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Crop Production and Road Connectivity in Sub-Saharan Africa

A Spatial Analysis

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Abstract

This study examines the relationship between transport infrastructure and agriculture in Sub-Saharan Africa using new data obtained from geographic information systems (GIS). First, the authors analyze the impact of road connectivity on crop production and choice of technology. Second, they explore the impact of investments that reduce road travel times. Finally, they show how this type of analysis can be used to compare cost-benefit ratios for alternative road investments in terms of agricultural output per dollar invested.

The authors find that agricultural production is highly correlated with proximity (as measured by travel time) to urban markets. Likewise, adoption of high-productive/high-input technology is negatively correlated with travel time to urban centers. There is therefore substantial scope for increasing agricultural production in Sub-Saharan Africa, particularly in more remote areas. Total crop production relative to potential production is 45 percent for areas within four hours' travel time from a city of 100,000 people. In contrast, it is just 5 percent for areas more than eight hours away. Low population densities and long travel times to urban centers sharply constrain production. Reducing transport costs and travel times to these areas would expand the feasible market size for these regions.

Compared to West Africa, East Africa has lower population density, smaller local markets, lower road connectivity, and lower average crop production per unit area. Unlike in East Africa, reducing travel time does not significantly increase the adoption of high-input/high-yield technology in West Africa. This may be because West Africa already has a relatively well-connected road network.

This paper—a product of the Sustainable Development Division, Africa Region—is part of a larger effort in the department to improve the global knowledge base on African infrastructure as part of the Africa Infrastructure Country Diagnostic. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at pdorosh@worldbank.org.

Produced by the Research Support Team

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Abbreviations and acronyms

AEZ	agroecological zone
CIESIN	Center for International Earth Science Information Network
ESRI	Environmental Systems Research Institute
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistical Databases
GDP	gross domestic product
GIS	geographic information system
GPW–UR	Gridded Population of the World, version 3, with Urban Reallocation
GRUMP	Global Rural-Urban Mapping Project
IFPRI	International Food Policy Research Institute
IIASA	International Institute for Applied Systems Analysis
kg/ha	kilogram per hectare
km/hr	kilometer per hour
LUTs	land utilization types
ORNL	Oak Ridge National Laboratory
SI	crop suitability index
SPAM	spatial crop allocation model
SRTM	Shuttle Radar Topography Mission
UNEP	United Nations Environment Programme

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There is substantial evidence that investments in roads and road connectivity positively effect agricultural productivity and output. Such evidence includes econometric analysis of subnational data on the effects of public spending (roads, agricultural research, education, and so on) on agricultural output, incomes, and poverty in the People's Republic of China and India (Fan and Hazell 2001). Econometric analysis of household data on the effects of road connectivity on input use, crop output, and household incomes in Madagascar and Ethiopia (Chamberlin and others 2007; Stifel and Minten 2008) suggests that remoteness negatively affects agricultural productivity and incomes at the household level. The impacts of road infrastructure on agricultural output and productivity are particularly important in Sub-Saharan Africa for three reasons. First, the agricultural sector accounts for a large share of gross domestic product (GDP) in most Sub-Saharan countries. Second, poverty is concentrated in rural areas. Finally, the relatively low levels of road infrastructure and long average travel times result in high transaction costs for sales of agricultural inputs and outputs, and this limits agricultural productivity and growth. Thus, investments in road infrastructure can have a significant impact on rural and national incomes through their effects on agriculture.

Lack of detailed household and subnational data, particularly time-series data, preclude analysis of the impacts of transport infrastructure on agriculture for most of Sub-Saharan Africa. Instead, this study adopts a cross-sectional spatial approach to examine the impact of transport infrastructure on agriculture in Sub-Saharan Africa using newly developed geographic information system (GIS) data on (a) agroecological zones and crop production potentials by the food and agriculture organization (FAO) and the International Institute for Applied Systems Analysis (IIASA), (b) GIS data on crop production from the International Food Policy Research Institute (IFPRI) spatial crop allocation model (SPAM), and (c) road infrastructure based largely on United Nations Environment Programme (UNEP) data and estimated travel times (Thomas 2007). Our approach involves econometric regressions of crop production or choice of technology for each location as a function of crop production potentials (which are in turn determined by agroecology and agronomic characteristics of individual crops), travel time, and other factors. But, as discussed below, econometric estimation using this cross-section spatial data presents several challenges, including controlling for endogeneity of road placement (construction), possible omitted variables (unobserved fixed effects), and measurement errors in estimation. Moreover, these reduced-form equations of agricultural production or input across locations do not—in the context of relatively abundant supply of land—readily capture constraints on overall market demand even with the inclusion of variables that proxy availability of markets. For this reason, we place these econometric results in a broader analytical framework that explicitly incorporates demand constraints. We address three main issues. First, we analyze the impact of road connectivity on crop production and choice of technology when we control basic supply and demand factors. Second, we investigate the impact on agricultural output of investments that reduce travel time on roads of various types. Third, we provide an example of how this type of analysis could be used to construct benefit-cost ratios of alternative road investments in terms of enhanced agricultural output per dollar invested.

This paper is organized as follows. Section 1 describes the databases used and presents basic descriptive statistics. Section 2 discusses the econometric methodology. Section 3 presents results of regressions of agricultural output and choice of technology for various Sub-Saharan crops and regions. Section 4 presents results of a simulation of improvements in road quality. The final sections, 5 and 6, summarize the paper, present policy implications, and discuss possible further work.

1 Data

Three major types of spatial data are used in the analysis: agroecological zones and crop potentials as derived by FAO and IIASA, estimates of the spatial allocation of crops from the IFPRI SPAM, and various measures of economic distance constructed on the basis of estimated travel times and market size. This section presents a brief description of this data and details of the SPAM.

Agroecological zones

The agroecological zone (AEZ) methodology developed by FAO and the IIASA combines georeferenced data on land resources (climate, soil, and terrain) with a mathematical model for the calculation of potential biomass and yields per crop and management system. Land resource data include an adjustment for estimated land requirements for housing and infrastructure, based on population and population density. The FAO-IIASA model produces biomass and yield estimates for 154 different land utilization types (LUTs) comprising various rainfed and irrigated crops, and fodder and grassland land uses, each at three generic levels of inputs and management (high, intermediate, and low).[1] The resolution of the model is 0.5-degree latitude/longitude cells. Crop agronomic potential in each location is summarized in the Crop Suitability Index (SI), which is defined as: $SI = VS*0.9 + S*0.7 + MS*0.5 + NS*0.3$, where VS, S, MS, and NS denote percentages of the grid cell with attainable yields that are 80 percent or more, 60–80 percent, 40–60 percent, and 20–40 percent of maximum potential yield. SI is essentially a measure of quality adjusted land area (the adjusted share of land suitable for cultivation of a particular crop or group of crops), with a maximum value of 0.9 and a minimum value of 0.[2]

IFPRI SPAM

The IFPRI SPAM (You and others 2007b) is designed to estimate the spatial distribution of crop production in Sub-Saharan Africa. The model combines data on national and subnational crop area and production (three-year average, 1999–2001), land cover, and land suitability using a cross-entropy regression to estimate the spatial allocation of crops at a resolution of 5x5 minutes (approximately 9x9 kilometers on the equator).[3]

Specifically, the model takes as inputs (a) crop area (the total physical area cultivated at least once per year from subnational estimates, generally from official government statistics), (b) total crop land (from

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[1] For irrigated land, only high and intermediate levels of inputs are defined.

