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Exploring Strategic Priorities for Regional Agricultural R&D Investments in East and Central Africa

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Contents

List of Tables

List of Figures

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The authors acknowledge initial analysis on this important topic, which contributed both to an East African strategic priority-setting exercise undertaken for the Association for Strengthening Agricultural Research in Eastern and Central Africa (Omamo et al. 2005) and subsequently to Abdulai, Johnson, and Diao (2006). The current study expands on these early contributions to provide detailed information on the data and analytical approach used and to include detailed spatial information on farming systems and agroclimatic and socioeconomic factors, which affect the scale and scope of economic benefits derived from technology spillovers. The authors acknowledge and thank the many reviewers who contributed to these earlier studies, particular Stanley Wood for his knowledge of *Dream* and his expertise in spatial analysis. The authors also thank Jordan Chamberlin for help with GIS analysis and Jock Anderson, John Pender, and Alejandro Nin-Pratt for invaluable review comments on a draft of the current paper.

ABSTRACT

Agriculture plays a dominant role in nearly all the countries of East and Central Africa, and many face similar agroecological, climatic, and development challenges. As a result, significant scale economies can be made through the regionalization of research and development (R&D) using networks such as the Association for Strengthening Agricultural Research in Eastern and Central Africa. The challenge for such networks, however, is to determine both regional and national research priorities with the highest potential rates of economic return. Methodology to assess regional research priorities is a critical input into this process, particularly when it comes to weighing likely complementarities among individual research programs, thus maximizing impact across countries at the regional level.

This paper presents such an approach using spatial analysis and the Dynamic Research Evaluation for Management (*Dream*) modeling software, which was developed by the International Food Policy Research Institute to assess potential economic returns to agricultural R&D and guide resource allocation decisions. *Dream* is applied to the East and Central African region to estimate potential economic and technological spillovers from country- and regional-level R&D investments for select commodities based on future projections of supply and demand, trade flows between countries and world markets, and shared agroecologies and farming systems.

The results of the study indicate significant potential for agricultural technology spillovers within the region. Countries will therefore reap greater economic benefits in their search for technology solutions if they pool their resources and pursue regional initiatives for the common good.

Keywords: *Dream*, technology spillovers, priority setting, economic surplus, East and Central Africa

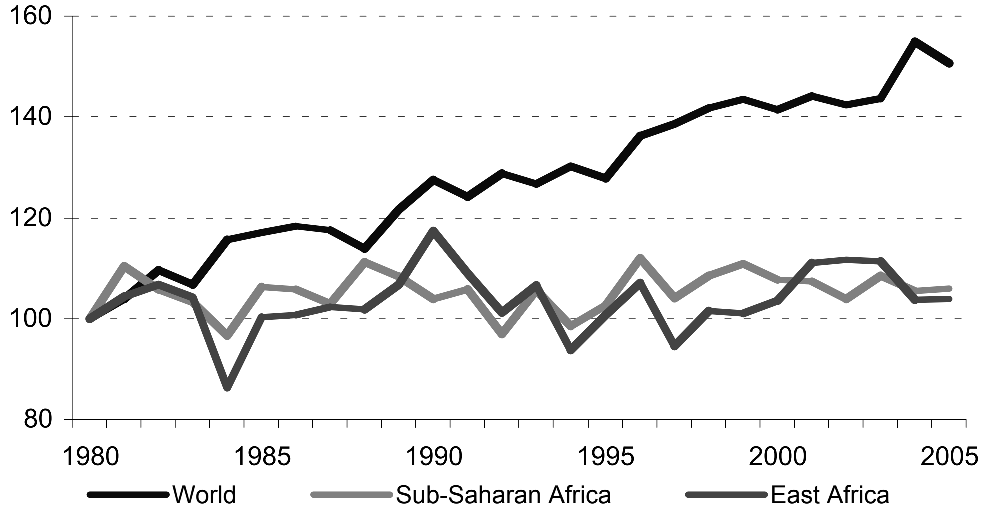
1. INTRODUCTION

Agriculture plays a dominant role in nearly all the countries of East and Central Africa, contributing more than 30 percent, and in some cases as much as 60 percent, to the value of gross domestic product (GDP) and employing over 70 percent of the region's population—the majority of which is rural and constitutes the highest levels of poverty and food insecurity. Growth in agriculture, therefore, not only contributes to regional economic growth, but also to food security for its numerous subsistence farmers.

Figure 1. Growth trends in net cereal and coffee yields, 1980–2005

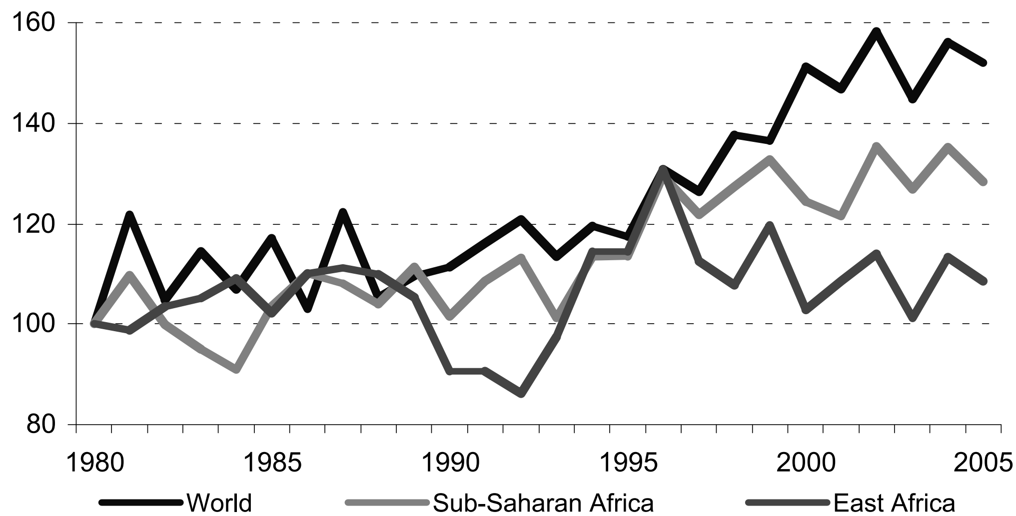
a. Cereals

Growth index (1980 = 100)



b. Coffee

Growth index (1980 = 100)



Source: FAO 2003b.

Note: Coffee data are based on green coffee beans.

Productivity, which is a key factor in agricultural output growth, has seen little growth in the region in recent years; for example, yields for both staples (cereals) and traditional exports (coffee) have changed little in the region over the past two decades compared with the rest of the world (Figure 1). Climate has certainly been a factor, given the increased frequency of droughts in the region, but with yields two to three times lower than averages in other developing world regions, the potential to fill this gap must still exist. A serious concern is the general neglect of public funding for agricultural research and development (R&D), especially during the past decade. Spending for agricultural R&D in the region slowed significantly throughout the 1990s, growing at a rate of only 0.9 percent per year compared with 5.1 percent in the 1980s (Beintema and Stads 2004); consequently, spending intensity ratios as a share of agricultural GDP have also declined (Beintema and Stads 2004). Years of drastically reduced funding for R&D have eroded local research infrastructure and capacity, creating higher marginal costs for even the most basic of research. The need therefore exists to find more cost-effective and sustainable ways to rebuild national agricultural R&D systems in Africa.

Given that many countries in the region are small and face similar agroecological, climatic, and development challenges, relying on expensive, country-level R&D programs is bound to prove inefficient and costly. Instead, potential economies of scale can be derived through the regionalization of R&D, as is the intention of regional organizations and networks such as the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA). Through such networks, national agricultural research systems (NARS) can pool scarce resources, collaborate more frequently, and share knowledge and information on technology solutions and applications for the common good. The challenge for such networks is identifying research priorities with the highest rates of economic return from both a regional and national perspective. Methodology to assess regional research priorities is a critical input, particularly when it comes to weighing likely complementarities among individual research programs, thus maximizing impact across countries at the regional level.

This paper presents such an approach. Chapter 2 focuses on quantitative and qualitative criteria and methodologies to identify a set of commodities for detailed economic analysis, while also providing a review of the literature on technology spillovers and their implications for the regionalization of agricultural research and development (R&D) in East and Central Africa; Chapter 3 discusses the geographic information system (GIS) methods used to explore and depict spatial similarities and differences in livelihood challenges and opportunities in the region; Chapter 4 applies the Dynamic Research Evaluation for Management model (*Dream*), developed by the International Food Policy Research Institute (IFPRI), to assess potential economic returns to agricultural R&D and guide resource allocation decisions. The *Dream* model and simulation scenarios are introduced in Chapter 5; Chapter 6 presents the modeling results; and the final chapter offers a summary and conclusions.

2. COMMODITY OVERVIEW

There are numerous agricultural crop and livestock commodities produced in East and Central Africa, but only a few represent a significant share of regional production and consumption patterns, especially when it comes to those produced by the majority smallholder farm population. Given that this study aims to identify products with a potentially wide impact on smallholder welfare and rural incomes, it is important to filter the full set of commodities using a variety of criteria. In order to rapidly increase productivity, sufficient markets are needed to absorb the increased supply; for this reason, demand growth opportunities need to be reviewed in domestic, regional, and international markets to further narrow the set of commodities for analysis. To begin, general criteria were adopted based on the Strategic Analysis and Knowledge Support System (SAKSS) framework presented in Johnson et al. (2004). These criteria follow logical and sequential questions, including the following:

1. Which commodities and farming systems predominate among smallholders in the region?
2. What is the scale of production of these commodities?
3. Which commodities have the most promising demand opportunities in regional and international markets?
4. Is there significant potential to raise the productivity of these commodities?

Answering these questions narrows the commodities to those with the potential to affect smallholder incomes based, in part, on the sheer size of their economic contribution to the region, their share of smallholder production, and projected future demand and supply growth. This requires evaluating the participation rate of smallholder farmers within each commodity system; the scale and growth potential in productivity and output; and the demand growth potential in domestic, regional, and global markets. Once this narrower set of commodities has been identified, economic returns from research-induced productivity improvements can be evaluated, along with the potential for technology spillovers across countries.

Scale of Production and Growth

The next set of criteria weigh the scale of production and future opportunity for growth of all commodities common in smallholder production systems in the region. In order to establish reasonable measures for the various criteria, certain assumptions must be made. First, it was assumed that the scale of production is reasonably approximated by the total value of production. Second, because smallholder systems are typically mixed cropping systems, including integrated crop and livestock systems, a broad coverage of the types of commodities commonly produced in these systems was included (Table 1). In this way, only those commodities typically grown by smallholders are retained.

Several steps were then taken to narrow the set of commodities for analysis. First, an equal number of commodities were ranked within each category based on their value of production, then commodities comprising less than 1 percent of the total value of agricultural production were eliminated, assuming at least one commodity remained in each category. Next, the potential for future production growth was weighed using historical growth rates, and, finally, potential growth in market demand and trade was weighed based on past growth rates and studies in the literature.

