. Dominant agricultural exports are coffee, tea, and sugar. Among livestock products, beef and dairy items are important. Market access is better close to major trade corridors, near cities, and in other relatively densely populated areas, such as the highlands of Ethiopia, Rwanda, and Burundi. Figure 2 maps the intersection of the three key attributes: population density, agricultural potential, and market access. To simplify the analysis, the map defines eight development domains with the attributes simply classified as "high" or "low."The largest domain in ASARECA's subregion combines high agricultural potential with low market access and low population density. This zone makes up almost 40 percent of the total land area. Areas with both high agricultural potential and high market access account for only about 4 percent of the land area. More than 60 percent of the rural population inhabits about half of the area classified as having high agricultural potential, but almost 40 percent of these areas have poor market access.

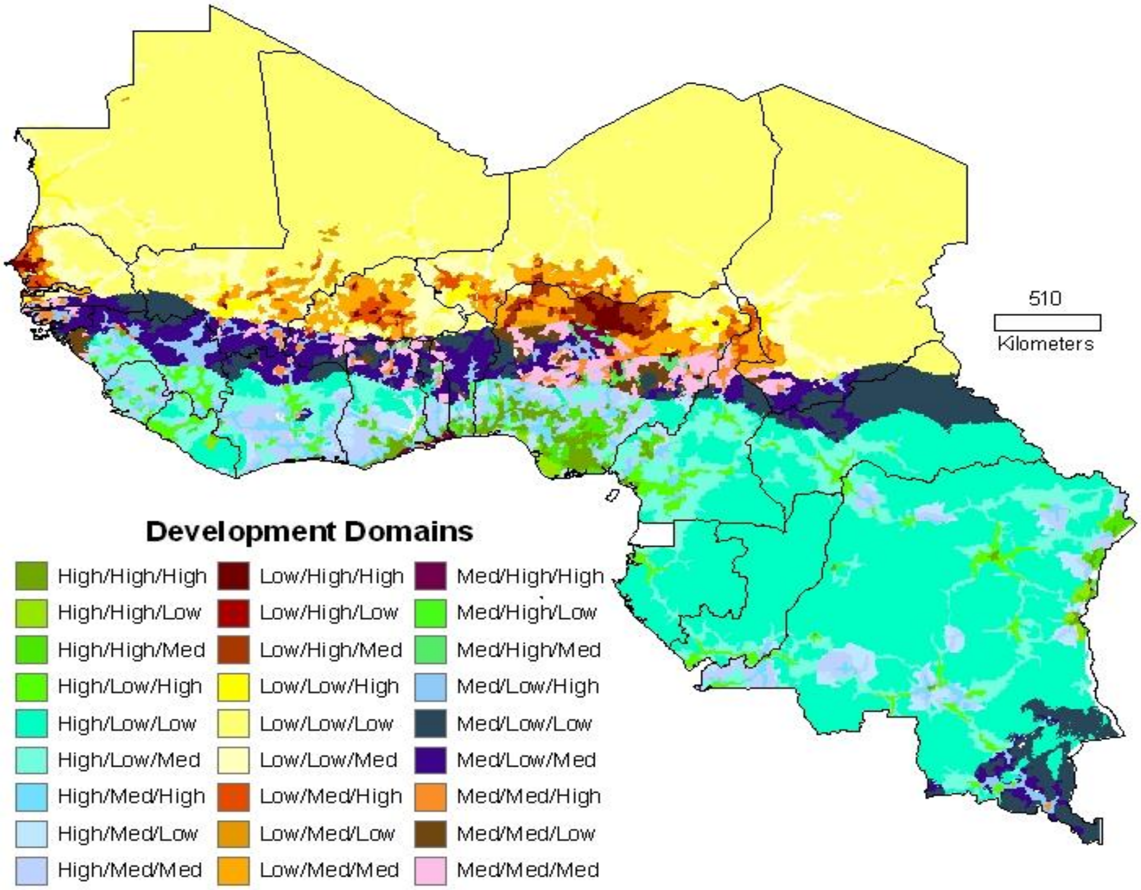
The spatial analysis in the CORAF/WECARD study resulted in 27 development domains. The same attributes were used as in the ASARECA case, but this time classified under three categories: "low," "medium," and "high" (Figure 3). Here, the largest development domain is the one with low agricultural potential, low population density, and low market access. This covers almost 40 percent of the subregion's land area. Areas with high agricultural potential and high market access account for only 2 percent of the land area, but almost 20 percent of the rural population lives there. Altogether, enormous expanses of the subregion remain economically underutilized. Large swaths of medium-and high-potential agricultural lands have poor market access and low population densities. The most densely populated areas are along the coast and the Niger River. Population densities tend to be quite low in much of the Sahel, as well as in the forested areas of Central Africa. Regarding market access, the Sahelian and Central African countries have the largest areas with poor market access, while the West African coastal countries have the broadest market access conditions. Still, nowhere are markets predominantly or uniformly highly accessible.

Figure 2. Development domains in East and Southern Africa



Source: Omamo et al. 2006.

Figure 3. Development domains in West and Central Africa



Source: Johnson et al. 2008.
Note: "Med" indicates medium.

Agroecological and climatic conditions across West and Central Africa give rise to a number of distinct humid, semi-humid, semiarid, and arid zones, clearly visible as three broad swathes when mapped (Figure 3). The sizable humid and subhumid zones, found mainly along the coast and into Central Africa, have tree crops and mixed farming systems, focusing especially on cocoa, palm oil, and roots and tubers (such as cassava and yams). The semi-arid zone in the Sahel is dominated by cereals (such as millet and sorghum) and livestock production. Generally speaking, the agroecological zones correspond to the length of growing periods and thus to degree of agricultural potential. The CORAF/WECARD study therefore used these zones as the basis for defining its key development domains across CORAF/WECARD member countries. This helped to simplify the domain classification for the application of the EMM and DREAM model analyses, considering the large number of countries in the subregion. More importantly, defining the development domains this way enabled the yield gap results from the spatial analysis to be incorporated more accurately for each major agroecological zone.