[2] For more information, consult FAO (2003, 1981); FAO, IFPRI, SAGE (2006); and Fischer and others (2001).

[3] The number of pixels per country is given in table A.1.

Africa Land Cover 2000), (c) suitable area (extracted from the FAO/IIASA global crop suitability surfaces), and (d) irrigated land area (from the global map of irrigation, Siebert and others 2001).

The model algorithm begins with an initial estimate of crop area and production by location derived from available production statistics and corresponding biophysical suitability maps. It then uses a cross-entropy regression to create a new allocation of crop area and production that satisfies a set of constraints yet minimizes the differences between the initial and final allocations. These constraints are:

- The sum of allocated crop areas/production is equal to existing statistical data.
- The actual agricultural area from the satellite image is the upper limit.
- The sum of allocated crop area cannot exceed the suitable area for the particular crop.
- The sum of allocated irrigated areas cannot exceed the area in the Africa map of irrigation.

The model produces estimates for four production systems: rain-fed/high-input, rain-fed/low-input, irrigated, and subsistence[4] for each of the following 20 crops:

- Six cereals: wheat, rice, maize, barley, millet, sorghum
- Seven pulses: potato, sweet potato and yam, cassava, plantain and banana, soybean, beans, other pulses
- Five fibers: sugarcane, sugar beets, coffee, cotton, other fibers
- Two others: groundnuts, other oil crops

In section 5, we present regression results for crop production for four crop groups: maize, cereals (wheat, rice, maize, barley, millet, and sorghum), cash crops (coffee, cotton, groundnuts), and the total of the 20 crops. In all cases, crop production is measured in U.S. dollars, using the median of the dollar price crop indices across Sub-Saharan Africa (see table A.2). Each crop or crop group is also disaggregated into three different production systems (rain-fed/high-input, rain-fed/low-input, including subsistence, and irrigated).

Transport networks and travel times

We constructed several road-connectivity measures, including distance to roads and travel time. We used UNEP road data[5] to calculate distance to the nearest type-1 (motorway/major road), type-2 (all weather/improved), and type-3 (partially improved/earth) roads.[6] For travel-time measures, we used

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[4] In our analysis presented below, we combine low-input/rain-fed and subsistence systems together, since they share similar characteristics and because estimates of the location of subsistence crop areas were generated based on the distribution of population using assumptions of low-input/rain-fed technology. See You and others (2007a, 2006).

[5] The United Nations Environment Programme (UNEP) road map was created as part of the fourth version of the Africa Population Database by Andy Nelson. The input road maps were from Digital Chart of the World (Environmental Systems Research Institute, ESRI, 1993) and Michelin Travel Publications (2004, Michelin Travel Assistance Services).

[6] Using spatial analysis tools in ESRI ArcGIS software, we calculate travel time from each point (pixel) to the nearest city of a specified size in Sub-Saharan Africa. These travel time raster data are exported to a standard-format database and then merged with the SPAM data sets for analysis. Note, however, that these estimates depend greatly

UNEP road data supplemented with national road information for Ethiopia, Uganda, and Kenya to construct separate variables for travel time to towns or cities of (a) 25,000 people or more, (b) 100,000 people or more, and (c) 500,000 people or more (Thomas 2007).[7] Total length and the estimated travel speed of each road type are shown in table A.3.

The road data are geoprocessed to create friction grids, and a one-hour delay is added in crossing country borders (see table A.8). To identify the nearest city and its population size, we used Global Rural-Urban Mapping Project (GRUMP) population data from the Center for International Earth Science Information Network (CIESIN).[8] These population counts for the year 2000 were adjusted to match UN totals. We then combined friction grids and the locations of cities with different sizes and calculated travel time to the nearest town or city of (a) 25,000 people or more, (b) 100,000 people or more, and (c) 500,000 people or more (Thomas 2007).[9]

Measures of local market size

Local market size, in addition to accessibility (travel time), may also influence crop production. There is no consensus on defining the boundary or size of a local market (or market potential measure), but a standard method is to use a distance-decay model and calculate population aggregates decayed over distance.[10] Thus, local market size, i, is calculated as:

$$\text{local market size}_i = \sum_k w_{ik} \cdot pop_k$$

where pop_k is the population aggregate in neighboring area k and

the distance weight $\mathrm{w}_{\mathrm{k,j}} = 1/(d_{k,i})^{\gamma}$ and

where $d_{k,i}$ is the Euclidean distance between k and i in kilometers and γ is the decay parameter.

The choice of the decay parameter is arbitrary. In this regard, we experimented with various measures of distance-weighted population aggregates and came up with two proxy variables: (a) a population count in its own pixel and (b) a distance-weighted population aggregate in neighboring areas (excluding its own population). We define neighboring areas as the areas within a 100-km radius. We divide these areas into six subgroups (radius between 1–2 km, 2–5 km, 5–10 km, 10–20 km, 20–50 km, and 50–100 km), as listed in table A.4. The input data from the GRUMP population counts in year 2000, at a 1-km resolution.

Roughness of terrain

To control for the endogeneity of road construction, we create a terrain-roughness variable. Specifically, we use the Shuttle Radar Topography Mission (SRTM) version 3, terrain elevation grids,

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on quality of the input geographic information system (GIS) data on road networks, which need to be updated frequently. See Murray (2007) for a description of the data.

[7] These calculations assume travel speeds of 50, 35, and 25 km/hr for type-1, type-2, and type-3 roads, respectively.

[8] Specifically, it is the Gridded Population of the World, version 3, with Urban Reallocation (GPW-UR).

[9] Details of the calculations for Mozambique are given in Dorosh and Schmidt (2008).

[10] See Deichmann (1997) for a review of the issues related to this methodology.

subtract the minimum from the maximum for each 30x30 arc second cells (approximately 1x1 km) in a pixel, and define it as the terrain roughness.