This exercise resulted in initial rankings and production growth rates for up to 30 commodities for the period 1961–2000 (Table 2). The resulting 18 crops and 10 livestock commodities account for more than 80 percent of total agricultural output in East Africa to a value of over US$21 billion (1998–2000 average). The largest number of commodities fell into the livestock category (beef and veal, cows' milk, mutton and lamb, goats' meat, goats' milk, chicken meat), followed by 5 cereal crops (maize, sorghum, paddy rice, wheat, and millet), and 3 roots or tubers (cassava, sweetpotato, and potato). The remaining categories each netted a single commodity: dry beans under pulses, allspice pimento under vegetables, and cotton lint under fiber crops. Of the remaining commodities, beef, cow's milk, and cassava ranked in the top in terms of their share of the total value of production in the East and Central

African region (a cumulative share of almost 25 percent). Plantain and maize follow closely behind cassava and cow's milk.

Table 1. Range of East and Central African commodity types

Commodity Type	Commodities
Cereals	Wheat, rice paddy, maize, millet, sorghum, and so on
Roots and tubers	Potatoes, sweet potatoes, cassava, yams, and so on
Pulses	Dry beans, chickpeas, cow peas, pigeon peas, and so on
Oil crops	Soybeans, groundnuts, sunflower seed, and so on
Fiber crops	Seed cotton, cotton lint, jute, sisal, and so on
Fruit	Bananas, plantains, citrus fruits, mangoes, pineapples, and so on
Vegetables	A net composite measure was used
Treenuts	Cocoa, coffee, cashew nuts, sugar cane, and so on
Livestock	Goat, sheep (mutton, lamb), chicken (poultry), beef, and so on
Fisheries	A net composite measure was used

Source: Compiled by authors.
Note: Commodity types are as defined in FAO (2003b).

Table 2. Scale of production and growth of key commodities in East and Central Africa

			Value of production		Annual growth rate				
			1998–2000 average		1961–70	1971–80	1981–90	1991–2000	1961–2000
Group	**Commodity**	**Rank**	**(%)**	**(million US$)**			**(%)**		**(%)**
Roots/tubers	Cassava	4	7.18	2,150	2.44	2.58	2.63	–1.10	–1.02
Fruit crops	Plantains	6	4.35	1,305	5.39	–0.29	2.48	–0.62	–0.72
Cereal	Maize	7	4.28	1,281	3.41	4.91	5.04	2.27	2.85
Pulses	Groundnuts	8	2.67	799	3.45	2.39	–0.71	5.32	4.59
Pulses	Dry beans	9	2.53	757	3.44	1.78	2.08	–0.59	–0.34
Cereal	Sorghum	10	2.46	737	1.45	3.63	–2.24	3.05	0.86
Cereal	Rice paddy	11	2.32	695	3.36	1.70	4.12	0.04	0.16
Fruit crops	Bananas	15	2.11	632	3.05	1.31	2.19	0.13	0.29
Roots/tubers	Sweetpotatoes	18	1.54	460	2.84	4.01	2.04	1.06	1.58
Cereal	Wheat	24	0.99	298	5.41	–2.10	2.49	2.89	2.36
Cereal	Millet	27	0.92	276	4.60	1.77	–1.50	3.33	1.95
Roots/tubers	Potatoes	28	0.89	267	2.93	4.91	0.47	3.90	4.64
Subtotal/average			***32.24***	***9,657***	***3.48***	***2.22***	***1.59***	***1.64***	***1.43***
Livestock	Beef and veal	2	11.23	3,363	2.61	2.91	1.18	1.99	2.31
Livestock	Cows' milk	3	7.48	2,243	2.50	3.16	4.97	2.33	2.50
Livestock	Mutton and lamb	12	2.29	686	1.25	3.29	–0.03	3.68	3.73
Livestock	Goat meat	14	2.20	658	0.69	2.47	3.15	3.03	2.86
Livestock	Goats' milk	16	1.80	539	0.97	4.04	0.58	4.31	4.45
Livestock	Chicken meat	19	1.26	378	4.17	3.54	2.88	2.00	2.16
Livestock	Sheep's milk	21	1.14	342	3.68	10.03	–0.14	1.99	2.54
Livestock	Pig meat	25	0.99	297	3.12	2.23	8.22	1.91	1.66
Livestock	Hens' eggs	26	0.95	284	2.68	4.06	1.90	1.60	1.52
Livestock	Game meat	29	0.83	248	0.84	1.17	2.18	1.14	1.10
Subtotal/average			***30.17***	***9,039***	***2.25***	***3.69***	***2.49***	***2.40***	***2.48***

Table 2. Continued

Group	Commodity	Rank	Value of production 1998–2000 average (%)	(million US$)	Annual growth rate 1961–70	1971–80	1981–90	1991–2000	1961–2000
					(%)				
Treenuts	Coffee, green	13	2.23	667	4.01	0.03	1.25	–0.34	–0.29
Treenuts	Tea	17	1.58	473	10.65	5.58	7.66	3.53	3.57
Treenuts	Sugarcane	20	1.20	359	6.20	2.87	2.19	1.80	1.98
Vegetables	Allspice pimento	22	1.14	340	1.89	0.94	–0.33	1.27	1.27
Vegetables	Sesame seeds	23	1.00	300	3.26	–3.26	–0.91	6.14	5.34
Fiber	Cotton	30	0.93	269	5.80	–6.99	–2.17	–1.44	–2.07
Nuts	Cashew nuts	31	0.27	80	5.87	–11.90	–7.17	11.11	–2.79
Vegetables	Vegetables	5	5.40	1,618	2.52	2.66	1.62	0.89	2.00
Fishery	Fish	1	12.41	3,718	9.04	1.82	6.70	1.12	3.57
Subtotal/average			***26.16***	***2,489***	***5.38***	***–1.82***	***0.08***	***3.15***	***1.00***
Total/average			**88.47**	**26,511**	**3.66**	**1.78**	**1.70**	**2.18**	**1.76**

Source: FAO 2003b.

In considering the historical and recent trends in production and consumption, commodities with less than 1 percent of total value of production but with exceptionally high growth rates were also retained. These commonly reflected nontraditional export commodities, which have experienced rapid growth in recent years without any signs of saturation in global markets (Diao et al. 2003). Cashew nuts and horticulture (vegetables and cut flowers) are two good examples.

The production growth rates for most other commodities vary over each decade with a majority experiencing growth rates that range between 1 and 5 percent annually, with some even declining over time (for example, tea). Others like cashew nuts and sesame seeds experienced a sharp production decrease in 1970s and 1980s but enjoyed a recovery in the 1990s, growing at rates of 6 and 11 percent, respectively, in part due to the devaluation of exchange rates associated with structural adjustment programs (Delgado and Minot 2000). Surprisingly, among staple food crops, cassava and plantain suffered negative growth rates throughout the 1990s. This may have been due to periodic droughts or the displacement of millions of smallholder producers in war torn regions like Congo Democratic Republic. For traditional crops like coffee and cotton, the decline was primarily driven by a reduced competitiveness in world markets, given that prices generally fell throughout the 1990s.

Market and Demand Opportunities

The next important criterion for consideration is whether any of the commodities identified as having production scale and growth potential face serious demand constraints into the future, given that any rapidly increasing productivity growth will require sufficient demand in domestic, regional, or international markets to absorb the increased supply. Several studies examine this issue directly, especially for some of Africa’s traditional exports (see Rosegrant et al. 2001, Ng and Yeats 2002, Diao and Yanoma 2003, and Diao et al. 2003). Ng and Yeats (2000), for example, paint a dismal picture; they note the stagnant, if not declining, trends in world prices for many of Africa’s traditional export commodities. Diao et al. (2003) draw similar conclusions, even after simulating an increase in world market shares following a large productivity shock for African agricultural exports. Since the 1980s, most African countries have lost market share to more competitive regions such as South Asia, but they still represent a large share of world trade for some commodities, such as cocoa.

In the East and Central African region, most traditional export commodities like coffee, cotton, nuts, sugar, and tea have lost market share. Increasingly, however, nontraditional exports like horticulture have captured a higher share of agricultural export earnings. Not all the 29 commodities selected in the previous section are exported. Recent average export values (1996 to 2000) and past growth rates (1961 to 2000) for those commodities that are exported are provided in Table 3, indicating potential for future growth.

Table 3. Value of exports and growth of key commodities in East and Central Africa

Group	Commodity	Rank	Export value 1996–2000 average (%)	Export value 1996–2000 average (thousand US$)	Annual growth rate (%) 1961–70	1971–80	1981–90	1991–2000	1961–2000
Staple crops	Dry beans	8	0.44	19,768	1.15	5.93	5.57	–4.45	3.64
	Maize	9	0.38	17,144	19.75	–10.46	42.14	–10.26	6.37
	Sorghum	10	0.30	13,645	–33.52	32.77	–7.04	15.18	6.08
	Beef and veal	12	0.16	7,311	2.01	–2.69	–27.82	60.88	–4.35
	Bananas	13	0.14	6,441	–5.53	1.22	10.47	–2.50	–2.43
	Groundnuts	14	0.05	2,407	–1.78	12.04	–20.22	17.40	–9.06
	Potatoes	15	0.02	844	–1.01	11.89	–6.40	38.59	–0.43
	Subtotal/average		*1.50*	*67,560*	*–2.70*	*7.24*	*–0.47*	*16.41*	*–0.02*
Nontraditional crops	Vegetables	7	0.54	24,358	5.40	4.15	7.54	7.82	5.78
	Fish	11	0.26	11,817	29.38	–13.19	13.68	7.64	11.18
	Sesame seeds	4	3.32	149,064	4.68	4.15	4.36	11.08	5.57
	Pimento, allspice	14	0.005	224	–4.17	–5.32	0.84	3.41	–5.91
	Subtotal/average		*4.12*	*185,462*	*8.82*	*–2.55*	*6.61*	*7.49*	*4.15*
Traditional crops	Coffee	1	24.42	1,097,923	9.00	18.78	–2.69	5.97	4.87
	Tea	2	12.21	548,809	10.90	17.22	5.68	6.93	8.43
	Cotton	3	3.73	156,302	4.37	2.28	3.14	–10.20	–0.66
	Cashew nuts	5	2.10	94,607	22.09	–3.15	–4.85	36.11	4.25
	Sugar	6	0.82	36,828	2.59	14.89	7.51	–20.02	1.89
	Subtotal/average		*43.28*	*1,934,468*	*9.79*	*10.00*	*1.76*	*3.76*	*3.76*
Total/average			**48.90**	**2,187,491**	**5.30**	**4.90**	**2.63**	**9.22**	**2.63**

Source: FAO 2003b.

Overall, total agricultural exports in East and Central Africa averaged about US$4,496 million per year between 1996 and 2000 (Diao et al. 2003). Therefore, the commodities shown in Table 3 represent almost half of that total. The first- and second-ranked commodities, coffee and tea, have a combined export value of more than one-third of East Africa's exports, while the third-ranked commodity, cotton, accounts for only 3 percent. Evidently, agricultural exports have focused on a few traditional exports, despite their declining export growth rates. Nontraditional exports, such as fishery products, livestock, and horticulture have grown more. Other exports like cashew nuts, beef and veal, groundnuts, and potatoes have also increased significantly.