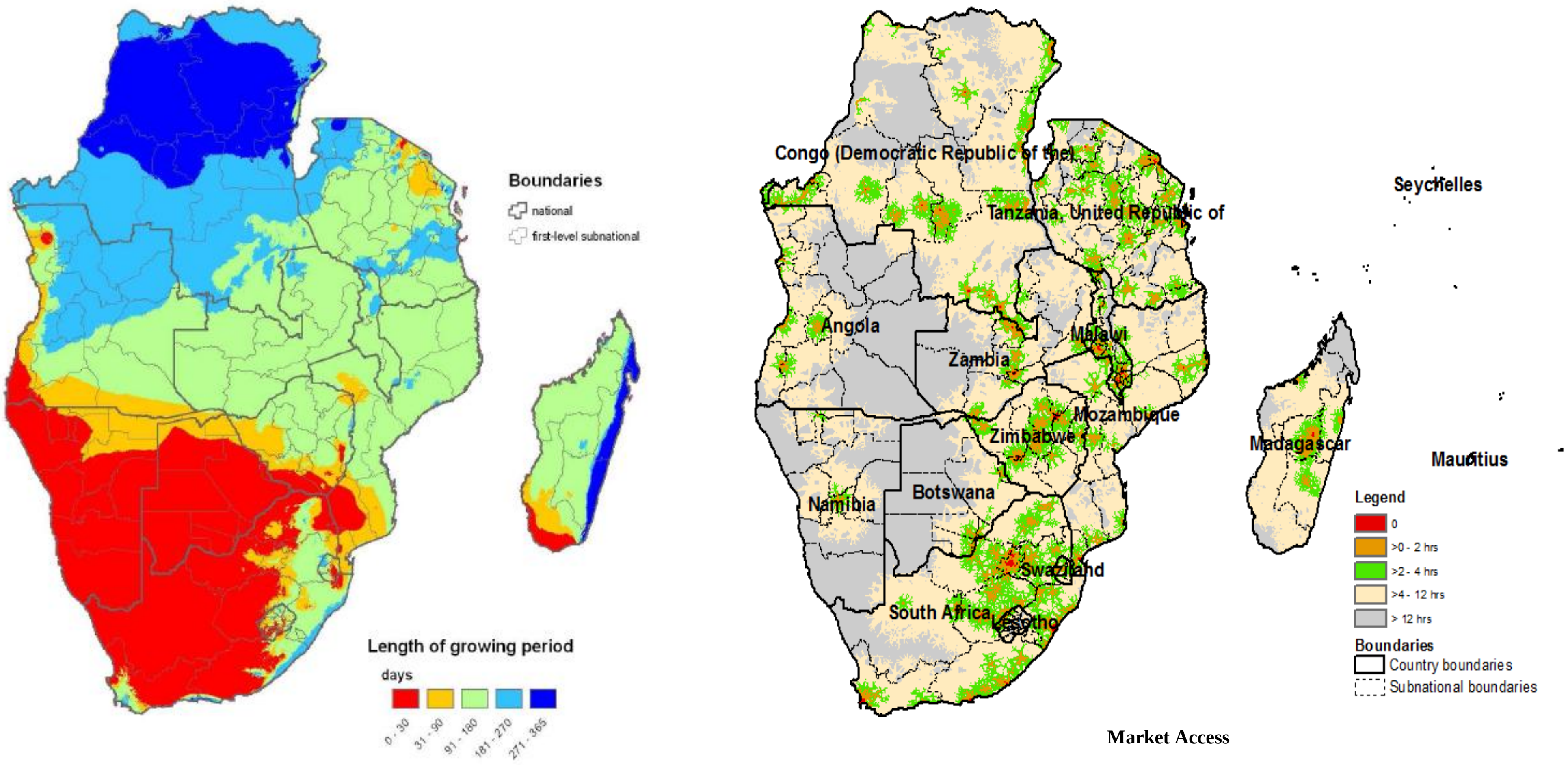
The yield gap analysis for West and Central Africa found that by simply eliminating constraints from biotic stress, yields could be increased by more than 10 percent over all crops, especially in the central and coastal areas. In most cases, farmers could more than double their yields by 2015 if they adopted more efficient and intensive production practices (Nin Pratt et al. 2011). For coarse grains, the yield increases could be even greater, at three to four times the, then, current levels. This rich information on yields was used to simulate a range of growth scenarios to determine long-term implications for growth within the agricultural sector and the overall economy.

The most recent of the three studies (for the SADC region) took a slightly different approach to mapping the development domains. The regional distribution of the attributes was depicted in separate maps. Figure 4 shows two of these: agricultural potential and market access. The population density map is very similar to that of market access. The Great Lakes area, Malawi, South Africa, and Zimbabwe have good market access and high population densities relative to elsewhere in the subregion. Subregional similarities in these characteristics point to high potentials for technology spillovers, both for commodity-specific technologies to eliminate biotic stress and for improved resource management practices.

The SADC study used the information from the spatial analysis to construct potential spillover matrixes. Inputs into this process were development domain characteristics, the corresponding yield gaps, and the overall status of national-level research capacities (the appendix provides more details on the methodology). Potential yield growth was estimated for selected crops for which data were available. Drawing on the same data and SPAM analysis as the CORAF/WECARD study, average gaps between current and maximum achievable yields were found to range from 30 to100 percent at the subregional level. This means that a doubling of yields is feasible in some cases.

As described earlier, the spillover matrixes combined three dimensions of information: similarity in production environment, probability of successful technology spill-ins, and probability of successful technology spill-outs. The analyses also identified potential source countries for research and technologies (based on national research capacities and yield gaps). They also pointed to which countries were most likely to benefit from research spill-ins (based on similarities in production systems, yield gaps, and capacity for adaptive research). For example, the potential for maize research spillovers is high for research originating in South Africa, Swaziland, Zambia, and Malawi (Figure 5). Many countries in Southern Africa have little comparative advantage in undertaking independent basic research in maize. Rather, they would benefit more from an adaptive research capacity. Angola, Botswana, and Tanzania are the largest potential beneficiaries of maize technology spill-ins.

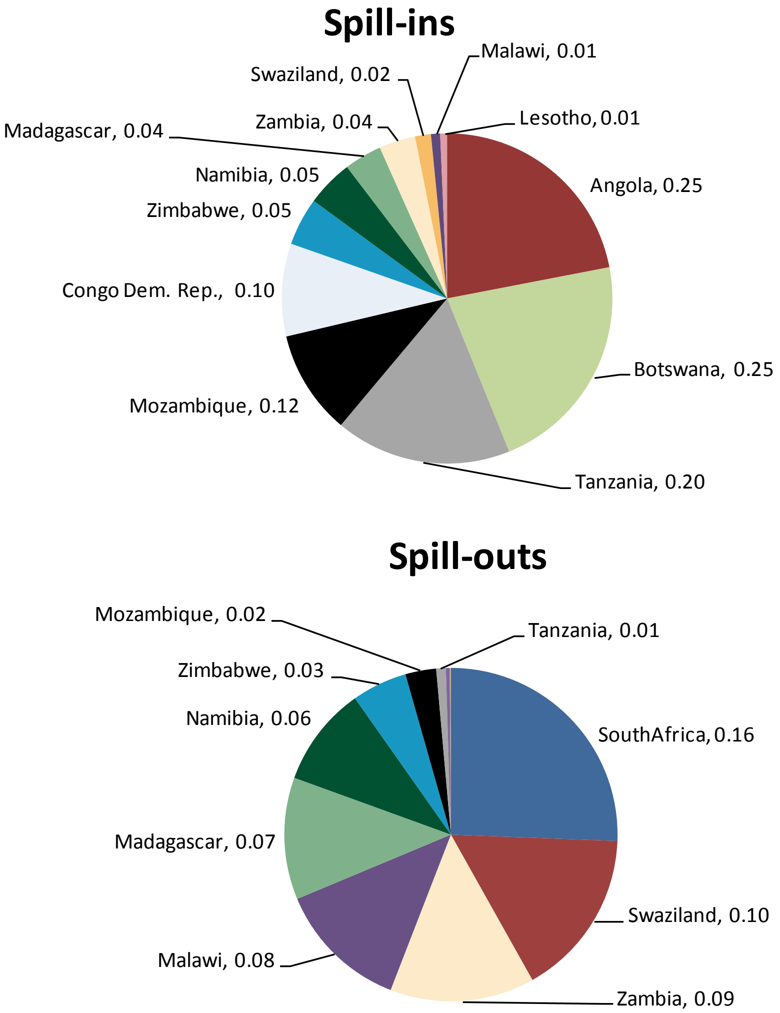
Figure 4.Agricultural potential (length of growing period) and market access in Southern Africa



Market Access

Source: ###.