Merging of data sets

Data sets of different resolutions (grid sizes) are aggregated at the IFPRI SPAM data resolution (5x5 minutes, approximately 9x9 km on the equator), exported to standard-format data sets, and then merged with the SPAM database. In aggregation, we control for differences in land area (mainly due to oceans or lakes), such that:

$$new\_travel\_time_{SPAM_i} = \frac{\sum_{k \in SPAM_i} \left(old\_travel\_time_k \times area_k \right)}{\sum_{k \in SPAM_i} area_k}$$

where $area_k$ is land area (km^2) at a 1-km resolution from GRUMP (CIESIN). The final data set includes 42 countries, which are listed in table A.1.

2 Descriptive statistics

Crop production

Low-input/rain-fed crop systems dominate crop production in Sub-Saharan Africa. For the 42 Sub-Saharan African countries in the SPAM sample, 63 percent of the $53 billion average annual production (1999–2001) of the 20 major crops is cultivated under such systems (table 2.1). The remainder of the production is nearly evenly split between high-input/rain-fed (20 percent) and irrigated systems (16 percent).[11] For the six major cereal crops (wheat, rice, maize, barley, millet, and sorghum), the overall distribution is similar: 60 percent were under low-input/rain-fed, 25 percent under high-input/rain-fed, and the remaining 15 percent under irrigated systems. But, when we look at three major cash crops (cotton, coffee, and groundnuts), 40 percent were produced under the irrigated system, which enables the highest yields among production systems. For example, table 2.2 shows that the potential yield of cash crops in kilogram per hectare (kg/ha) under the irrigated production system is as many as 15 times higher than that under low-input/rain-fed production. A summary of each of the 20 crops is given in table A.5.[12]

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[11] Again, 20 crops are aggregated using the medians of country-level individual crop prices.

[12] See You and others (2007a) for a summary of country-level crop production.

Table 2.1 Crop production in Sub-Saharan Africa, average 1999–2001 estimates

		Share (%)		
	Crop production (mn $)	High-input/rain-fed	Low-input/rain-fed	Irrigated
Total crops (20)	52,822	20.8	63.1	16.1
Cereals (6)	12,997	25.0	59.6	15.4
Cash crops (3)	10,091	19.9	39.5	40.6

Source: Calculated from output of the IFPRI SPAM.

Table 2.2 Potential yield by production system in Sub-Saharan Africa (kg/ha)

	High-input/rain-fed	Low-input/rain-fed	Irrigated
20 crops	107.7	9.5	142.0
6 cereals	254.3	33.6	406.3
3 cash crops	107.7	9.5	142.0
Coffee	134.4	13.5	186.7
Cotton	38.4	2.7	58.0
Groundnuts	150.2	12.3	181.4

Source: IFPRI SPAM, originally from FAO/IIASA.

Travel time, population, and agricultural production

To examine the relationship between connectivity/remoteness (as measured by travel time to the nearest city of 100,000 people or more), population, and crop production in Sub-Saharan Africa, table 2.3 presents data sorted by travel-time decile.[13] Given the spatial distribution of road infrastructure and population in 2000, the average person in Sub-Saharan Africa lived 4.6 hours from a city of 100,000 people or more. The 10 percent of the population (214 million people) that lived closest to (and in) cities of 100,000 people or more, however, had an estimated travel time of less than 1.7 hours. These urban areas and their immediate surrounding areas accounted for nearly one-fourth of crop production in value terms. In contrast, only 8.4 million people (1.6 percent of the population) lived in the decile farthest in travel time from large cities, for whom the average travel time was nearly 25 hours.

Thus, not surprisingly, average travel times are inversely related to population size. On average, areas with larger populations have better road networks and therefore less travel time to nearby cities. Total crop production shows the same pattern: higher crop production is observed in the areas with larger populations and better road networks. Likewise, per capita production shows a broadly similar pattern to the first (mainly urban) decile. Thus, the average value of per capita production, which is only $58 per person in the first decile, is $139 per person for deciles 2 through 6 and falls to $113.3 per person in deciles 7 through 10 (table 2.4 and figure 2.1).[14]

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[13] Table A.6 presents this data for all deciles.

[14] Note that the value of production per capita in decile 10 ($167 per person) is actually higher than that of all other deciles, likely reflecting the very small population size of that decile and perhaps the relative dominance of noncereal crops over cereals in these most remote areas.

Table 2.3 Travel time, population, and crop production in Sub-Saharan Africa

Travel time decile	Average travel time (hrs)[1]	Total population (mns)	Total crop production (mn $)	Share of high-input / rain-fed production	Total crop production / potential
1	1.7	213.9	12,469.3	0.174	0.411
2	3.0	69.3	10,167.9	0.184	0.456
3	4.1	52.6	7,822.9	0.188	0.466
4	5.1	46.5	6,958.5	0.188	0.332
5	6.3	38.3	4,593.6	0.186	0.202
6	7.6	30.8	3,478.9	0.180	0.163
7	9.3	23.8	2,580.3	0.180	0.082
8	11.7	18.3	2,030.6	0.179	0.059
9	15.4	14.2	1,315.8	0.177	0.047
10	24.8	8.4	1,404.5	0.166	0.029
Total/average	4.6	516.1	52,822.3	0.182	0.191

Source: Own calculations.

Note: Travel time is the estimated time to the nearest city with 100,000 people or more; 10 percent of [land] area in Sub-Saharan Africa is within 1.7 hours of a city with 100,000 people or more; 40 percent of [land] area is more than 7.6 hours from a city with 100,000 people or more. Crop production is estimated using median prices (in US dollars) for each of the 20 crops.

Table 2.4 Travel time, population, and crop production in Sub-Saharan Africa

	Population		Crop production		Production per capita
Travel time	(mns)	(%)	(bn $)	(%)	($ per person)
<2.5 hrs	213.9	41.4	12.5	23.6	58.3
2.5–8.4 hrs	237.5	46.0	33	62.5	139.0
> 8.4 hrs	64.7	12.5	7.3	13.9	113.3
Average	516.1	100.0	52.8	100.0	102.3

Source: Own calculations.

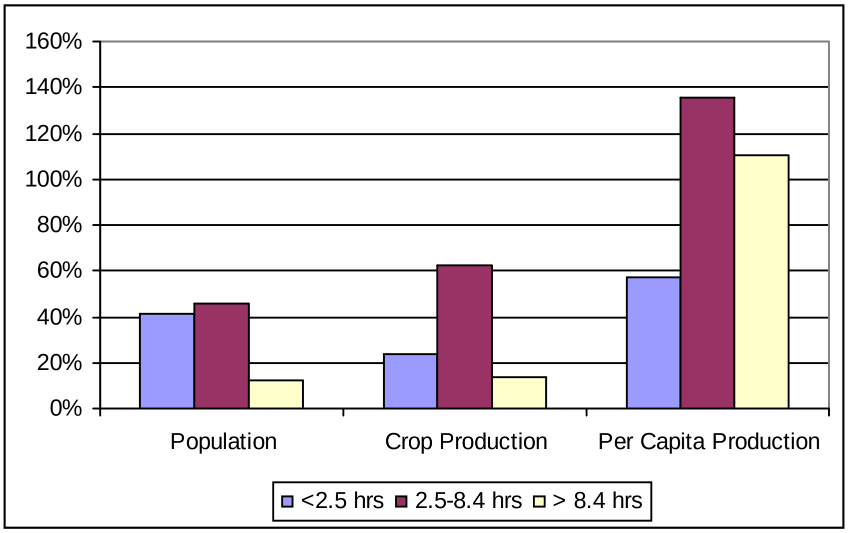
Note: Travel time (in hours) is calculated to the nearest city with 100,000 people or more.