Market demand projections for food staples and livestock can be derived from a variety of source Rosegrant et al. (2001), for example, predict that meat demand/production will rise faster than cereal demand/production (3.2 percent per year compared with 2.8 percent per year), but because this rapid growth in meat demand/production will also lead to sharp increases in feed demand, demand for some cereals like maize may outpace production, increasing imports. The FAO (2003a) also estimates that demand for food staples in Sub-Sahara Africa will continue to grow at rate of 2.9 percent per year, which is one of the highest growth rates in the world due to population growth (and rates for many countries in East Africa will be significantly higher). However, the composition of food commodities is expected to change as incomes rise, and demand for dairy products, meat, and vegetables increases (FAO 2003a).

Table 4. Selection of candidate commodities for analysis

Commodity	Group	Large smallholder base	Tradability			Future demand	Accepted for inclusion in *Dream* analysis
			Domestic markets	Regional markets	Global markets		
Maize	Cereals	Yes	Yes	Yes	Yes	High	✓
Millet	Cereals	Yes	Yes	No	No	Medium	
Rice	Cereals	Yes	Yes	Yes	Yes	High	✓
Sorghum	Cereals	Yes	Yes	No	No	High	✓
Wheat	Cereals	No	Yes	Yes	No	High	
Cotton	Fiber crops	Yes	Yes	No	Yes	Medium	✓
Bananas	Fruit	No	Yes	Yes	Yes	High	
Plantains	Fruit	Yes	Yes	No	No	High	✓
Groundnuts	Oil crops	Yes	Yes	Yes	No	Medium	✓
Sesame seeds	Oil crops	No	Yes	Yes	Yes	Low	
Beans	Pulses	Yes	Yes	Yes	Yes	Medium	✓
Cassava	Roots and tubers	Yes	Yes	Yes	No	Medium	✓
Potatoes	Roots and tubers	Yes	Yes	Yes	No	Low	✓
Sweetpotatoes	Roots and tubers	Yes	Yes	No	No	Low	
Cashew nuts	Treenuts	Yes	Yes	No	Yes	Medium	✓
Coffee, green	Treenuts	Yes	Yes	Yes	Yes	High	✓
Sugarcane	Treenuts	No	Yes	Yes	Yes	Medium	
Tea	Treenuts	No	Yes	Yes	Yes	Medium	
Vegetables	Vegetables	Yes	Yes	Yes	Yes	High	✓
Pimento	Vegetables	No	Yes	No	Yes	Medium	
Beef and veal	Livestock	Yes	Yes	Yes	Yes	High	✓
Chicken meat	Livestock	No	Yes	Yes	Yes	Medium	
Cows' milk	Livestock	Yes	Yes	No	No	High	✓
Game meat	Livestock	No	Yes	No	No	Low	
Goat Meat	Livestock	Yes	Yes	No	No	Low	
Goat Milk	Livestock	Yes	Yes	No	No	Low	
Hens' eggs	Livestock	No	Yes	Yes	No	Low	
Mutton and lamb	Livestock	Yes	Yes	No	No	High	✓
Pig meat	Livestock	No	Yes	No	No	Low	
Sheep's milk	Livestock	No	Yes	No	No	Low	
Fish	Fishery	No	Yes	Yes	Yes	High	

Source: Compiled by authors.

The scope for expanding intraregional trade is particularly high because regional exports from member countries represent less than 7 percent of total exports, which are valued at $300 million (Diao et al. 2003), and regional growth in the demand and production of food staples and livestock products in the region is expected to be high. In the absence of quantitative commodity-specific demand projections, future demand for commodities was estimated as high, medium, or low. These demand estimates were then combined with the assessments of scale of production, production growth potential, and relevance in smallholder production systems to determine a final set of 16 commodities for inclusion in the *Dream* analysis (Table 4). Bananas were eliminated because demand for plantains is greater, and plantains were considered to have more relevance for smallholder systems in the region. Finally, tea and sugarcane were determined to be inappropriate for smallholder production, so they were dropped from the analysis.

3. AGRICULTURAL R&D REGIONALIZATION AND SPILLOVERS

Regionalization can significantly improve the efficiency, effectiveness, and quality of agricultural research, particularly by targeting local conditions and needs. Efficiency gains result from reduced duplication of research, greater specialization across countries and institutions, and maximization of complementarities and comparative advantages in research capacity (Gijsbers and Contant 1996). Regionalization also allows for greater scope and scale economies in R&D. Greater scope for research occurs as collective action among countries permits a broader range of research topics to be covered. Meanwhile, economies of scale provide the necessary critical mass to enable research systems to achieve goals that lie beyond their individual capacities. However, these benefits only accrue if the administrative and transaction costs associated with the collaborative process do not unduly erode the marginal returns to investments in such endeavor (Alston et al. 2004).

A fundamental criterion for determining the applicability of a regional research perspective is whether technology applications have the potential to spill beyond their originally intended boundaries. By failing to account for benefits derived from technology spillovers, economic rates of return to R&D investment are typically underestimated, leading to underinvestment in R&D (Alston, Norton, and Pardey 1995). Armed with such knowledge, the optimal size, type, and location of agricultural research can be economically assessed from both a regional and a national perspective.

Empirical evidence of technology spillovers has been shown for commonly grown commodities like maize and wheat (see Maredia and Byerlee 2000 and Byerlee and Eicher 1997), and in Africa, improved germplasm for food staples like cassava has been shown to have spread beyond targeted regions and countries (Johnson and Masters 2006; Nweke, Spencer, and Lynam 2002). In international agriculture, early efforts to measure agricultural technology spillovers empirically can be found in the works of Evenson (1978, 1989) and White and Havlicek (1981). Evenson showed significant direct spillovers of crop and livestock technologies within similar agroecological regions in the United States. He also found that relatively small research systems benefited more from spillovers than larger ones.

Other studies in the literature focus on the theory and empirical methods for assessing the economic benefits of technology spillovers, including Davis, Oram, and Ryan (1987) and Alston, Norton, and Pardey (1995). The measurement of potential spillover coefficients is a key element in these studies, requiring estimates of how much a single technology derived through R&D is adoptable in different parts of a country and across countries. Potential adaptability is therefore a function of agroecological and socioeconomic similarities. Other efforts to measure spillovers directly have examined the "proximity" of the research or the extent to which research in one institution overlaps that of another. For example, Pardey (1986) assesses the disciplinary mix of U.S. agricultural experiment stations to derive an index for measuring proximity. Thorpe and Pardey (1990) use a citation index to estimate knowledge spillovers among Latin American countries. More recently, Maredia and Byerlee (2000) use the yield performance of improved varieties to directly estimate spill-in coefficients. They show substantial spillover of wheat varieties from the International Maize and Wheat Improvement Center (CIMMYT), implying that many developing countries—including Africa—would fare better by allocating their scarce resources to the adaptation of wheat technology spill-ins.

What these studies have in common is the finding that agricultural R&D spillovers can be significant, especially among countries with similar agroecological constraints and climates. Hence, the high degree of similarity in agroecological characteristics and farming systems in the East Africa region suggests strong potential for significant agricultural R&D spillovers across national boundaries. Nevertheless, sufficient diversity exists in the region to necessitate a spatially disaggregated analytical approach to measuring spillover potential. Using this approach, quantifiable measures of the extent to which technologies are applicable across national boundaries can be generated to facilitate an accurate determination of the most relevant research and commodities to be funded at the regional level.

The spatial nature of the analysis presented in this paper requires adequate information on the distribution of farming systems and practices, the agroclimatic conditions, the natural resource base, and current and future market conditions. Geographical information systems (GIS) analysis is especially suitable for distinguishing the spatial distribution of various types of farming systems, economic livelihoods, and agroecological characteristics in the East and Central African region. The resulting spatial units of shared similarities can span many countries and vary widely within a country, thus permitting a simultaneous focus on both national and regional priorities. For each unique and homogenous spatial unit, potential economic gains from technology spillovers can then be analyzed using the economic surplus approach. Results provide a quantifiable means of assessing the impacts of agricultural R&D and the spillover potential across major commodities and spatial areas.

4. SPATIAL ANALYSIS OF AGRICULTURAL PRODUCTION IN EAST AND CENTRAL AFRICA

Formulating and evaluating agricultural development strategies for a region as large and diverse as East and Central Africa is extremely challenging and requires multiple perspectives and judicious simplification. GIS tools and databases were used to disaggregate the region into geographical units (termed “development domains”) in which similar agricultural development problems or opportunities are likely to occur (Omamo et al. 2005). The development domains are characterized on the basis of agricultural potential, the size of cultivated land holdings, and irrigation conditions. The mapping of the domains utilizes the spatial distribution maps of You, Wood, and Wood-Sichra (2004). According to the length of the growing period (LGP), each subnational region is disaggregated into either a low (LGP < 180 days) or a high (LGP > 180 days) measure of agricultural potential, and each crop, along with its growing areas, is delineated as either irrigated or non-irrigated (that is, rainfed). According to these definitions, almost 70 percent of East and Central Africa’s cultivated land has high agricultural potential, while less than 10 percent is irrigated. Finally, cultivated land density—measured as the ratio of cultivated land to rural population (on 9 x 9 square kilometer pixels, the resolution for crop distribution maps [You, Wood, and Wood-Sichra 2004])—is categorized as high, medium, or low for each country. This measure attempts to reflect the degree to which land constraints exist, given the per capita size of land under cultivation. A ratio of more than 120 percent of a country’s average is considered high, implying a greater likelihood that access to land is limited—typical in areas of high population density. A ratio between 80 and 120 percent of a country’s average indicates a medium level of land constraints, while a ratio of below 80 percent is considered low, signifying an unbinding land constraint.

The density of cultivated land is provided in hectares per person in Table 5 and by country in Table 6. For the region as a whole, cultivated land density is about 0.2 hectares per rural person. Almost 70 percent of the rural population lives in areas where access to cultivated land is limited, accounting for less than 15 percent of the regional total or one-fifth of the regional average. By country, Ethiopia, Kenya, Burundi, and Rwanda have the least available cultivated land per capita (averaging about 0.11 hectares per person compared with 0.64 hectares per person in Sudan). Distribution by size is wider for large countries like Democratic Republic of Congo and Sudan. Indeed, for most countries, a majority of the rural population lives in areas with limited available cultivable land.

Table 5. Cultivated land density for East and Central Africa

Category	High density	Medium density	Low density
Land share (%) (regional total = 100)	14.75	11.32	73.92
Rural population share (%) (regional total = 100)	68.17	10.47	21.36
Land per rural population (hectares per person) (regional average = 0.2)	0.04	0.21	0.69

Source: Table 3.1 in Omamo et al. 2005.
Note: Cultivated land density is measured as the ratio of cultivated land to rural population. High density represents more than 120 percent of the national average; medium density represents between 80 and 120 percent of the national average; and low density represents less than 80 percent of the national average.

Table 6. Cultivated land density by country

Country	National average	High density	Medium density	Low density
Burundi	0.16	0.09	0.15	0.28
Congo Democratic Republic	0.20	0.03	0.20	0.88
Eritrea	0.24	0.03	0.24	0.89
Ethiopia	0.11	0.03	0.11	0.30
Kenya	0.11	0.03	0.10	0.31
Madagascar	0.18	0.06	0.18	0.48
Rwanda	0.25	0.16	0.24	0.42
Sudan	0.64	0.10	0.64	3.28
Tanzania	0.20	0.03	0.19	0.60
Uganda	0.31	0.08	0.31	0.79

Source: Table 3.2 in Omamo et al. 2005.
Note: Cultivated land density is measured as the ratio of cultivated land to rural population. High density represents more than 120 percent of the national average; medium density represents between 80 and 120 percent of the national average; and low density represents less than 80 percent of the national average.