Figure 5.Potential beneficiaries and sources of technology: The example of maize in Southern Africa



Spill-ins (the beneficiaries): This is the average effect on productivity in country *x* due to the adoption of technologies generated in other Southern African (SADC) countries, relative to the productivity effect associated with adoption of country *x*'s own technologies.

Spill-outs (the sources): This is the effect on average productivity in the rest of the SADC region due to the adoption of technologies generated in country *y* (the source country), relative to own-technology productivity effects in the other countries.

Source: SADC (2012, forthcoming).

Other important producers of research were identified in the subregion as well: Lesotho and Madagascar for beans; Tanzania for cassava; Botswana and Zambia for cotton; Swaziland, Malawi, and Zambia for maize; DRC, Tanzania, and Zambia for millet; Malawi, Swaziland, and Tanzania for sugarcane;[2] Namibia, Angola, Zimbabwe, and Madagascar for wheat; and Botswana and Namibia for cattle. Countries that could benefit most from research spill-ins include Angola for beans, groundnuts, maize, millet, and rice; Botswana for maize and sorghum; DRC for cotton and rice; Mozambique for groundnuts, rice, sorghum, and sugarcane; Swaziland for cotton and potatoes; and Zimbabwe for cassava, millet, and sorghum. For livestock, Tanzania could benefit in cattle and pigs; Botswana in poultry; and Lesotho in sheep and goats.

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[2] Mauritius would likely have emerged as a source for research and technologies on sugarcane, but it was not included in the analysis.

Alternative Growth Scenarios and Commodity Priorities

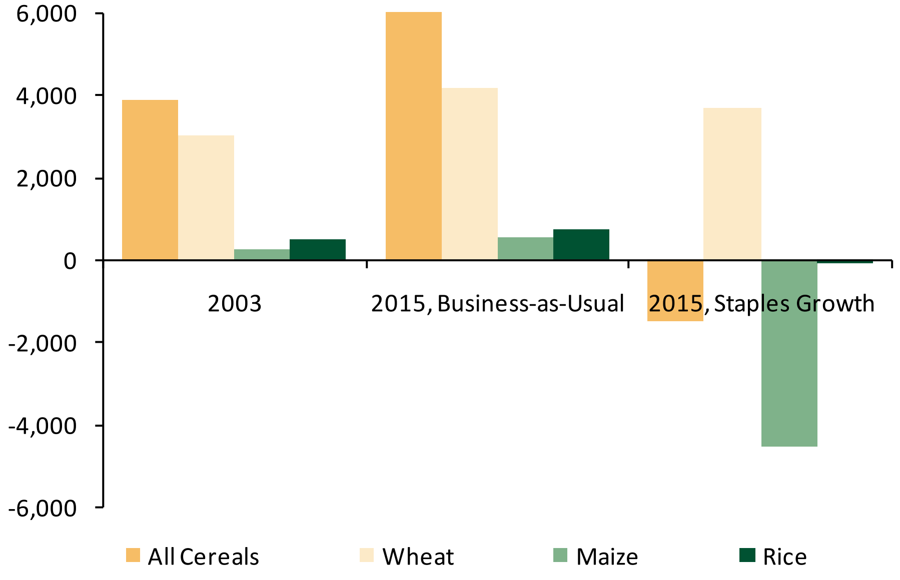
All three studies explored future economic growth scenarios with various assumptions of research-induced productivity shifts. Effects were estimated for overall agricultural sector growth, economic performance, and food security. Results generally show very little improvement under existing trends, emphasizing the need for greater investment in R&D and research capacities.

Results indicated that ASARECA's member countries, with the exception of Sudan and Uganda, would require significant improvements in agricultural productivity in order to raise overall GDP growth rates to more than 3 percent per year to 2015. Among the subregion's key subsectors, dairy emerged as the most important for generating both agricultural and overall GDP growth. Oilseeds, cassava, and fruits and vegetables also ranked high. Commodities with the largest effects on GDP were those for which demand tends to increase with incomes—such as high-value crops and livestock products. This kind of demand growth permits sustained productivity growth without negative price effects. However, growth in food staples can also contribute to large gains in GDP through consumption linkages; as prices fall, disposable incomes increase because the share of the household budget required for food decreases. Food staple commodities, therefore, were shown to contribute the most to GDP gains, followed by livestock products, vegetables and fruits, and oilseed.

Aside from contributing to growth, a strategy that focuses on raising food staple productivity and output was also shown to improve subregional food security. The study found that ASARECA member countries could potentially generate a food surplus by increasing maize supplies during 2003–2015 (Figure 6). To avoid a complete collapse of prices, however, it was found that demand would also need to grow, either in response to growth in other sectors (for example, through agro-industrial processing for livestock feed) or from better access to regional and international markets.

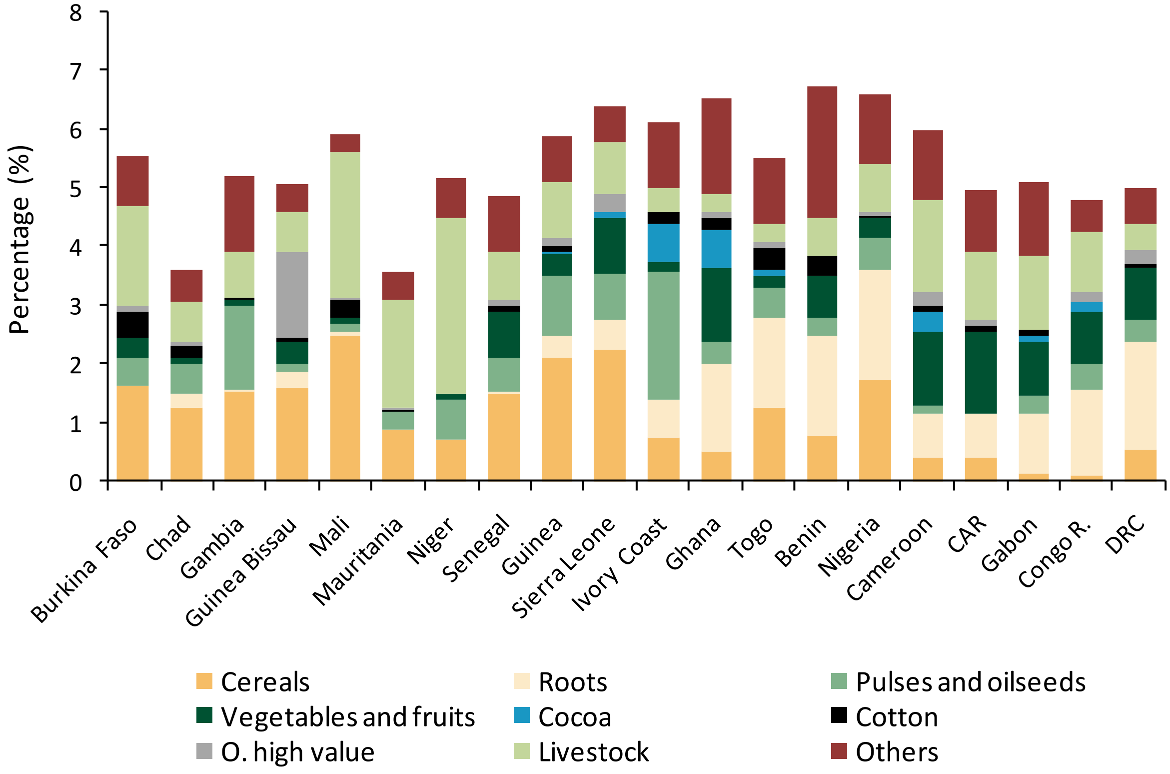
The CORAF/WECARD analysis found that existing levels of productivity growth would potentially result in a decline in per capita agricultural GDP growth to below 1 percent per year in 13 of the 20 countries. In turn, this would also lead to widening food deficits in the subregion, especially for cereals, as output would only represent 27 percent of total subregional demand. The study did find, however, that the potential to increase productivity did exist: by simply overcoming biotic constraints and thereby increasing yields, results indicated that agricultural growth could be increased by 1 percent per year during 2006–15. If maximum yields were attained from intensification and improved management practices, 8 of the 20 countries (Benin, Nigeria, Ghana, Guinea, Côte d'Ivoire, Sierra Leone, Cameroon, and Mali) were found to be capable of approaching the 6 percent growth target (Figure 7).