Moreover, actual crop production as a share of potential, which averages 0.191 overall, declines monotonically from the third to the tenth travel time deciles, from 0.466 to only 0.029 (table 2.3). Note that in no case is the ratio of actual production to potential production greater than 0.466, suggesting that agronomic potential production is perhaps an unrealistically high standard. Even so, the ratio of actual to potential production in the last four travel-time deciles falls far below the maximum ratio actually achieved, suggesting that there is enormous untapped potential for expansion of agricultural production in the more remote areas of Sub-Saharan Africa. Inadequate supply of labor and insufficient demand (either for self-consumption or for sale) are probably the major factors for lower output in these remote areas.

There are, however, some differences in the impacts of road connectivity across the three crop-production systems. Farmers who adopt the high-input/rain-fed production system are likely to be more sensitive to transport costs for intermediate inputs, such as fertilizer and pesticide, than those using low-input/rain-fed technology. Therefore, we expect high-input/rain-fed production will be more concentrated in the areas of well-connected road networks. Interestingly, the pattern we obtained from the sample shows an inverted-U-shape relationship between the relative adoption of the high-input production system and travel time (table 3.3 and figure 3.2). In the areas of well-connected road networks and large populations, small-scale crop production done mainly for subsistence (and, therefore, under low-input/rain-fed production) dominates other crop-production systems. In these areas of the first to third deciles, reducing travel time actually decreases the relative share of high-input/rain-fed crop production. But, after the median travel time areas, increasing travel time discourages the adoption of high-input production. In the areas of the third and fourth deciles, the relative adoption of high-input crop production is the highest.

The intensity of land utilization for crop production generally has a similar, inverted U shape. In the areas of large populations and well-connected road networks (and, therefore, with short travel time), land use for crop production has to compete against highly productive urban land use, and increasing road networks reduces land-use intensity for crops. But increasing travel time combined with decreasing population density eventually reduces land-use intensity for crop production. In summary, the ratio of actual crop production to potential (maximum) crop production has an inverse-U-shape relationship with travel time.

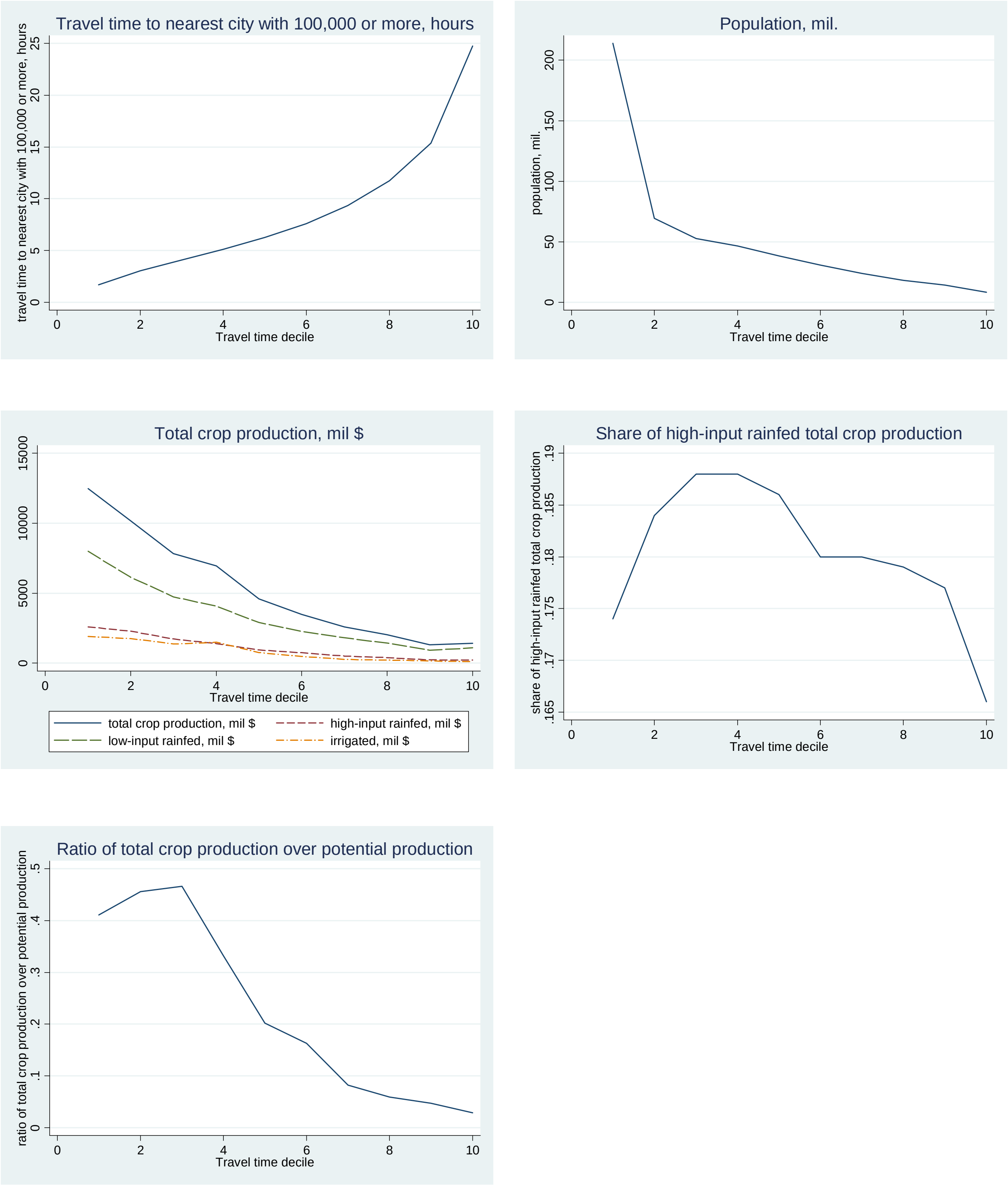
Figure 2.1 Travel time, population, and crop production in Sub-Saharan Africa



Source: Own calculations.

Note: Population and crop-production figures indicate percentages of the totals for Sub-Saharan Africa. Per capita production figures indicate percentage of the average for Sub-Saharan Africa.