The measures of cultivated land density are combined with the measures of agricultural potential and the type of production system (that is, irrigated versus rainfed) to establish 12 homogenous geographical regions or development domains (Table 7). As expected, crop production in East and Central Africa is dominated by rainfed agriculture, whereas rice is the only moderately irrigated crop. Hence, the majority of each of the 10 crops is grown in development domains that are rainfed and considered to have high agricultural potential.

National boundaries still play an important role in agricultural R&D investment and technology spillovers. Cross-referencing the 11 major countries of the East and Central African region with the 12 development domains described above yields a total of 96 separate domains. The number of domains per country varies from only 4 in Eritrea to the full 12 in Kenya, Madagascar, and Tanzania. This level of disaggregation enables the spatial heterogeneity of the region to be considered in terms of R&D impact, technology diffusion, adoption process, and spillover effects. Appendix Table B.1 presents the shares of crop production according to the 96 disaggregated development domains.

Table 7. Crop production by agricultural development domain

Development domain			Beans	Cassava	Coffee	Cotton	Ground-nuts	Maize	Plantains	Potatoes	Rice	Sorghum
Irrigated	Agricultural potential	Cultivated land density						(percent)				
No	Low	High	3.26	0.81	6.70	8.79	13.46	1.61	0.26	6.20	0.83	4.40
No	Low	Medium	2.36	0.58	3.45	3.11	3.27	1.22	0.27	2.08	1.15	2.98
No	Low	Low	6.13	2.78	10.44	9.12	12.10	22.86	3.34	5.84	4.66	43.56
No	High	High	22.40	11.48	20.32	31.58	22.96	15.10	11.32	22.49	7.81	7.77
No	High	Medium	16.73	7.95	11.10	9.53	7.14	8.55	15.97	18.25	4.61	4.98
No	High	Low	48.08	76.39	47.38	37.87	16.12	48.86	68.65	43.34	25.03	23.37
Yes	Low	High	0.44		0.28		5.58	0.12	0.06	0.48	1.93	1.52
Yes	Low	Medium	0.04		0.03		1.18	0.04	0.01	0.02	1.60	0.19
Yes	Low	Low	0.55		0.10		18.11	0.51	0.08	1.30	12.54	10.26
Yes	High	High	0.01		0.15		0.03	0.23	0.01		10.42	0.45
Yes	High	Medium			0.01		0.01	0.16			6.39	0.17
Yes	High	Low	0.01		0.04		0.05	0.73	0.02		23.01	0.36
Total			100	100	100	100	100	100	100	100	100	100
								(thousand tons)				
Production			1,403.7	31,992.2	695.9	161.9	1628.1	10,445.7	13,414.1	2,413.2	3670.9	5,936.6

Source: Calculated by authors.
Note: Cultivated land density is measured as the ratio of cultivated land to rural population. High density represents more than 120 percent of the national average; medium density represents between 80 and 120 percent of the national average; and low density represents less than 80 percent of the national average.

5. *DREAM* MODEL AND SIMULATION STRATEGIES

Next, the economic surplus approach (discussed in Chapter 3 of this paper) was applied using *Dream* (Alston, Norton and Pardey 1995; Wood, You, and Baitx 2000). The model is particularly suited for analyzing both price and technology spillovers. It is a single commodity and multimarket model that can be set within an open or closed economy depending on whether a commodity is regionally or internationally traded. Essentially, the model estimates shifting supply and demand curves over time to solve for a stream of equilibrium prices and quantities under "with" and "without" research scenarios, where both price and research spillover effects can be permitted between countries. A research-induced supply shift originating in one country represents the "with" research outcome and permits quantity changes that may or may not influence prices depending on whether the country is a small or large producer of the commodity (see Appendix A for details).

Dream was programmed with the 96 development domains described in the previous chapter. The rest of Sub-Saharan Africa (which includes all countries of West and southern Africa) and the rest of world (which includes all countries and regions beyond Sub-Saharan Africa) were added as independent regions depending on the trade situation for each individual commodity. Whether a commodity is traded in domestic, regional, or international markets can only affect the extent of price effects from a research induced supply shift in domestic or regional markets. Among the commodities analyzed, cashew nuts, coffee, cotton, dry beans, maize, rice, vegetables, and beef are treated as internationally traded commodities; cassava, groundnuts, and potatoes are assumed to be traded regionally; and plantains, sweetpotatoes, sorghum, millet, cows' milk, and mutton are considered to be traded within domestic markets only (that is, as in autarky or the absence of trade).

The most critical parameters in *Dream* relate to technology, defining the extent to which R&D influences productivity gains for each commodity. These parameters include factors like the additional gain in yield from technology adoption, maximum adoption potential, and the time it takes the new technology to reach maximum adoption. Because the analysis in this study covers a broad area involving many countries and development domains, it is virtually impossible to rely on the usual source of data on technology parameters, which is farm-level or expert surveys. Instead, an innovative approach was adopted using simulated yield gaps estimated for the entire region. Essentially, the yield gap measures the difference between the actual yield experienced in farmers' fields and the yield attainable using existing technologies (and considering agroclimatic conditions). Closing these yield gaps, therefore, primarily involves targeting a series of suitable and adaptable technologies and practices to reach the agroclimatically attainable yields estimated within each of the development domains. The domains determine whether local agroclimatic conditions are sufficiently suitable for growing certain crops. This is possible using spatially disaggregated data on crop distributions and yields (that is, at the pixel level) from You, Wood, and Wood-Sichra 2005. This pixel-level data was then aggregated to form the 96 development domains incorporated in the *Dream* simulations and associated economic analysis (Table 8).

The agroclimatically attainable yield data is drawn from agroecological zone (AEZ) analysis (Fischer et al. 2001). Agroclimatically attainable yield (that is, potential yield) is defined as the site-specific maximum yield that can be obtained under the geographic and ecological conditions of a location, using the best available technologies and farming practices to avoid all types of biotic stresses. The yield potential not only accounts for local biophysical conditions (soil, water, climate, and so on), but also for different technology and farming practices such as high-input irrigated, high-input rainfed, low-input rainfed, and subsistence farming practices. The potential maximum yield is estimated according an AEZ model for each 9 by 9 square kilometer pixel. Similar to the estimates of actual crop yields, this pixel-level data of maximum attainable yields was aggregated into the 96 development domains and then national averages were calculated from the potential yields within all the domains in each country (Table 9). Yield gaps vary by country, by crop, and by technology and farming system. For example, the current yield levels for coffee, maize, and sorghum are quite low compared with their potential yields. In contrast, the actual yields of cassava and potatoes are quite close to their potential levels.

Table 8. Crop yield levels in East Africa, 2000–04 average

8a. Irrigated (tons per hectare)

Country	Rice	Maize	Sorghum	Cassava	Plantains	Potatoes
Burundi	3.04	1.21	1.48			
Congo Democratic Republic	2.68					
Eritrea		1.72	1.10			8.00
Ethiopia		2.57	2.17		12.56	
Kenya	3.33					
Madagascar	2.03					
Rwanda	3.63					
Somalia	2.39					
Sudan	1.28	0.96	1.51		12.76	7.27
Tanzania	3.49	4.13				
Uganda	3.05					

Country	Groundnuts	Beans	Coffee	Cotton	Cashew nuts	Vegetables
Burundi						
Congo Democratic Republic						
Eritrea						
Ethiopia		2.14		1.06		
Kenya						
Madagascar						
Rwanda						
Somalia						5.00
Sudan	2.10	3.17				5.75
Tanzania						
Uganda						

8b. Rainfed (tons per hectare)

Country	Rice	Maize	Sorghum	Cassava	Plantains	Potatoes
Burundi		0.96	1.02	9.45	5.13	2.40
Congo Democratic Republic	0.78	0.68	0.65	10.08	5.47	1.83
Eritrea		0.61	0.43	6.38		
Ethiopia		2.09	1.23	6.38	4.31	5.36
Kenya		1.34	0.88	6.77	4.64	5.38
Madagascar	1.74	0.81	0.45	5.33	4.14	5.92
Rwanda	1.84	0.70	0.91	6.64	5.16	8.90
Somalia		1.91	0.80	2.00	2.00	8.19
Sudan		0.54	0.57	1.73		
Tanzania	1.36	1.43	1.02	5.65	2.63	7.64
Uganda	1.36	1.74	1.40	6.08	5.96	7.41
	Groundnuts	**Beans**	**Coffee**	**Cotton**	**Cashew nuts**	**Vegetables**
Burundi	0.73	0.80	1.31	0.73		2.97
Congo Democratic Republic	0.80	0.33	1.07	0.41		6.45
Eritrea	0.88	0.56				5.97
Ethiopia	0.88	0.56	1.14			6.36
Kenya	1.77	1.17	1.01	0.50	5.02	6.20
Madagascar	0.73	1.07	0.43	1.38	0.41	5.75
Rwanda	1.14	0.65	0.98			4.48
Somalia	0.86	0.41				4.35
Sudan	1.10	1.25				4.42
Tanzania	0.64	0.71	1.10		1.25	4.65
Uganda	0.70	0.61	1.27	0.27		5.87

Source: Compiled by authors.

Table 9. Potential yield level in meeting yield potential by 2015

9a. Irrigated (tons per hectare)

Country	Rice	Maize	Sorghum	Cassava	Plantains	Potatoes
Burundi	7.86	4.46	2.66			
Congo Democratic Republic	4.73					
Eritrea		9.90	7.57			9.79
Ethiopia		7.39	4.18			
Kenya	6.67					
Madagascar	5.34					
Rwanda	7.99					
Somalia	7.22					
Sudan	7.32	9.69	7.43			7.86
Tanzania	7.22	7.62				
Uganda	5.48					

	Groundnuts	Beans	Coffee	Cotton	Cashew nuts	Vegetables
Burundi						
Congo Democratic Republic						
Eritrea						
Ethiopia		3.39		1.62		
Kenya						
Madagascar						
Rwanda						
Somalia						5.50
Sudan	3.10	3.36				7.17
Tanzania						
Uganda						

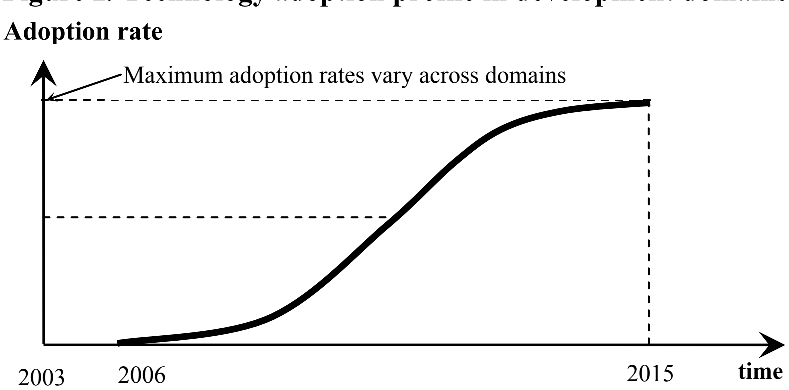
9b. Rainfed (tons per hectare)

	Rice	Maize	Sorghum	Cassava	Plantains	Potatoes
Burundi		2.94	1.78	9.77	7.52	3.55
Congo Democratic Republic	3.37	2.11	1.61	10.98	8.09	2.50
Eritrea		0.85	1.70	9.54	8.23	6.00
Ethiopia		3.03	1.83	9.54	8.55	6.58
Kenya		2.95	2.20	7.30	5.92	6.69
Madagascar	3.34	2.50	2.08	6.22	6.78	6.03
Rwanda	2.30	1.45	1.00	7.29	5.57	9.36
Somalia		4.62	1.00	3.00		8.57
Sudan		4.95	3.57	4.79		
Tanzania	3.09	3.25	2.64	5.98	6.36	7.80
Uganda	2.49	3.06	2.02	6.28	6.52	8.30
	Groundnuts	**Beans**	**Coffees**	**Cottons**	**Cashew nuts**	**Vegetables**
Burundi	0.97	1.36	2.78	0.86		3.18
Congo Democratic Republic	0.89	1.04	4.57	0.54		6.62
Eritrea	1.15	0.58				7.06
Ethiopia	1.15	0.58	4.60			6.88
Kenya	1.91	1.27	4.59	0.64	5.50	6.47
Madagascar	0.90	1.47	4.47	1.42	1.50	6.51
Rwanda	1.55	0.97	4.20			6.38
Somalia	1.40	1.58				5.06
Sudan	2.10	1.39				5.16
Tanzania	1.37	1.33	2.48		3.00	4.90
Uganda	0.75	1.06	4.54	0.31		6.51

Source: Compiled by authors.