Figure 6. Projected net imports of major cereals among ASARECA member countries in 2003 and under two alternative growth scenarios to 2015



Source: Omamo et al. 2006.
Note: Negative values indicate net exports.

Figure 7. Projected subsector contributions to yearly agricultural growth among CORAF/WECARD member countries resulting from closing yield gaps through improved technologies and greater intensification, 2006–15 average



Source: Johnson et al. 2008.

The rate of growth and importance of each subsector to overall growth varied across countries and major subregions, but even more so in the coastal countries. In general, cereals and livestock were found to be more important in the Sahel; tree and root crops, as well as high-value products, were more important in coastal countries; and livestock and root crops were more important in Central African countries. Overall, the livestock, cereal, and root crop subsectors dominated in all three subregions. These commodities had a relatively large production base to start with, large agroclimatic growth potential, and a large and growing demand within the subregion.

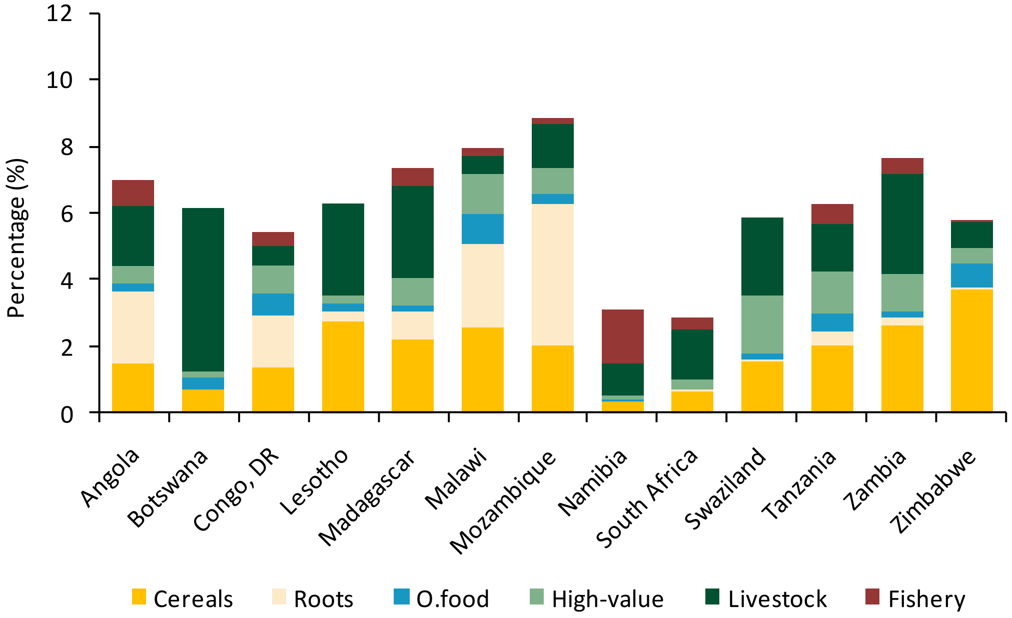
Under a more optimistic growth scenario, net exports were found to rise to US$7 billion by 2015, compared with 2006 deficits of almost $2 billion, in the absence of significant improvements in agricultural productivity. Without growth, results indicated that cereal imports could easily reach US$5.7 billion by 2015, and livestock demand was also expected to lead to net import position by 2015.

In the SADC region, results from the EMM simulations, once again under existing trends, indicated slower growth in agriculture than in the overall economy due to faster growth in the nonagricultural sector and, in turn, growing demand for high-value products such as meat. With low rates of agricultural growth, the subregion was found to be unlikely to meet growing demand. Similarly, meat imports were projected to more than double by 2015. At the same time, net imports for grains were projected to increase and lead to larger deficits by 2015.

To achieve the yield growth targets set by SADC, an accelerated growth scenario for the grains sector, for example, indicated that growth rates would need to reach 9 percent per year between 2009 and 2015 in order to close existing yield gaps. This represents a near doubling of the 2009 average growth rate of 5.4 percent, and for most other subsectors, the rate would need to more than double. As output growth increases due to yield improvements, and relative crop prices change, land allocation would eventually begin to shift away from grains to higher value crops. Results indicated that introducing more rapid productivity growth in key subsectors could potentially double the subregion's agricultural growth rate from 3.0 in 2009 to 6.2 percent by 2015. Overall GDP growth at the subregional level was projected to increase more modestly, from 5.0 to 5.8 percent. Nevertheless, poor households in both rural and urban areas would likely benefit more from this structure of growth because food prices would fall. When viewed across all countries in the subregion, the grains and root crop subsectors would have to generate almost 40 percent of agricultural growth, especially from the perspective of the lower income countries. Among the individual countries, significant growth was projected to occur in Angola, Madagascar, Malawi, Mozambique, and Zambia, at rates well above the 6.2 percent subregional growth rate (Figure 8). Namibia and South Africa would not gain as much given the lesser role of agriculture in these middle-income economies.

In terms of grain supplies and trade positions, only two countries, Malawi and South Africa, are currently net exporters of maize. Almost all countries are rice and wheat importers, with imports making up 32 percent of total consumption for rice and 85 percent of wheat. For livestock products, only Botswana and Namibia are net exporters. All of the other countries are net importers of livestock products. For maize, results indicated that the subregion could potentially move closer to self-sufficiency. A final important point is that there seems to be scope for the subregion to experience high output growth for many agricultural products without dramatic declines in prices. Prices were projected to fall only modestly for most crops, and barely change for most livestock products.

Figure 8. Projected subsector contributions to subregional agricultural growth among SADC countries under a growth scenario, 2009–15



Source: SADC (2012, forthcoming).

Potential Benefits of Regional Cooperation

The analyses described in the previous sections ranked subsectors according to their potential to fuel agricultural and overall economic growth and to contribute to food security, but they did not incorporate the potential for research spillovers.