Figure 2.2 Crop production and population distribution, by travel time



Source: Own calculations.

Note: Travel time deciles are based on travel time to the nearest city with 100,000 people or more.

Estimated crop-surplus regions

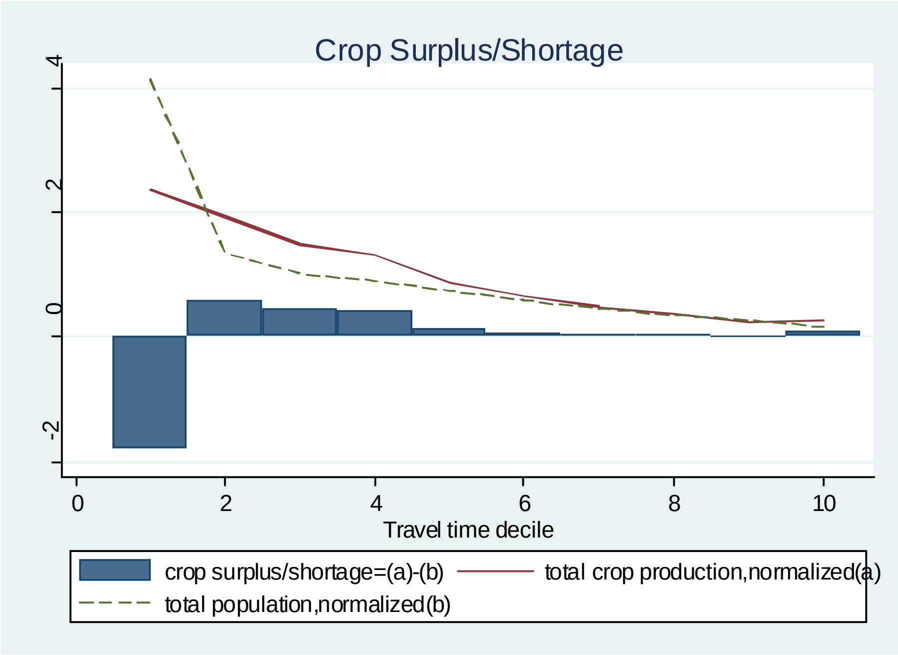
Based on the observed patterns above, we develop an indicator that gives an approximate measure of the crop surplus or deficit in each pixel. The indicator measures the gap between crop production and demand. The supply side is simple: the total crop value produced in a pixel. On the crop-demand side, we measure effective (or normative) demand, rather than observed (or supply-constrained) demand. The basic assumption is that the total crop demand in a pixel is proportional to the total population size in the pixel. To make supply and demand comparable, we normalize crop production and demand in each pixel using sample averages (Sub-Saharan African total).

$$\text{normalized crop production}_i = \frac{\text{total crop production}_i}{\text{mean of total crop production}}$$

$$\text{normalized crop demand}_i = \frac{\text{population}_i}{\text{mean of population}}$$

As crop production is the major source of rural household income, this crop balance indicator also indirectly measures rural income generation relative to population. But we do not include food imports in the analysis as in Miller (2001).[15]

Figure 2.3 Crop surplus and shortage, by travel time



Source: Own calculations.

Note: Travel time deciles are based on travel time to the nearest city with 100,000 people or more.

Figure 2.3 and table 2.5 show how crop balance varies across different travel time deciles. As travel time (to the nearest city with 100,000 people or more) increases, crop production responds by decreasing almost linearly, but crop demand (proportional to population) decreases exponentially. This pattern can be explained by agglomeration economies. Agglomeration of populations near well-connected road networks produces positive externalities, or external economies of scale, which in turn induce people to cluster more. This process creates urban centers and clustering of road networks where

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[15] Miller (2001) calculates food supply as the sum of total domestic food production and food imports. For food demand, in scenario (i) he uses the 1998 Food and Agriculture Organization Statistical Databases (FAOSTAT) national averages for daily caloric consumption and the 1998 Oak Ridge National Laboratory (ORNL) population density data, and in scenario (ii) he uses an average food consumption of 2,000 calories per day per person.

people and urban economic activities agglomerate more densely (Henderson and others 2001). But crop production may not exhibit the same magnitude of scale economies as urban activities, and clustering of crop production in response to road connectivity is limited.[16]

The first decile area shows the largest shortage of crop production, as food demand exceeds local crop production in areas close to and including large cities. This deficit is filled by surplus crop production mainly in the second to fourth decile areas. Interestingly, the large deficit in the first decile is almost cancelled out by the surplus in the next three deciles, so that, overall, the remote areas after the fifth decile (with weaker road networks and higher travel times to large cities) are generally in an autarkic situation, with local demand met by local crop production.

When these crop balances are aggregated to the country level, Ethiopia, Tanzania, Kenya, Sudan, South Africa, and Zambia show significant crop deficits, while Zimbabwe, Uganda, and Côte d'Ivoire exhibit large crop surpluses (table A.6). When we look at regional patterns, most West African countries near the Gulf of Guinea show large crop surpluses, whereas many East African countries display significant crop shortages, with the few exceptions of Malawi, Madagascar, Uganda, and Zimbabwe.

Table 2.5 Estimated crop surplus and deficit by travel time deciles

Decile (number of pixels)	Travel time (hours)[1]	(a) Crop production normalized[2]	(b) Population normalized	(a–b) Crop surplus or deficit
1 (14,762)	1.7	2.36	4.15	–1.78
2 (14,763)	3.0	1.93	1.34	0.58
3 (14,762)	4.1	1.48	1.02	0.46
4 (14,763)	5.1	1.32	0.90	0.42
5 (14,763)	6.3	0.87	0.74	0.13
6 (14,762)	7.6	0.66	0.60	0.06
7 (14,763)	9.3	0.49	0.46	0.03
8 (14,762)	11.7	0.39	0.35	0.03
9 (14,763)	15.4	0.25	0.28	–0.03
10 (14,819)	24.8	0.27	0.16	0.10

Source: Own calculations.

Note: 1. Travel time to the nearest city with 100,000 people or more, in hours.

2. 20 crops, aggregated using the medians of country-level crop prices.

Figure 2.4 maps pixel-level crop balances in Sub-Saharan Africa. We observe significant spatial variations in crop surplus and shortages even within a country. As crops need to be transported and traded from crop surplus areas to deficit areas, mapping spatial distribution of crop balances could provide important insights into potential crop trade flows and corresponding transportation and logistic demands.