It was assumed that the targeted yield levels could easily be attained by 2015 if sufficient resources were invested in R&D and extension. The growth rate of each crop's yield over time is defined at the domain level and within each country. Technology adoption is assumed to begin in 2005 and follows a sigmoid adoption curve over time to 2015. The adoption profile for development domains, which is typical for agricultural technology adoption is shown in Figure 2 (Alston, Norton, and Pardey 1995). The initial adoption rate is slow, but it accelerates after the initial adoption and slowly reaches its maximum.

Figure 2. Technology adoption profile in development domains



Source: Devised by authors.

To undertake the *Dream* analysis, a simple experiment with corresponding assumptions was developed. First, it was assumed that initial R&D takes place in only three countries: Kenya, Tanzania, and Uganda. This makes a strong assumption that these three countries have greater scope to undertake and expand R&D investments across all major commodities grown in the region. This is not necessarily true considering the size and capacity of NARS for different commodities in other countries in the region; the choice was essentially defined by an initial study undertaken for the U.S. Initiative to End Hunger in Africa (IEHA) to determine the extent to which additional R&D investments among these three countries have the potential to benefit the region as a whole. Nevertheless, it is not expected that the regional spillover results generated under this assumption will be dissimilar to those under any scenario defining other technology sources.

To measure regional spillover potential and welfare impacts, the *Dream* simulations were conducted according to two strategies: an initial strategy without technology spillovers and a second strategy introducing spillovers. The first strategy ("without spillovers") takes on a national perspective in which a commodity ultimately reaches its maximum potential yield in the three selected countries. The second strategy ("with spillovers") takes on a regional perspective by analyzing the potential benefits resulting from targeting technologies according to development domains across all the countries of East and Central Africa. This assumes that existing technologies and farming practices will be adopted in all countries, irrespective of national boundaries, as long as they are suitably targeted within similar development domains. Finally, the difference in economic surplus or welfare both between the two strategies and accruing to the region as a whole measures the potential welfare gains from the spillovers. In turn, this helps to define which commodities a regional R&D program should focus on—that is, those offering greater spillover potential or adaptability across countries and thus larger regional economic welfare gains. Economic welfare is measured as a stream of annual gross benefits in consumer and producer surpluses accruing to each country and the region as a whole by 2015. Because we were unable to incorporate R&D costs due to limited data, the more appropriate calculation of net economic returns from investments was not used. Nevertheless, this does not affect our overall methodology nor the results in commodity rankings if the average R&D cost required for raising yields by one percent (and thus a shift in the supply curve) are not significantly different across individual commodities.

The extent to which agricultural research spillovers to other countries occur will depend on the degree to which other countries share the same agroclimatic and socioeconomic characteristics with the country that originated the research (as a measure of research proximity). Under the "with spillover" scenario, the additional assumption that technologies can move freely between similar domains within the region is made. This assumes that technologies are typically developed to address domain-specific constraints to crop production and processing (for example, increasing the drought, frost, or water-logging tolerance of crops), or to alter the susceptibility of crops and animals to different pests and diseases. Similarly, some technologies are targeted to specific types of farming systems (for example, irrigated versus rainfed) with the result that a commodity may perform better in a particular domain, irrespective of the country within which it is located. Because adequate data for livestock productivity improvement is not available, comparable growth in the livestock sector was estimated for the major commodities (milk, beef, and lamb) according to their comparative advantage in different countries.

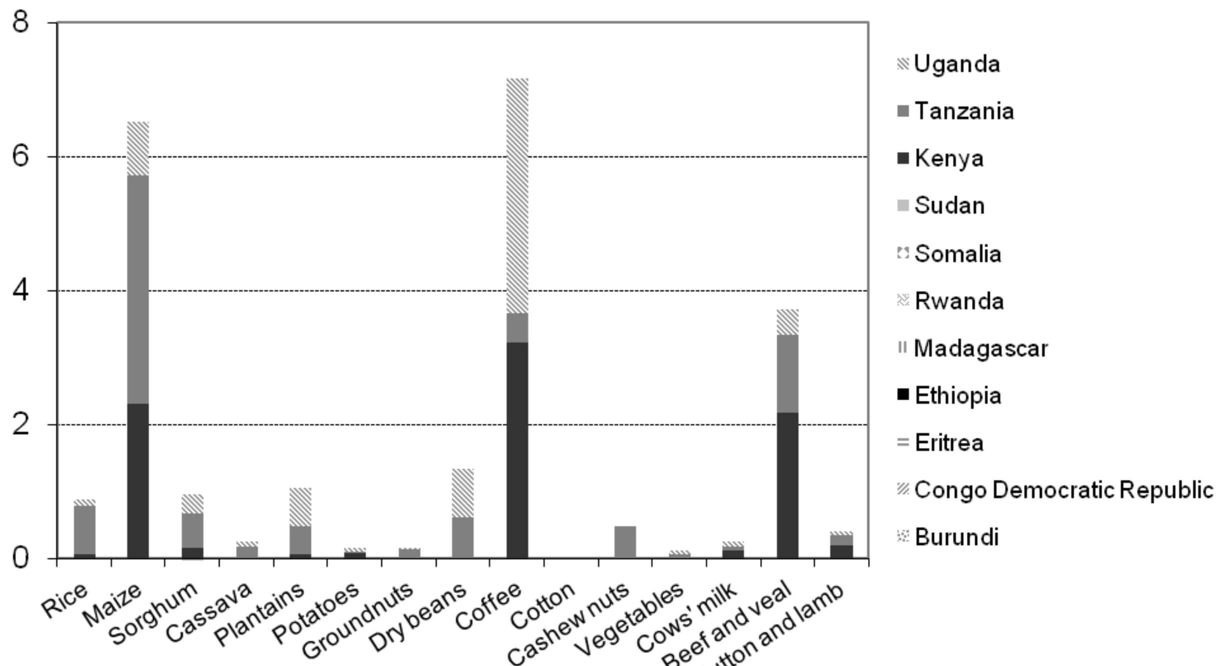
6. MODEL RESULTS

Since most smallholder producers consume their own production (Degaldo 1997; von Braun, Teklu, and Webb 1999), distinguishing between producer and consumer benefits is not as useful as determining total welfare measures. Consequently, the total benefit—that is, the sum of producer and consumer benefits—is presented (Figure 3). In the case of the "without spillovers" scenario, the only spillovers allowed are price effects due to increased supply among the innovating countries. For the domestically traded commodities (plantains, cows' milk, goat meat, and mutton and lamb), no cross-country price effects are allowed, but even among the regionally or internationally traded commodities, the cross-country price effects are negligible due to the originating countries' small market shares in regional or global markets. Therefore, price-related benefits mostly accrue to the three countries originating the technologies, but the other countries gain large benefits from the spillovers.

Figure 3. Annual regional benefits from meeting yield potential in Kenya, Tanzania, and Uganda, with and without spillovers

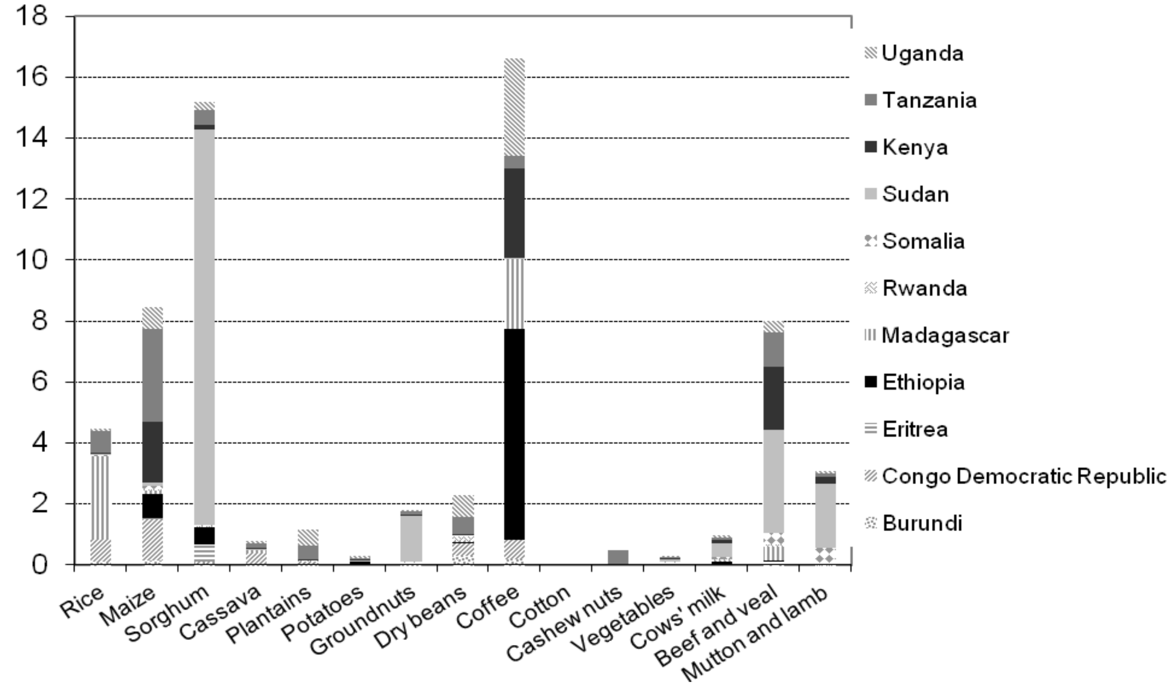
3a. Without spillovers

Million U.S. dollars per year



3b. With spillovers

Million U.S. dollars per year



Source: Compiled by authors from *Dream* simulation results.