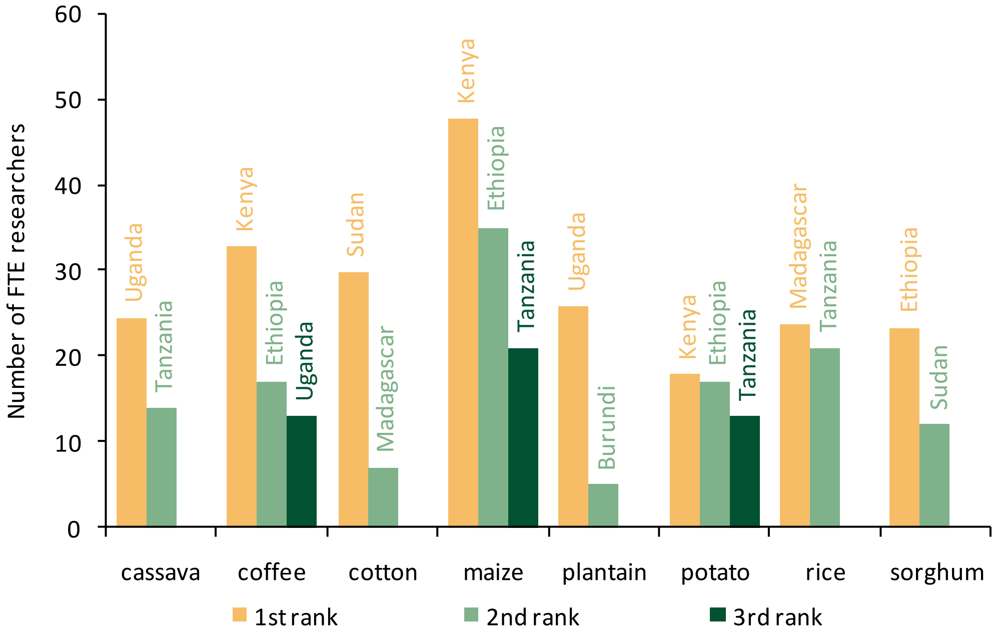
The ASARECA study used the DREAM model to quantify potential spillover benefits for some of the key commodities. Four stylistic assumptions were imposed derived from the findings of the EMM analyses:(1) basic R&D and technology development for all commodities originated in Kenya, Tanzania, and Uganda); (2) the technologies were transferable only within the subregion and took five years to be fully adopted by farmers to a ceiling of 80 percent; (3) due to imperfect adaptation of technologies across countries, technology spill-ins in the rest of the ASARECA countries translate into half the productivity gains realized in the source countries; and (4) research-induced productivity in each of the source countries is shocked by a 1-percent increase. Results clearly showed large potential gains from regional spillovers, totaling US$20 million across all commodities. Of this, US$3 million is derived from dairy, with spillovers accounting for about 40 percent of the subregion's total benefits (Table 2).

Table 2. Scope of agricultural R&D spillovers among countries in the ASARECA subregion

	Total regional gains without spillovers (thousand US$ per year)	Additional gains with spillovers (thousand US$ per year)	Gain to region from spillovers (%)	Spillover gains as a share of total regional gains (%)	Variation in spillover gains (index)
Commodity	**A**	**B**	**B/A**	**B/(A+B)**	
Cassava	5,200	2,581	50	33.4	2.29
Cows’ milk	4,456	2,984	67	40.8	1.71
Plantain	6,575	659	10	9.2	2.49
Maize	5,659	1,477	26	20.7	1.99
Beef	3,741	2,409	64	39.2	1.44
Coffee	2,566	1,461	57	37.7	2.22
Sorghum	1,064	2,059	194	66.3	1.83
Vegetables	1,742	956	55	35.4	1.09
Dry beans	1,701	626	37	27.0	1.09
Rice	854	1,355	159	61.3	2.51
Mutton/lamb	467	1,399	300	75.6	1.75
Groundnuts	553	1,254	227	69.5	2.07
Potatoes	982	490	50	33.7	1.32
Cotton	427	251	59	37.1	1.64
Cashews	396	5	1	1.6	3.00
Subregional total	**36,381**	**19,965**			

Source: Abdulai, Johnson, and Diao (2006).

Figure 9. Rankings of full-time equivalent researchers by crop among ASARECA member countries, 1999–2001 average



Source: You and Johnson (2010, Figure 3).

Notes: The number of researches by crop was determined by combining data on two ASTI indicators: research focus of public research staff (%) and full-time equivalent (FTE) researchers within public agencies (1992–2001 average).

Based on the assumption that Kenya, Tanzania and Uganda are a key source of technology spillovers, Figure 9 summarizes research capacity among some of the subregion's key commodities. In addition, however, Ethiopia has a comparative advantage in research on coffee and maize, whereas Tanzania and Uganda dominate cassava research. Individual countries dominate research on other key commodities, including: Madagascar in rice, Sudan in cotton, and Uganda in plantains. Evidently, potential exists for specialization in the subregion, particularly for rice, plantains, sorghum, and cotton (You and Johnson 2010).

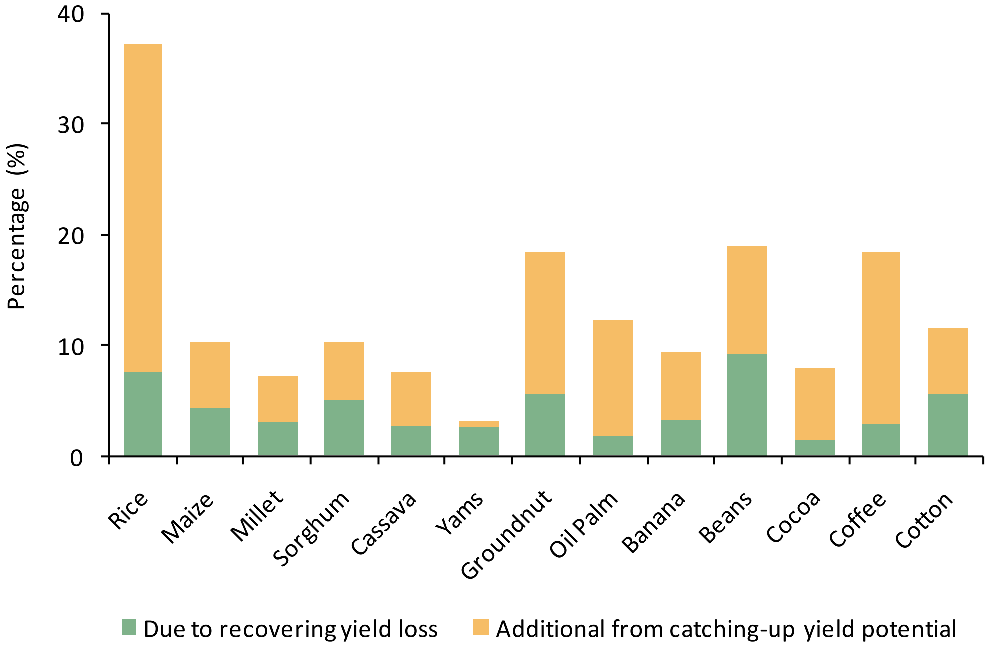
The CORAF/WECARD study did not explicitly analyze spillover potential. Rather, it assumed spillover potential to be represented by the individual yield effects of improved technologies within each development domain, irrespective of national borders. The analysis did not account for any costs associated with technology transfer and adaptive research, and the source of research was assumed not to matter; research products were determined to be equally available to each country, so the effect of spillovers on productivity levels depended on initial yield levels and potential yield gaps associated with each domain and across countries. As a result, the presence of spillovers was implicitly assumed to be based on agricultural suitability.