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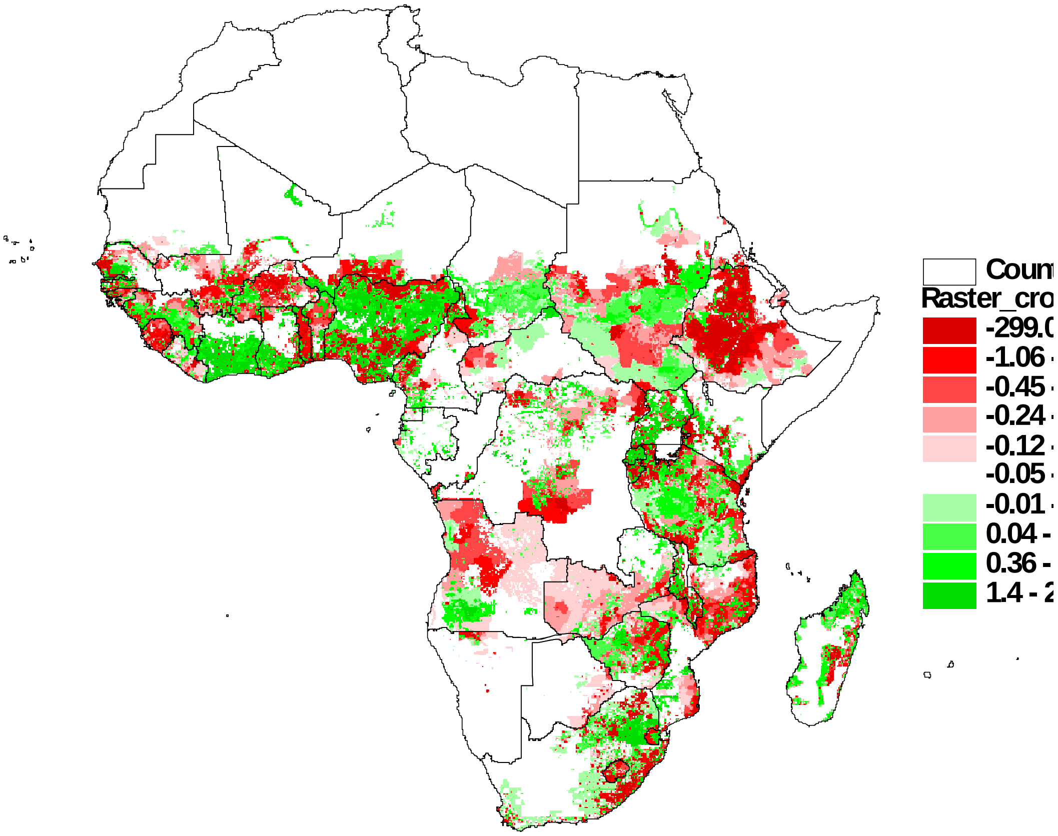
[16] Physical constraints, such as limited suitable land areas, also contribute to less clustering in crop production.

Figure 2.4 Sub-Saharan African crop balances by country and pixel



Source: Own calculations.

3 Conceptual framework and model

In assessing the implications of location and investments in transport costs on crop production and productivity in Sub-Saharan Africa, we adopt a conceptual framework in which transport investments affect both the supply and demand for crop production.

On the supply side, production of crop *j* under production system *l* in location (pixel) *i* depends on the agronomic potential p_j, under the production system *l* in location *i*, and unobserved location-specific variables (Ω_i) such as output and factor prices and available technology.

Demand for a crop produced in location *i* depends on the size of the local market surrounding location *i*, which is in turn determined by population, distribution of per capita incomes, and the trade regime (especially whether the domestic market is integrated with the international market).

The hypothesis to be tested is that better road connectivity increases crop production (or productivity) after controlling for other factors. This effect is assumed to take place through reduction in transport costs of goods and services that raise crop producers' prices (depending on the elasticity of demand as well as supply).[17] Reduced transport costs also lower producers' input costs (increasing profitability and supply) and may increase access to technology, including extension services.

There are also possible compositions of production effects, as lower transport costs result in a greater percentage reduction in the price of perishable, bulky items such as vegetables, thus increasing their relative profitability. Finally, where the transport cost reduction is sufficiently large and widespread, there are potential general equilibrium effects on rural and urban nonfarm sectors, wages, and overall incomes (Diao and others 2006).

Thus, the basic model, expressed as a reduced-form crop-production function, is:

$$\textit{Crop production}_{ijl} = f(\textit{agronomic potential}_{ijl}, \textit{local market size}_{i}, \textit{road connectivity}_{i}, \Omega)$$

Agronomic potential, or potential crop production, reflects the supply-side constraints on the quantity and quality of suitable land. It measures the maximum crop-production estimates, given suitable land size and quality, in a pixel. In estimation, we multiply the suitable land size by corresponding potential yield (of each crop and production system) in a pixel. Data for both variables are from FAO/IIASA and are used as inputs in the IFPRI SPAM.

To control for the local market size, a main determinant of crop demand, we propose two variables: population count in a pixel and the distance-weighted population aggregate in neighboring areas (up to a 100-km radius). Road connectivity is measured by the travel time to the nearest city with (a) 25,000 people or more, (b) 100,000 people or more, or (c) 500,000 people or more. We experiment with these three road-connectivity measures in turn. Finally, we add country dummies to control for (unobserved) country fixed effects.

Econometric issues

First, it is necessary to correct for bias in the regression estimates arising because the dependent variables (crop production and productivity) are left-censored data (that is, by definition, their values are never less than a certain value, in this case zero).[18] To overcome this potential bias, we estimate the equations using a Tobit (censored regression) model. In addition, we have dropped observations (pixels) that are unsuitable for agricultural production from our regression.

Second, in the basic model, one of the explanatory (right-hand-side) variables—road connectivity—can be endogenous, since it may be determined by unobserved local factors that also influence crop

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[17] The price gain to producers increases as demand becomes more elastic.

[18] A crop is produced in an area only when the climate and soil are suitable for the crop and when its production is profitable (the revenue generation from the crop production should be greater than the costs). In mathematical terms, we may express this in the crop-production function: $yi^* = \beta' xi + \varepsilon i$. We observe crop production in location i ($yi=yi^*$ if $yi^*>0$) only when it is profitable; otherwise, there is no production in that location ($yi=0$ if $yi^*<0$). Standard regression methods fail to account for the qualitative difference between limit (zero) observations and nonlimit (continuous) observations and thus produce biased parameter estimates (Greene 2003). In our data set, there are in fact many locations where production of certain crops is zero.

production. For example, a road may have been initially constructed primarily to connect a mining area to a port. There may likewise be a concentration of food production around the mining center because of the demand for food of the population working in the mining area. In this case, both crop production and road connectivity are determined by a common exogenous factor (location of a mining area).

Moreover, measurement error (poor road data quality that influence our travel-time estimates) may also lead to attenuation bias (biasing parameter estimates toward zero).