There are a few obvious patterns in annual benefits from regionally oriented R&D investments (Figure 4). First, coffee and maize show potential as regional commodity priorities. The total benefits to East and Central Africa are $7 million and $6.2 million per year, respectively, without spillovers, and $16.5 million and $8.4 million per year, respectively, with spillovers. The priority commodities for the three focus countries (that is, those countries originating the R&D effort) are coffee, maize, and beef when there are no spillovers and maize, sorghum, beef, and coffee when spillovers occur. The benefits from productivity improvements for these priority commodities are much higher than those for the remaining commodities. Second, benefits are much greater in the presence of spillovers (that is, when development domains are targeted and spillover effects are taken advantage of) than when spillovers do not occur and benefits accrue to the three focus countries only. Annual net gains from spillovers are estimated to range between $10,000 per year for cotton to over $14 million per year for sorghum (Table 10). Proportionate spillover gains as a proportion of total regional benefits accruing to non-innovating countries range from 9 percent for plantains to over 90 percent for sorghum (fifth column); these gains translate as spillover multipliers of 1.1 and 17.4, respectively (fourth column). Sorghum, groundnut, and rice technologies, in particular, demonstrate high spillover multipliers. The potential benefits from technology spillovers from the focus countries reflect the agroecological similarity of the focus and nonfocus countries. The table also indicates the benefits of a regional program established to facilitate technology transfer and adaptation.

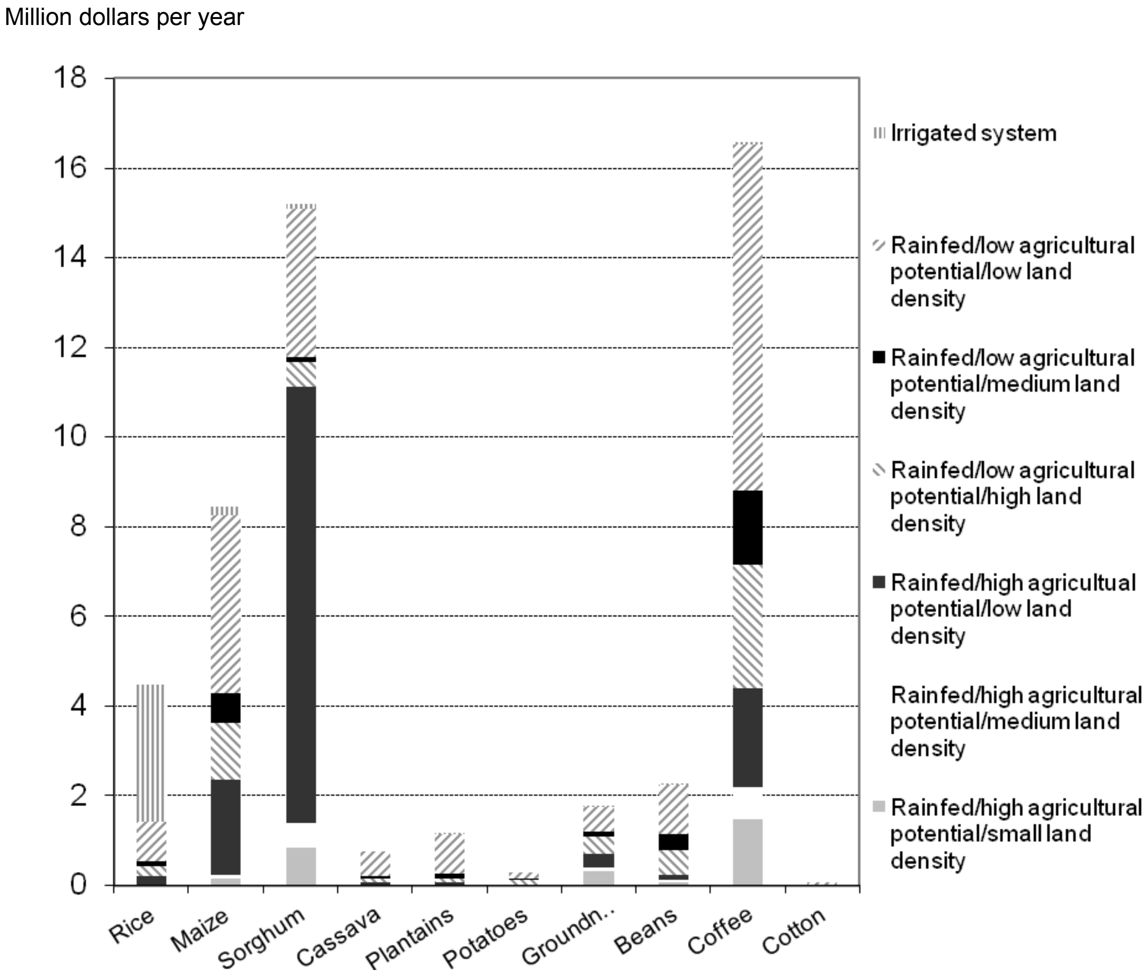
Initial R&D investments occur in Kenya, Tanzania, and Uganda. Technology spillovers are assumed to occur when regional arrangements are in place to aid the transfer and adaptation of R&D to other countries in the region. The spillover multiplier is the ratio of total benefit to initial benefit without spillovers. Total regional gains include initial gains accruing to the innovating countries and the gains resulting from the spillover. The degree of cross-country variation in spillover gains is measured as the coefficient of variation across countries (that is, the standard deviation divided by the mean).

Table 10. Distribution and scope for technology spillovers in East and Central Africa

Commodity	Total regional gains without spillovers (million $ per year) *a*	Additional gains with spillovers (million $ per year) *b*	Spillover multiplier *(a + b)/a*	Spillover gains as a share of total regional gains with spillovers (%) *b/(a + b)*	Degree of cross country variation in spillover gains (index)
Rice	0.88	3.58	5.06	80.2	2.51
Maize	6.52	1.90	1.29	22.6	1.99
Sorghum	0.88	14.30	17.33	94.2	1.83
Cassava	0.25	0.51	3.02	66.9	2.21
Plantains	1.06	0.11	1.10	9.4	2.67
Potatoes	0.15	0.13	1.86	46.3	1.35
Groundnuts	0.17	1.62	10.70	90.7	2.14
Dry beans	1.34	0.93	1.70	41.1	1.23
Coffee	7.02	9.56	2.36	57.7	2.11
Cotton	0.05	0.01	1.12	10.6	1.64
Cashew nuts	0.49		1.00		3.21
Vegetables	0.12	0.18	2.55	60.8	1.04
Cows' milk	0.26	0.69	3.67	72.8	1.70
Beef and veal	3.72	4.29	2.15	53.6	1.52
Mutton and lamb	0.40	2.66	7.57	86.8	1.82

Source: Compiled by authors from *Dream* simulation results.
Notes: %) lover multiplier countries.

Figure 4. Annual benefits from regionally oriented R&D investments by commodity and development domain

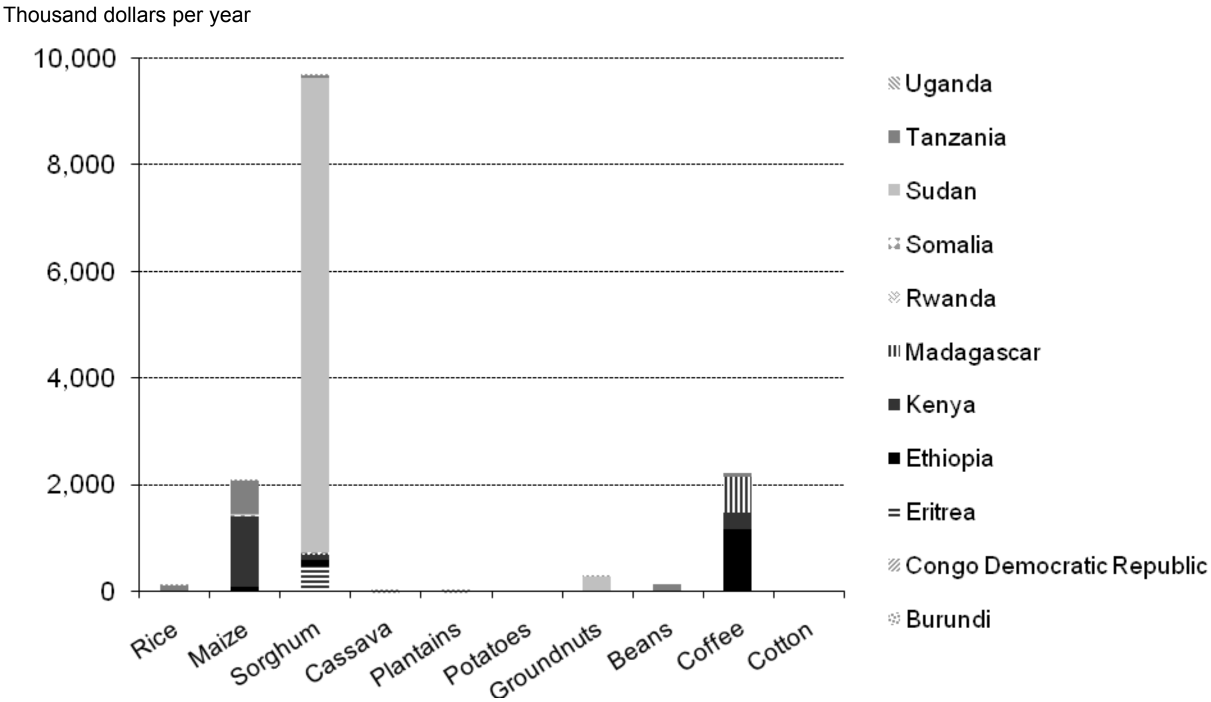


Source: Compiled by authors from *Dream* simulation results.