To examine the impact of alternative growth scenarios at the commodity level and rank returns to R&D investment, the CORAF/WECARD study incorporated the same productivity shocks used in the EMM analysis into the DREAM model—that is, the yield growth rates required to close the estimated yield gaps within each development domain and across countries. This represented an improvement on the ASARECA study, which used ad hoc estimates for productivity changes and simple assumptions on the origins of spillovers. The CORAF/WECARD study explicitly avoided introducing such stylized facts, other than assumptions on potential diffusion and adoption ceilings for which data were not available.

Results from the DREAM analysis showed that, for the CORAF/WECARD region as a whole, catching up to the maximum rice yield potential could generate the greatest gains for farmers—for example, as much as 35 percent gains in producer surplus for rice (Figure 10). Among food crops, beans, cassava, groundnuts, maize, and sorghum, also generated higher percentage gains for farmers, which together also implied higher potential spillovers if many countries benefit. At the subregional level, rice, groundnuts, and cotton ranked highest. Priority crops varied from country to country and zone to zone, but rice consistently delivered higher producer benefits from the adoption of improved technologies and practices.

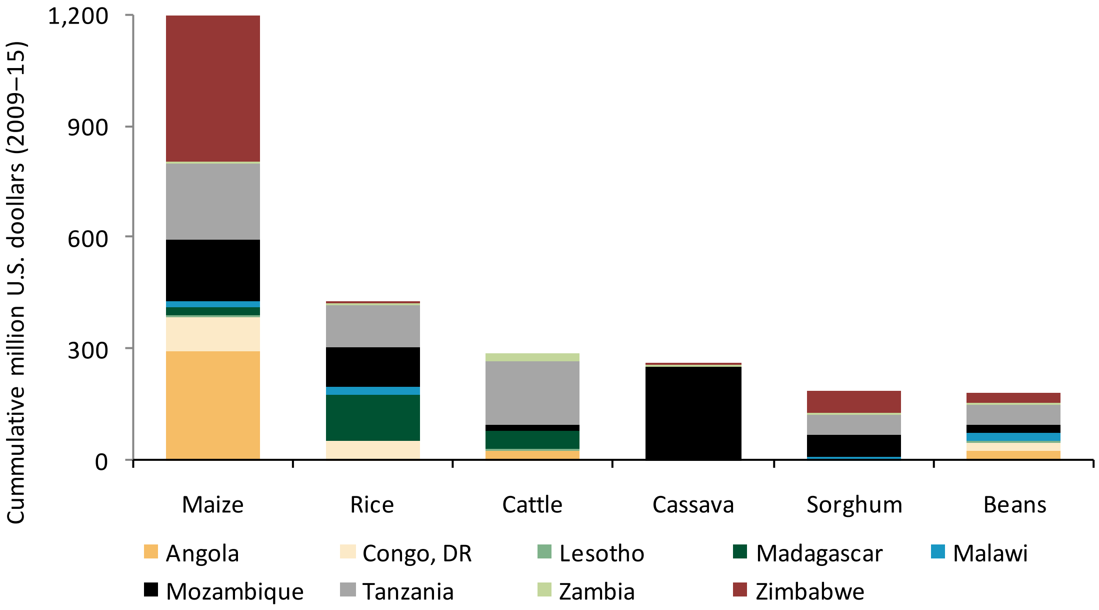
The SADC study replaced the DREAM analysis with spillover matrixes, which enabled the decomposition of results from the EMM model into those generated from a country's own R&D and those from research spill-ins. Results showed that the ability to capture technology spill-ins can dramatically increase the likelihood of rapid yield growth in the subregion. Taking maize, for example, results indicated that achieving the average SADC yield target of 2.0 mt/ha by 2015 would require many countries to raise their yields by more than 30 percent—a daunting goal for many countries, but one that would be more feasible if existing technologies could be adapted to meet their unique needs.

Figure 10. Average yearly producer benefits to CORAF/WECARD member countries, 2006–15



Source: Johnson et al. 2008.
Note: The cumulative percentage gains in producer benefits between 2006 and 2015 were averaged across the 10-year period.

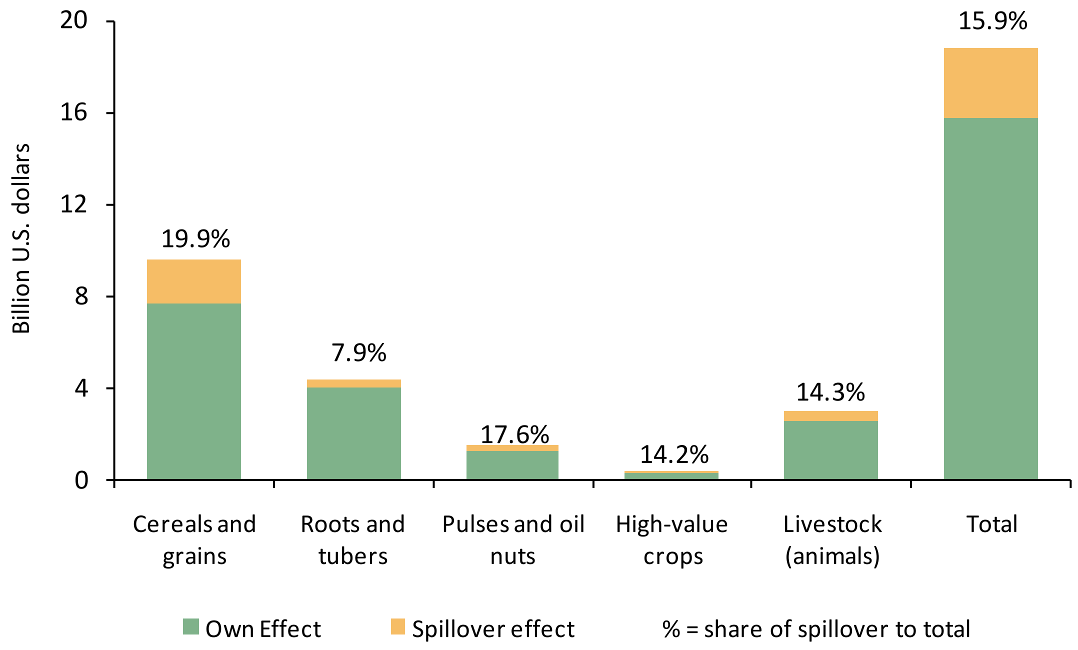
Figure 11. Beneficiaries of spillovers by commodity among SADC countries, 2009–15



Source: Data in this figure were generated from Table 5.5 in SADC (2012, forthcoming), drawing from low-income countries only and for the commodities with largest spillover gains at the subregional level.