To minimize the magnitude of possible bias arising from the endogeneity of road connectivity and measurement error, we use predicted values of the road connectivity indices from instrumental variable regressions. For this first-stage regression, we use terrain roughness (difference between maximum and minimum elevations), total populations of each cell and its surrounding areas (within 100 km), population density, and the exogenous variables from the main regression as instruments. The Wald test of the exogeneity of the instrumented variables in the IV-Tobit estimation confirms the endogeneity of travel-time variables in most specifications.[19]

Combining the Tobit model and IV estimation, we use the IV-Tobit estimation, or the Tobit model with endogenous regressors, for the econometric analysis.[20]

4 Econometric estimates

The impacts of road connectivity on crop production

Table 4.1 shows the basic results of the regressions for road-connectivity impacts on total crop production under 3 production systems in all 42 Sub-Saharan African countries in the sample. All the regressors are significant with expected coefficient signs. Physical constraints (potential maximum production) and local market size have significant effects on total crop production. After controlling for these effects and (unobserved) country fixed effects, road connectivity measures and travel times to the nearest cities have significant effects on total crop production across three crop-production systems.

Two distinct patterns emerge from this analysis. First, the elasticity of crop production increases (in absolute magnitude) as we measure travel time to “larger” cities. For example, under low-input production systems, the elasticities of travel time to the nearest city with a population of 25,000, 100,000, and 500,000 are –2.3, –2.9, and –4.8, respectively. Under high-input production systems, these elasticities are –1.2, –1.6, and –1.6, respectively; and for irrigated systems, the corresponding elasticities are –1.5, –1.8 and –3.5. Thus, the regressions suggest that there is much greater concentration of production in regions surrounding large cities than in regions surrounding smaller ones. This pattern is consistent with previous findings given in table 4.1 and figure 2.3, which show significant crop shortages in the first decile areas (mainly urban centers) and large crop surpluses in the second to fourth decile areas.

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[19] In most cases, we can easily reject the null hypothesis of the exogeneity of travel-time variables.

[20] Specifically, we use Newey’s efficient two-step estimator, which is easier than the conditional maximum-likelihood estimator.

Table 4.1 The impact of road connectivity on crop production: Sub-Saharan Africa total

Equations	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dependent variable	Ln (total crop production, high-input)			Ln (total crop production, low-input/subsistence)			Ln (total crop production, irrigated)		
Estimation method	IV-Tobit	IV-Tobit	IV-Tobit	IV-Tobit	IV-Tobit	IV-Tobit	IV-Tobit	IV-Tobit	IV-Tobit
Ln (travel time to nearest 25K city)	–1.189***			–2.251***			–1.479***		
	(0.075)			(0.064)			(0.089)		
Ln (travel time to nearest 100K city)		–1.557***			–2.864***			–1.807***	
		(0.090)			(0.079)			(0.106)	
Ln (travel time to nearest 500K city)			–1.593***			–4.814***			–3.508***
			(0.159)			(0.153)			(0.207)
Ln (potential production high-input)	1.193***	1.197***	1.194***						
	(0.010)	(0.010)	(0.010)						
Ln (potential production low-input)				0.257***	0.247***	0.283***			
				(0.008)	(0.008)	(0.008)			
Ln (potential production irrigated)							0.410***	0.417***	0.402***
							(0.008)	(0.008)	(0.009)
Ln (population)	0.115***	0.119***	0.132***	0.159***	0.163***	0.192***	0.020**	0.031***	0.045***
	(0.007)	(0.007)	(0.006)	(0.005)	(0.006)	(0.006)	(0.008)	(0.008)	(0.008)
Ln (neighbor population aggregate)	0.249***	0.104***	0.180***	–0.093***	–0.328***	–0.728***	–0.308***	–0.453***	–0.855***
	(0.029)	(0.035)	(0.050)	(0.025)	(0.030)	(0.046)	(0.035)	(0.042)	(0.064)
Country dummies	yes	yes	yes	yes	yes	yes	yes	yes	yes
Constant	yes	yes	yes	yes	yes	yes	yes	yes	yes
Wald test of exogeneity	235.50	252.75	87.31	1,146.17	1,286.72	1,188.36	343.29	378.44	469.19
(p-value)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Left-censored observations	25,793	25,793	25,793	10,990	10,990	10,990	34,780	34,780	34,780
Uncensored observations	100,189	100,189	100,189	116,677	116,677	116,677	71,742	71,742	71,742
Total observations	125,982	125,982	125,982	127,667	127,667	127,667	106,522	106,522	106,522

Source: Own calculations.

Note: 1. Ln (x) refers to the natural logarithm of variable x.

2. Total crop production (value) is the 20-crop aggregate using the medians of African country-level crop prices.

3. Standard errors in parentheses.

4. * significant at 10 percent; ** significant at 5 percent; *** significant at 1 percent.

The second broad pattern observable in these regressions is that the elasticities of travel time on crop production under the low-input crop-production system are almost two times higher than those under high-input and irrigated systems. For example, a 1 percent reduction in travel time to the nearest city with 100,000 people or more increases low-input crop production by 2.9 percent, but results in only a 1.6 percent increase in high-input crop production and a 1.8 percent increase in irrigated crop production. For travel time to the nearest city with 500,000 people or more, the elasticity on low-input production is –4.8, compared to –1.6 for high-input and –3.5 for irrigated production. For travel time to the nearest city with 25,000 people or more, the same coefficients are –2.3, –1.2, and –1.5, respectively. As discussed below, the implied own-price elasticities of supply from these regressions are extremely high, suggesting that these travel-time elasticities are capturing a long-term relationship involving the location of population centers (markets) and location of crop output, particularly for low-input technologies. For high-input/rain-fed and irrigated crop-production systems, which often involve large farms (for example, as in Sudan), location of production may be driven more by the availability of irrigation facilities and water than by self-consumption or proximity to final markets in urban centers.

Table 4.2 tests the robustness of the results across different crop categories: (a) six cereal crops of wheat, rice, maize, barley, millet, and sorghum and (b) maize (the most commonly produced crop in Africa). Overall, we observe the same patterns as in the regressions for all crops combined. Low-input/rain-fed crop production has the highest elasticity of road connectivity on crop production. Better road connection to larger cities has larger impacts on crop production.

Table 4.2 Impacts of road connectivity on the production of different crops: Sub-Saharan Africa total

Elasticity of travel time to nearest city with 100,000 people	(1) High-input crop production	(2) Low-input and subsistence crop production	(3) Irrigated crop production	(4) All combined
Estimation method	IV–Tobit	IV–Tobit	IV–Tobit	IV–Tobit
Total crops	–1.557***	–2.864***	–1.807***	–2.396***
	(0.090)	(0.079)	(0.106)	(0.059)
Cereals	—	–1.975***	–2.488***	–2.003***
	—	(0.099)	(0.135)	(0.087)
Cash crops	–3.649***	–3.933***	1.862***	–3.132***
	(0.033)	(0.110)	(0.136)	(0.104)
Maize	—	–2.829***	–1.746***	–3.331***
	—	(0.149)	(0.156)	(0.146)

Source: Own calculations.