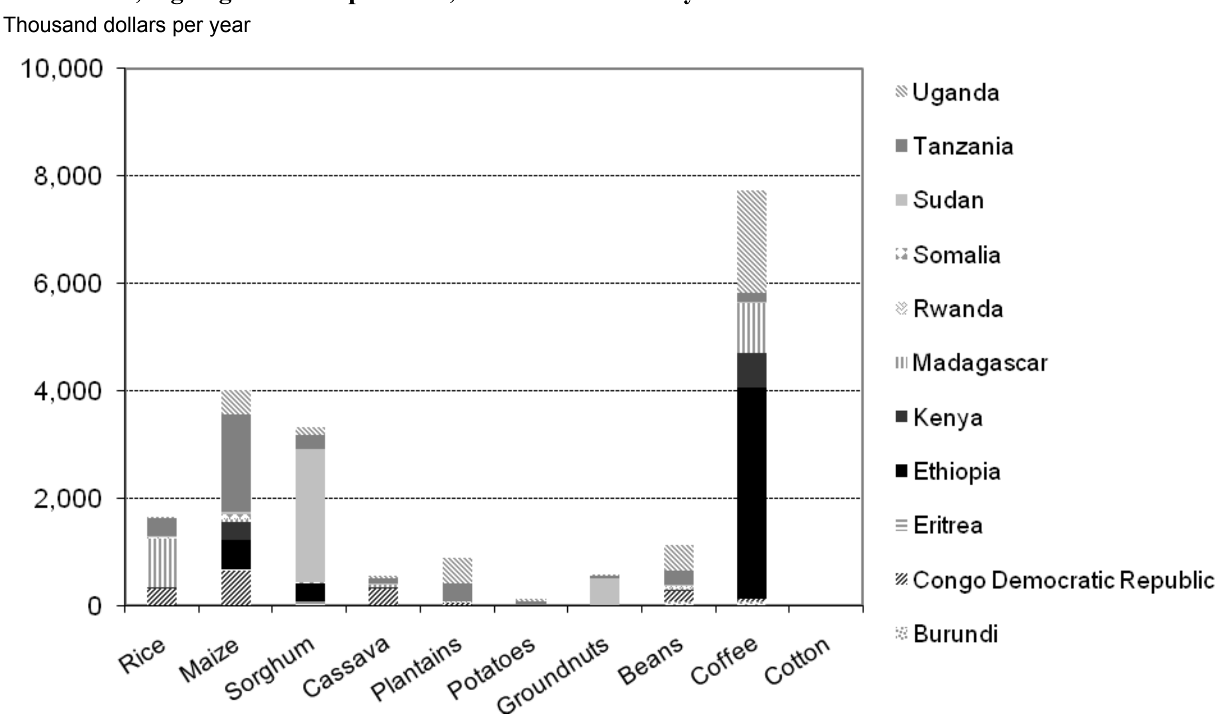
The above comparison shows the great potential for technology spillovers in the region. Developing technologies targeting specific domains and establishing a regional program for technology adaptation would likely reap huge payoffs. Location-specific technology effects are far more likely to vary by local agroecological conditions, farming systems, and availability of cultivated land. This is the reality in Africa, where a mosaic of agroclimatic conditions, land densities, and rainfed farming systems coexist across the rural landscape. The benefit to irrigated agriculture is limited by the small amount of irrigated area in the region (Figure 5). Irrigated development domains mostly benefit from improvements in rice technologies because current, large-scale irrigation schemes were developed for rice, mostly in Madagascar. Among the six rainfed domains, technologies targeting the following four domains could greatly benefit the region: low agricultural potential and low land density, and high agricultural potential with all three land densities.

Figure 5. Annual benefits by development domains

5a. Rainfed, low agricultural potential, and low land density



5b. Rainfed, high agricultural potential, and low land density



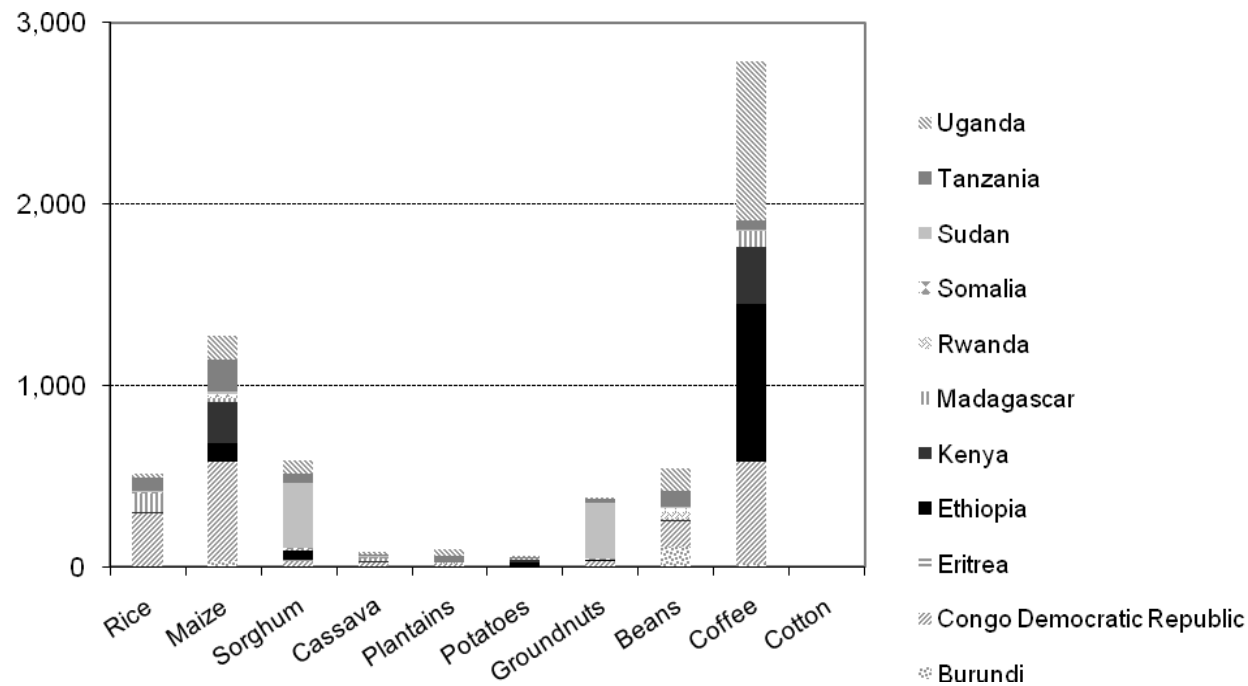
Source: Compiled by authors from *Dream* simulation results.

To determine which countries benefit the most from each technology introduced, a breakdown of the range of gross economic benefits derived within the four major domains is presented by country (Figure 5). Large absolute gains accrue within low land density areas with both high and low agricultural potential, benefiting staple crops like sorghum and maize, as well as coffee (Figure 5a and 5b). The countries with the largest absolute gains include Sudan (for sorghum), Tanzania (for maize), and Madagascar and Ethiopia (for coffee). These benefits accrue mostly in the rainfed, less land-constrained, and high agricultural potential areas. This particular domain is characterized by larger than average cultivated land sizes per capita, either due to commercial and mechanized agriculture, or (as is far more likely) due to extensive agricultural practices among subsistence farmers, as is the case in many remote rural areas. In rainfed, high agricultural potential areas, benefits to coffee production are far greater than to any other commodities, particularly in Uganda, Ethiopia, and the Democratic Republic of Congo (Figure 5c and 5d). Maize and rice production in the Democratic Republic of Congo and sorghum and groundnut production in Sudan also benefit from technologies targeting rainfed, high agricultural potential areas. These areas most probably practice intensive farming systems, such as mixed cropping, or have high population densities where access to cultivated land is severely limited.

Figure 5. Continued

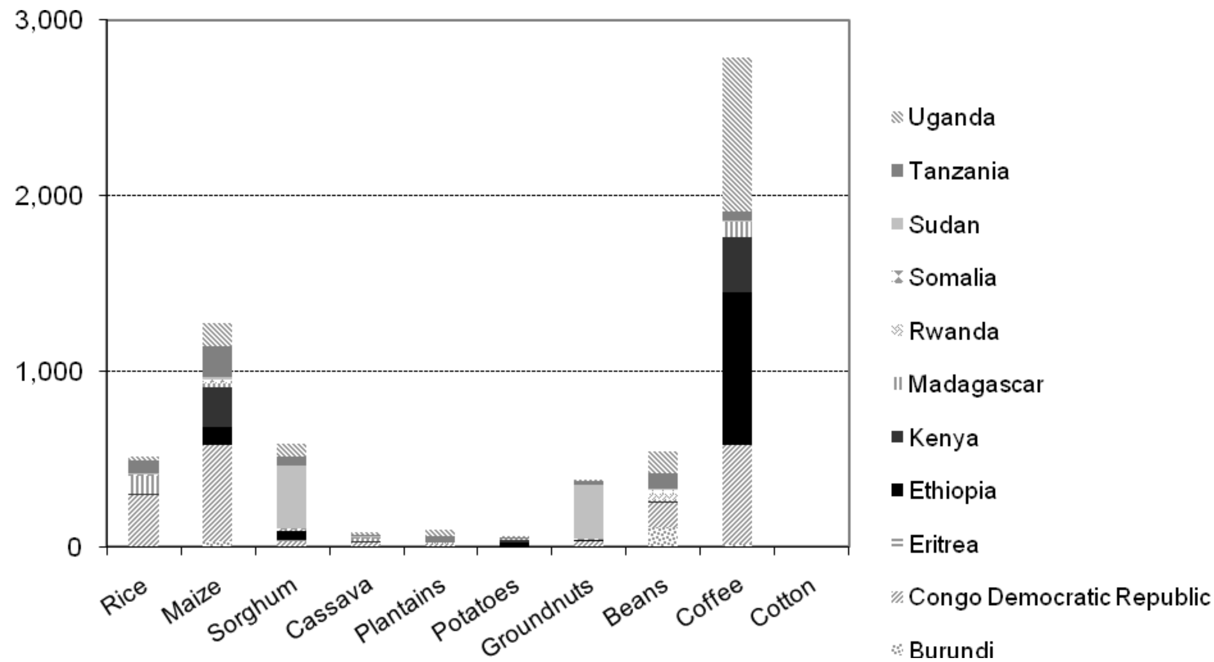
5c. Rainfed, high agricultural potential, and high land density

Thousand dollars per year



5d. Rainfed, high agricultural potential, and medium land density

Thousand dollars per year



Source: Compiled by authors from *Dream* simulation results.

The regional simulations by development domain illustrate the magnitude and spread of potential spillover benefits across countries, benefiting those countries with a significant share of production within a specific domain. Since development domains represent differentiated supply responses to technology adoption as a consequence of the varied patterns in agroecology, crop intensities, and access to water, the estimates are far more realistic in terms of the size and incidence of research benefits at the regional level. The potential for countries to gain from regionally focused R&D programs is especially high in those countries that are able to adopt the technologies more extensively.

7. CONCLUSIONS

Rather than "going it alone" by individual countries, the countries of the East and Central African region could reap potentially large economic benefits by pooling their resources to find common technology solutions to shared problems. Regionalization would not only allow for greater research scope at a lower unit cost due to scale economies, but also provide for larger national gains by providing the critical mass that is normally beyond the capacity of national systems. Moreover, regionally focused technology programs can take advantage of ongoing R&D investments in select countries, especially when they have a high potential for adaptation in neighboring countries. Regionalization of relevant R&D efforts will also depend on a focus on commodities with the largest scope to benefit smallholder farming communities.

Based on this preliminary study, investments in maize, sorghum, coffee, and beef in the three focus countries of Uganda, Kenya, and Tanzania have been shown to potentially satisfy such criteria. Under a regional research initiative, coffee could potentially yield the largest benefits to the three focus countries and to the whole region due to the spillover of technology. Ideally, the stream of benefits accruing from the wide spread diffusion of productivity-enhancing technologies among these commodities alone could be sustained over time through steadily rising producer incomes. This could occur if farmers were able to become more competitive and as a result eventually be integrated into domestic, regional, and global markets. The principal challenge facing the region would be to ensure that domestic and regional markets remain sufficiently open and accessible to absorb a steadily increasing supply, especially given the typical problems of poor physical infrastructure, weak transportation networks, and a host of restrictive trade barriers, together with a flood of cheap food imports or substitutes that are often a direct result of high agricultural subsidies in developed countries. Many of these factors combine to constrain the growth of markets in the region.

Finally, although knowing something about the future economic returns to research is very useful for informing research priority-setting processes, it is by no means the only criterion. Stakeholder preferences relating to the usefulness of the technology in addressing local needs, customs, or environmental considerations is just as important. Like any other economic analysis, results are intended to contribute to the policy debate and offer quantifiable weights for ranking purposes. The danger arises when too many noneconomic considerations are introduced, ultimately rendering the economic analysis irrelevant.