Among the SADC countries, the commodities that were projected to gain the most from technology spillovers are beans, cassava, maize, rice, sorghum, and cattle (Figure 11). Gains were estimated to be higher than US$100 million in cumulative terms for the 2009–15 period. With the exception of cassava, the shares of spillovers in the total gains were also higher across these commodities, ranging from 16.3 to 33.2 percent. Although the analysis focused on commodities, improved natural resource management technologies were also found to be very likely to exhibit high spillover potential across countries and by development domain. The countries that stand to benefit most from technology spillovers, across all commodities are Angola, DRC, Mozambique, Tanzania, and Zimbabwe, accounting for about 86 percent of total regional benefits from spillovers. For maize alone, Angola, Mozambique, Tanzania, and Zimbabwe capture up to 90 percent of the total spillover gains among SADC countries. Madagascar, Mozambique, and Tanzania gain the most from spillovers in rice. Finally, at the subregional level and among the lower income countries, cereals generate the largest gains from spill-ins at almost 20 percent of the total value-added gains from increased yields attributable to spillovers (Figure 12). Pulses, oil nuts, and livestock follow closely behind.

Figure 12. Gains from R&D spillovers among low-income SADC countries and by major subsector, 2009–15



Source: Figure 3.5 in SADC (2012, forthcoming).
Notes: Results are based on EMM and spillover matrix results. Gains are computed as the total value-added benefits accruing over six years (2009–15) from the difference between the growth and baseline scenarios.

Some important differences underlie the overall results. Angola and DRC both stand to gain primarily because their yields are much lower than in the high-performing countries. The gains in Tanzania and Zimbabwe are due mainly to their more advanced research capacities. Regarding spill-outs (sources of technology), Malawi, Madagascar, South Africa, Swaziland, and Zambia, generate about 82 percent of the spillovers, because these countries are the primary source of maize technologies. Tanzania dominates as the source of cassava, while Namibia, Lesotho, and South Africa are the primary sources of bean technologies.

Final Rankings and Policy Implications

A number of criteria emerge from the results of the three studies that facilitate a ranking of subregional R&D priorities:

1. What investment and policy options, in which key commodity areas, offer the best potential for accelerating agricultural sector growth and national incomes as a means of reducing poverty and food insecurity in the region?
2. In devising subregional R&D programs, which of the key commodities would be most suitable in terms of their potential for adaptation and direct transfer (or spillovers) across countries?
3. What kinds of constraints and other complementary or cross-cutting issues need to be considered in order to enhance productivity growth in SADC countries?

In answering these questions, a number of key policy recommendations emerge for subregional agricultural strategies in general, and agricultural R&D investments in particular. These are discussed in turn below.

Seeking Accelerated Productivity Growth in Key Subsectors with High Potential Demand

Among all subregions, the analysis revealed that agricultural growth had the largest poverty reduction impacts in subsectors with greatest local demand, particularly staple foods and livestock products. Other high-value commodities, such as oilseeds and fruits and vegetables, were promising. These subsectors constitute large shares of total agricultural production in most countries but also have room to grow based on large yield gaps and a broad demand base. In West Africa, rice, cassava, and livestock show the highest potential for growth and thus could deliver the greatest potential gains to producers. In Southern Africa, maize and cassava lead the way, particularly among the poorer countries where these commodities have high potential to drive future growth. In fact, as of 2009, studies found that—with sufficient productivity growth—Southern Africa had the potential to become self-sufficient in maize by 2015. At the same time, modeling results indicated moderate reductions in maize prices due to output growth, providing benefits for both producers and consumers. Even if prices fell further, producers would still benefit based on the rate of yield increases, assuming sufficient investments were made in storage and processing technologies, and stronger links were forged with the feed and biofuel industries in order to absorb the rapid output growth.

Strengthening Agricultural Markets and Intraregional Trade Linkages

Agricultural productivity growth alone is insufficient to bring about adequate agricultural sector growth. Corresponding improvements are also needed in domestic markets as are subregional market linkages. This emerged clearly in the ASARECA and CORAF/WECARD studies, where reduced barriers to regional level market access were shown to lower the likelihood of significant declines in domestic prices. The SADC study found that sufficient longer term growth in demand due to rapidly growing nonagricultural sectors—especially in neighboring middle-income countries—could potentially absorb any future output growth in the presence of relatively efficient domestic and subregional markets.

A key challenge to market efficiency in all three subregions is infrastructure. Better roads, railways, and telecommunications networks could contribute substantially to short-term growth. Another challenge is a range of institutional constraints, such as poor access to credit for agricultural traders, the high cost of obtaining market information and linking buyers and sellers, and difficulty in enforcing contracts. Limited storage capacity and poor access to formal financing often lead to volatile prices. Making matters worse, these constraints are greatest for staple foods because private-sector investments yield less than investments in high-value cash crops. On the input side, more efficient markets could reduce the cost of farm inputs, such as fertilizer. Promoting a regional common market could play a key role in this regard (for West Africa, see Bumb, Johnson, and Fuentes 2011).

Promoting Growth Linkages with Nonagricultural Sectors

In much of Africa, high transport costs and other structural factors prevent producers in many of the poorer countries from taking advantage of subregional markets for local products. This is especially true for nontradable goods (such as electricity and water). Growth would be stimulated by links beyond the farm, for example, to food and feed processing industries and to manufacturers of other intermediate products. In subregions such as Southern Africa, tapping into the agro-industries of middle-income countries offers potential complementarities among countries within the region through greater trade and investment linkages. There may also be room for institutional and organizational arrangements between agro-industrial firms and farms, for example, through vertical integration and greater involvement of producer organizations and cooperatives, as well as contract farming.

Exploiting Opportunities for Greater Subregional Cooperation

All three regions could gain substantially by exploiting R&D spillovers. In the ASARECA region, spillovers from innovations originating in a small subset of countries could constitute 40 percent of total regional benefits from agricultural R&D. In the SADC region, almost 17 percent of subregional R&D benefits could be attributed to spillovers. In combining both growth and spillover criteria, food staples such as grains and livestock once again provide the highest potential returns from subregional cooperation.

Strengthening National Agricultural Research Systems and their Adaptive Research and Extension Capacities

In all three subregions, certain countries have been able to maintain a strong NARSs (for example, South Africa) or advanced programs in low-income countries (for example, Tanzania). Subregional collaboration, consultation, and coordination should be promoted. One foreseeable challenge will be to generate sufficient incentives among member countries to share technologies. In addition to commodity research, regional analytical capacity will be needed in research priority setting and impact assessment, which would also benefit from strong support from universities, donors, and international institutions.

Translating analytical results such as those presented here into subregional agricultural R&D priorities requires consultation and participatory dialogue with stakeholders. ASARECA, for example, explicitly incorporated the development domains and spillover analysis into its subregional collaboration priorities for staple foods. Similarly, CORAF/WECARD directly incorporated rankings into its priority-setting exercises with member countries and development partners, including the recent West African Agricultural Productivity Program. SADC is now using the results to inform priority setting for a future subregional organization following the ASARECA and CORAF/WECARD models.

In practice, subregional agricultural strategies and policies are built on the foundation of existing national policies. The agricultural program of the Economic Community of West African States (ECOWAS) is a case in point. While subregional organizations conduct studies and workshops to identify agricultural research priorities, the planning process often begins with national workshops before moving onto subregional ones that incorporate wider considerations. This is a sensible means of ensuring that local priorities are not lost when the focus shifts from the national to the subregional level (Johnson et al. 2008).