APPENDIX A: THE *DREAM* MODEL

Dream stands for Dynamic Research EvAluation for Management (Wood, You, and Baitx 2000). *Dream* is designed to measure economic returns to commodity-oriented research under a range of market conditions, allowing price and technology spillover effects among regions as a consequence of the adoption of productivity-enhancing technologies or practices in an innovating region. Linear equations are used to represent supply and demand in each region with market clearing enforced by a set of quantity identities and price identities. It is a single-commodity model without 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. In particular, *Dream* assumes all commodities are tradable between countries (although a spectrum of possibilities from free trade to autarky can be represented). Supply, demand, and market equilibrium are defined in terms of border prices that 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 regions between the farm and border. The linearity of *Dream* is good for small equilibrium displacements, such as single-digit percentage shifts of supply or demand. The small equilibrium displacement is common for most of agricultural technology changes. Alston and Wohlgenant (1990) showed that changes in benefit estimates from comparatively small equilibrium displacements in linear models provides a reasonable approximation of the same shifts (in this case parallel shifts) with various other function forms. Small shifts have an added virtue in 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 will). Even with all these simplifications, which make *Dream* tractable, significant effort is needed to parameterize and use the model to simulate market outcomes under various scenarios (Alston, Norton, and Pardey 1995).

The primary parameterization of the model's supply and demand equations is based on a set of demand and supply quantities, prices, and elasticities in a defined "base" period. *Dream* also allows for underlying growth of supply and demand to be built into the model to project a stream of shifting supply and demand curves into the future that can be solved for a stream of equilibrium prices and quantities, in the "without research" scenario. These "without research" outcomes can be compared with "with research" outcomes 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 profile representing the pattern of adoption of the technology over time. Finally, measures of producer and consumer surpluses are computed and compared between the "with research" and "without research" scenarios, and these are discounted back to the base year to compute the present values of benefits. In the case where the costs of the research responsible for the supply shift being modeled are known, *Dream* will compute a net present value or internal rate of return (IRR).

Dream has been developed as a computer software package (Wood, You, and Baitx 2000). It has menu-driven, user-friendly interface that hides complex computations to allow the user to focus on methodology, data collection, and policy interpretation. *Dream* explicitly includes four market types: a horizontal multimarket, an open economy, a closed economy, and a three-level vertical market. The region in *Dream* can be any spatial unit, either a geopolitical region such as country, province, county, or an agroecological zone such as a humid and temperate zone, the tropics, and an arid zone. *Dream* allows users to specify technology shifts, adoption, elasticities, and exogenous growth rates that change over the simulation period. It provides a framework for exploring various kinds of policy, technology, extension ,and trade issues (Alston, Norton, and Pardey 1995).

APPENDIX B: SUPPLEMENTARY TABLES

Table B.1. Crop production shares by development domains

a. Burundi

Domains	Rice	Maize	Sorghum	Cassavas	Plantains	Potatoes	Groundnuts	Beans	Coffee	Cotton
BYRLH							0.01	0.04	0.01	0.08
BYRLM				0.02		0.02	0.02	0.02	0.03	0.06
BYRLL		0.04	0.03	0.05	0.16	0.03	0.03	0.05	0.03	0.02
BYRHH		0.25	0.32	0.23	0.16	0.43	0.35	0.38	0.11	0.12
BYRHM		0.15	0.09	0.33	0.23	0.28	0.29	0.23	0.36	0.32
BYRHL		0.14	0.14	0.37	0.44	0.24	0.29	0.27	0.46	0.39
BYILH			0.02	0.01						
BYILL	0.01		0.03							
BYIHH	0.04	0.07	0.19							
BYIHM	0.20	0.07	0.08							
BYIHL	0.75	0.29	0.09							
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

b. Congo Democratic Republic

Domains	Rice	Maize	Sorghum	Cassavas	Plantains	Potatoes	Groundnuts	Beans	Coffee	Cotton
CGRLM				0.02		0.01	0.02	0.02	0.03	0.06
CGRLL		0.03	0.02	0.05	0.12	0.03	0.03	0.05	0.02	0.02
CGRHH	0.40	0.40	0.55	0.08	0.16	0.06	0.50	0.31	0.80	0.61
CGRHM	0.10	0.10	0.07	0.02	0.09	0.04	0.08	0.16	0.04	0.04
CGRHL	0.44	0.47	0.36	0.84	0.63	0.85	0.37	0.46	0.11	0.26
CGIHH	0.03									
CGIHL	0.03									
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

c. Eritrea

Domains	Rice	Maize	Sorghum	Cassavas	Plantains	Potatoes	Groundnuts	Beans	Coffee	Cotton
ERRLH		0.25	0.04			0.02		0.30		
ERRLM		0.09	0.03					0.03		
ERRLL		0.48	0.83					0.67		
ERILL		0.18	0.10			0.98				
Total		1.00	1.00			1.00		1.00		

d. Ethiopia

Domains	Rice	Maize	Sorghum	Cassavas	Plantains	Potatoes	Groundnuts	Beans	Coffee	Cotton
ETRLH		0.03	0.04		0.02	0.06	0.06	0.03	0.03	
ETRLM		0.03	0.04			0.02	0.02	0.01	0.02	
ETRLL		0.09	0.19		0.14	0.04	0.07	0.08	0.17	
ETRHH		0.13	0.09		0.09	0.27	0.43	0.22	0.13	
ETRHM		0.08	0.06		0.18	0.13	0.10	0.11	0.09	
ETRHL		0.64	0.57		0.54	0.48	0.32	0.54	0.56	
ETIHL			0.01		0.04					
Total		1.00	1.00		1.00	1.00	1.00	1.00	1.00	

e. Kenya

Domains	Rice	Maize	Sorghum	Cassavas	Plantains	Potatoes	Groundnuts	Beans	Coffee	Cotton
KERLH			0.05	0.10	0.06	0.25	0.30		0.29	0.34
KERLM			0.06	0.02	0.05	0.04	0.06		0.13	0.10
KERLL		0.64	0.83	0.35	0.62	0.14	0.20		0.10	0.38
KERHH		0.13	0.03	0.17	0.12	0.26	0.24		0.09	0.08
KERHM		0.05		0.06	0.04	0.09	0.06		0.12	0.02
KERHL		0.17	0.04	0.29	0.12	0.22	0.15		0.23	0.09
KEILH	0.15								0.02	
KEILM	0.03									
KEILL	0.56									
KEIHH	0.09								0.01	
KEIHM	0.03									
KEIHL	0.14									
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00

f. Madagascar

Domains	Rice	Maize	Sorghum	Cassavas	Plantains	Potatoes	Groundnuts	Beans	Coffee	Cotton
MARLH		0.05	0.09	0.03	0.03	0.07	0.12	0.11	0.14	0.20
MARLM		0.04	0.04	0.03	0.02	0.07	0.06	0.09	0.09	0.09
MARLL	0.02	0.12	0.08	0.07	0.06	0.10	0.12	0.09	0.29	0.20
MARHH	0.03	0.16	0.28	0.18	0.19	0.25	0.19	0.21	0.04	0.07
MARHM	0.03	0.14	0.13	0.12	0.12	0.17	0.12	0.11	0.04	0.05
MARHL	0.16	0.48	0.39	0.56	0.59	0.36	0.39	0.39	0.40	0.39
MAILH	0.02									
MAILM	0.02									
MAILL	0.17									
MAIHH	0.15									
MAIHM	0.09									
MAIHL	0.32									
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

g. Rwanda

Domains	Rice	Maize	Sorghum	Cassavas	Plantains	Potatoes	Groundnuts	Beans	Coffee	Cotton
RWRHH	0.11	0.31	0.50	0.29	0.19	0.24	0.41	0.25		
RWRHM	0.12	0.35	0.38	0.46	0.30	0.35	0.36	0.34		
RWRHL	0.04	0.34	0.12	0.26	0.51	0.41	0.23	0.41		
RWIHH	0.28									
RWIHM	0.05									
RWIHL	0.40									
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		

h. Somalia

Domains	Rice	Maize	Sorghum	Cassavas	Plantains	Potatoes	Groundnuts	Beans	Coffee	Cotton
SORLM			0.28				0.36			
SORLL	0.12		0.17							
SORHH	0.10	0.31	0.40	0.29			0.41	0.21		
SORHM		0.25		0.46				0.37		
SORHL	0.04	0.44	0.15	0.26			0.23	0.42		
SOIHH	0.38									
SOIHM	0.06									
SOIHL	0.30									
Total	1.00	1.00	1.00	1.00			1.00	1.00		

i. Sudan

Domains	Rice	Maize	Sorghum	Cassavas	Plantains	Potatoes	Groundnuts	Beans	Coffee	Cotton
SURLH		0.20	0.06	0.55			0.20	0.22		
SURLM		0.04	0.04	0.07			0.05	0.04		
SURLL		0.08	0.68	0.19			0.18	0.11		
SURHH		0.06		0.16			0.11	0.11		
SURHM				0.01			0.04			
SURHL				0.01			0.01			
SUILH	0.24	0.06	0.03		0.31	0.97	0.09	0.22		
SUILM	0.08	0.03			0.07	0.02	0.02	0.02		
SUILL	0.65	0.51	0.20		0.57		0.30	0.28		
SUIHL	0.04	0.02			0.04					
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		

j. Tanzania

Domains	Rice	Maize	Sorghum	Cassavas	Plantains	Potatoes	Groundnuts	Beans	Coffee	Cotton
TZRLH	0.03	0.03	0.04	0.02	0.02	0.08	0.09	0.06	0.11	
TZRLM	0.04	0.03	0.04	0.02		0.06	0.05	0.06	0.06	
TZRLL	0.17	0.22	0.16	0.09	0.04	0.23	0.15	0.17	0.18	
TZRHH	0.08	0.06	0.12	0.07	0.08	0.13	0.19	0.16	0.14	
TZRHM	0.07	0.07	0.10	0.06	0.08	0.09	0.10	0.09	0.09	
TZRHL	0.44	0.59	0.54	0.74	0.78	0.42	0.43	0.46	0.43	
TZILH	0.02									
TZILM	0.01									
TZILL	0.04									
TZIHH	0.02									
TZIHM	0.01									
TZIHL	0.06	0.01								
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	

k. Uganda

Domains	Rice	Maize	Sorghum	Cassavas	Plantains	Potatoes	Groundnuts	Beans	Coffee	Cotton
UGRLL	0.02	0.02	0.02	0.03			0.03			
UGRHH	0.28	0.19	0.26	0.19	0.07	0.21	0.29	0.19	0.27	0.34
UGRHM	0.16	0.16	0.16	0.15	0.11	0.11	0.20	0.15	0.15	0.15
UGRHL	0.35	0.63	0.56	0.63	0.82	0.69	0.49	0.66	0.58	0.51
UGIHH	0.04									
UGIHM	0.02									
UGIHL	0.13									
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Source: Compiled by authors.
Note: Each development domain is identified by a two-letter country code, rainfed (R) or irrigated (I), high or low agricultural potential (H or L), and high, medium, or low cultivated land density (H, M, or L). For example: KERHH means a Kenyan (KE) development domain with rainfed (R), high agricultural potential (H), and high land density (H).

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