4. CONCLUSION

Comparing and contrasting the three studies reviewed in this paper produced lessons in several areas, including the conceptual approaches and methods used, the policy implications that resulted, and the future subregional priorities for agricultural research in SSA.

First, the degree to which the various models were integrated in the analyses remains limited, despite efforts to improve such integration with each successive study. Further work is needed to improve the integration between the EMM and DREAM models, for example, by incorporating the dynamic technology adoption features into the EMM model. Moreover, construction of the spillover matrixes could be improved upon and incorporated into the model.

Second, sufficient and accurate data is often lacking, especially agricultural and socioeconomic data at lower administrative levels (for example, on production, consumption, prices, and incomes). An even more serious problem in some countries is incomplete information on research resources, capacities, and expenditures by commodity or research discipline (to determine unit cost of research), although ASTI is continuing efforts to fill such gaps. Moreover, better information is needed on the probability of technology adoption and diffusion based on past observations, including yield performance by technology type or farming system (both actual and on-farm trials). Such information would improve future applications of the DREAM model, especially if well-constructed spillover matrixes could also be incorporated. With this in mind, more work is needed to improve the data systems on commodity-specific costs, capacities, and adoption and outcome variables, such as time lags, probabilities of adoption and diffusion, rates of return estimates for R&D, and yield effects. ASTI might consider pursuing such information to improve its own databases on agricultural R&D in Africa.

Despite these modeling and data limitations, the results of all three studies proved to be highly policy relevant. This underscores the usefulness of such analysis to inform priority-setting processes for subregional R&D strategies. The study results are also a testament to the value of evidence in setting research priorities, and therefore to the need to build regional analytical research capacities in priority setting and impact assessment. Support from universities, donors, and international institutions could play a key role in further developing this capacity within Africa.

Also on the policy front, to exploit the benefits of cross-country cooperation in R&D, the three regional strategies must overcome many institutional and administrative barriers to managing and coordinating such systems across many national ones (Pardey et al. 2007). Indeed, cooperation across complex systems can incur high transaction costs, especially if some systems are far more advanced than others. Moreover, cross-country collaboration is affected by each country’s own program needs and desire to maintain a bargaining position for domestic resources. Even if collaboration is desirable, any likely transaction costs must be weighed against potential benefits (Pardey et al. 2007).

Finally, donors have traditionally dominated the attention and support of regionally based research organizations such as ASARECA and CORAF/WECARD. Once the benefits of greater regional cooperation and economic integration become more evident and understood, the political will of member states to commit national resources to regional efforts is likely to increase. Growing national interest is already evident in the support of individual countries to programs such as the West African Agricultural Productivity Program and the East African Agricultural Productivity Program.

APPENDIX. CONSTRUCTION OF THE SPILLOVER MATRIX IN THE SADC STUDY

The spillover matrixes constructed for the SADC study draw on three dimensions of information: similarities in the production environment (based on similar endowments in agroecology and climate), probability of the successful “spill-in” of research and technologies (based on capacity for adaptive research in the receiving country), and probability of successful spill-outs of research and technologies (based on the size of the yield gaps in each country). Spillover matrix construction follows Jaffe (1986, 1989); Davis, Oram, and Ryan (1987); and Pardey et al. (2007).

First, similarities in agricultural production environments in countries *I* and *j* were measured as

$$\omega_{ij} = \frac{\Sigma_m f_{im} f_{jm}}{(\Sigma_m f_{im}^2)^{\frac{1}{2}} \left(\Sigma_m f_{jm}^2\right)^{\frac{1}{2}}}, \qquad (1)$$

where f_{ik}, is defined for each country, i, within a vector $f_i = (f_{i1}, f_{i2}, \ldots f_{iM})$, which is the share of resource attribute *k*in country *i*. Following Pardey et al. (2007), f_{ik} represents the share of cultivated land in agroecological zone *k* in country *i*. By definition, the shares sum to one over all of the attributes, and so ω_{ij} can be likened to a correlation coefficient that varies between zero and one. At one extreme, a zero value indicates no similarity in agricultural production environment, indicating that research in either country has no potential spillover effect in the other. At the other extreme, a value of one indicates a perfect match in agricultural production environments and therefore a 100-percent potential spillover effect. The measure is also assumed to be symmetric (that is, $\omega_{ij} = \omega_{ji}$), implying that spillovers between two countries are potentially the same in either direction.

Second, capacity for adaptive research (the pull or demand side of technology spill-ins) follows the presumption that research undertaken in one country is rarely directly useable in other countries without the addition of adaptive research in the importing country. To measure the probability of success of adaptive research in country *i*, estimated rates of return (ROR) to agricultural research were used, drawing from several African countries, including 10 from the SADC group (Alene and Coulibaly 2009). The probabilities of successful adaptive research ranged from 5 percent in Lesotho to 62 percent in Tanzania. A high ROR indicates a high efficiency in adaptive research. It therefore corresponds to a high probability of success in capturing research or technology spill-ins. The RORs are controlled for the effects of other key factors, such as research expenditures and stocks (from the ASTI database), input and factor use, population density, total government expenditure, and the differential influence of NARSs versus international agricultural research capacities.

Finally, to capture the probability of successful research production and adoption (the push or supply-side effect in the technology generation–consumption continuum), the yield gap, τ_{ij}, is measured across countries using yield data from the SPAM analysis. The gap is measured as a ratio, where τ_{ij} is the yield in country *j* relative to the yield in country *i*, such that $\tau_{ij} = 1/\tau_{ij}$. It is logical that productivity-enhancing technologies, practices, and knowledge flow from higher to lower productivity areas, at least in net terms. Therefore, $\tau_{ij} > 0$ implies a net flow from country *j* to *i*, while $\tau_{ij} < 0$ implies a net flow from country *i* to *j*.

Combining the three dimensions results in a potential spillover matrix, δ_{ij}, for each crop considered in the analysis as follows:

$$\delta_{ij} = RD_i \cdot \omega_{ij} \cdot \tau_{ij}{}' \qquad (2)$$

This is an *n* x *n* matrix of potential spillover effects, with *n* representing the number of countries. Each element of the matrix measures the effect of agricultural productivity growth in county *i* due to agricultural research outputs originating from country *j*. As these are relative measures, each cell in the matrix, or δ_{ij}, measures the effect on agricultural productivity in country *i* due to adoption of technologies originating from country *j*, but relative to the productivity effect associated with adoption of country *I*’s own technologies.

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The Agricultural Science and Technology Indicators (ASTI) initiative compiles, analyzes, and publishes data on levels and trends in agricultural R&D investments, capacities, and institutional arrangements in developing countries. ASTI is managed by the International Food Policy Research Institute (IFPRI) and involves collaborative alliances with many national and regional R&D agencies.

Jointly convened by ASTI/IFPRI and the Forum for Agricultural Research in Africa (FARA), the conference, "Agricultural R&D—Investing in Africa's Future: Analyzing Trends, Challenges, and Opportunities," brought together experts and stakeholders from the region to contribute their expertise for the purpose of distilling new insights and creating synergies to expand the current knowledge base. The themes under focus were (1) why African governments under invest in agricultural R&D; (2) how human resource capacity in agricultural R&D can be developed and sustained; (3) how institutional structures can be aligned and rationalized to support agricultural R&D; and (4) how the effectiveness of agricultural R&D systems can be measured and improved.

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