Note:

1. Total crops include 20 crops; cereals (6) are wheat, rice, maize, barley, millet, and sorghum; cash crops (3) are coffee, cotton, and groundnuts. All crops are aggregated using the medians of African country-level crop prices (US$).
2. Standard errors in parentheses.
3. * significant at 10 percent; ** significant at 5 percent; *** significant at 1 percent.

Road connectivity and adoption of high-input/high-yield technology: Sub-Saharan Africa total

In this section, we examine the impacts of road connectivity on the adoption of high-input/high-yield crop-production technology. We measure the adoption of high-input technology by the share of high-input/rain-fed production in total crop production, again for the 20-crop aggregate. For a measure of high-yield crop-production technology, we choose high-input/rain-fed crop production rather than the irrigated system, which is mainly constrained by external factors (irrigation infrastructure) that farmers cannot control.

For control variables, we use the same group of regressors as in the previous section. But to control for physical constraints, we use the share of high-input potential (maximum) production in total potential production in each pixel. The total potential production (value) is the sum of potential production (potential yields multiplied by suitable areas) across the three production systems in a pixel.

The results in table 4.3 are consistent with our prior result. Longer travel time discourages the adoption of high-input/high-yield crop-production technology more than other production systems. Better road connectivity makes high-input production more profitable and therefore increases its share of production. This shift toward high-input production systems is driven through both direct and indirect channels. In the direct channel, roads increase crop production by shifting outward both the crop demand curve (through access to a larger market) and the crop supply curve (through better access to intermediate inputs and new technology). In the indirect channel, roads facilitate the adoption of high-input/high-yield crop production and therefore increase crop production by replacing low-input/low-yield crop production.

Table 4.3 Impacts of road connectivity on the adoption of high-input crop production system: Sub-Saharan Africa total

Equations	(10)	(11)	(12)
Dependent variable	Share of high-input crop production in total crop production		
Estimation method	IV–Tobit	IV–Tobit	IV–Tobit
Ln (travel time to nearest 25K city)	–0.020***		
	(0.005)		
Ln (travel time to nearest 100K city)		–0.027***	
		(0.006)	
Ln (travel time to nearest 500K city)			–0.089***
			(0.011)
Share of high-input potential production in total potential production of all crops	0.149***	0.150***	0.151***
	(0.004)	(0.004)	(0.004)
Ln (population)	–0.001*	–0.001	–0.000
	(0.000)	(0.000)	(0.000)
Ln (neighbor population aggregate)	0.016***	0.013***	–0.005
	(0.002)	(0.002)	(0.003)
Country dummies	yes	yes	yes
Constant	yes	yes	yes
Wald test of exogeneity	25.25	25.64	71.77
(p-value)	0.000	0.000	0.000
Left-censored observations	17,596	17,596	17,596
Uncensored observations	83,129	83,129	83,129
Total observations	100,725	100,725	100,725

Source: Own calculations.

Note: Total crop production (value) is 20-crop aggregate using the medians of African country-level crop prices. Standard errors in parentheses.

* significant at 10 percent; ** significant at 5 percent; *** significant at 1 percent.

Table 4.3 also confirms that the impacts of road connectivity on the adoption of high-input/high-yield crop production are consistent across the different measures of travel time—to the nearest city with a population of 25,000, 100,000, and 500,000 or more. Interestingly, the impact is higher as we consider road connectivity to more populous cities. The semielasticity on the share of high-input crop production is –0.09, –0.03, and –0.02 for travel time to the nearest city with a population of 500,000, 100,000, and 25,000 or more, respectively.

Comparing East and West Africa

The above regressions for all of Sub-Saharan Africa include countries with vast differences in agroecological conditions, infrastructure, and crops. Although these regressions include country dummies that are designed to capture fixed effects at the country level, we also run regressions on more homogeneous sets of countries, namely five coastal West African countries of the humid and subhumid tropics where root crops and cereals dominate food crop-production systems (Nigeria, Benin, Togo, Ghana, and Côte d'Ivoire) and seven large countries of East and southern Africa (Kenya, Uganda, Tanzania, Zambia, Malawi, Mozambique, and South Africa) where maize is the major staple.

On average, the East African region has lower population density, smaller local markets (based on the market definition in the previous sections), and lower road connectivity (table A.7). For example, the average population density in East Africa is just 43 percent of that in West Africa; the average population in a pixel, 42 percent; and the distance-weighted population aggregate, 40 percent. Interestingly, the average travel time to the nearest city with 25,000 people or more in East Africa is 242 percent of that in West Africa; of 100,000 or more, 224 percent; and of 500,000 or more, 221 percent. This large difference in travel time comes from type-2 (all-weather/improved) and type-3 (earth/partially improved) road differences. The average straight line distance to type-1 (motorway/major) roads in East Africa is similar to that in West Africa (95 percent), but the average distances to type-2 and type-3 roads in East Africa are 175 percent and 190 percent of those in West Africa, respectively.

The difference between East and West Africa is more distinct when we compare the average total crop production per pixel in the two regions. First, there is no large difference in terms of average suitable areas and potential (maximum) production in a pixel. The average suitable area in East Africa is 93 percent of that in West Africa, and the average potential production is about 88 percent. But the average crop production per pixel in East Africa is just 30 percent of that in West Africa. The average high-input/rain-fed crop production in East Africa is 35 of that in West Africa; low-input/rain-fed, 31 percent; and irrigated, 15 percent.

Given these distinct agrodemographic differences between East and West Africa, it is not surprising that road connectivity has different impacts in the two regions. In East Africa (table 4.4), we observe basically the same patterns as for total Sub-Saharan Africa (table 4.1). Longer travel time decreases total crop production. This pattern is consistent across different travel-time measures and different production systems. Again, travel time to a larger city gives higher crop-production elasticity, and the elasticity is the highest under the low–input/rain-fed production system. It is worthwhile to note that in all specifications, the elasticities in East Africa are lower than those in the sum of Sub-Saharan African countries. Similarly, the elasticities from regressions for various crop subgroups for East Africa (table 4.5) are generally lower than those for all Sub-Saharan Africa (table 4.2).

Table 4.4 The impacts of road connectivity on crop production: East Africa

Equations	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dependent variable	Ln (total crop production, high-input)			Ln (total crop production, low-input/subsistence)			Ln (total crop production, irrigated)		
Estimation method	IV–Tobit	IV–Tobit	IV–Tobit	IV–Tobit	IV–Tobit	IV–Tobit	IV–Tobit	IV–Tobit	IV–Tobit
Ln (travel time to nearest 25K city)	–0.162			–1.265***			–0.781***		
	(0.112)			(0.113)			(0.104)		
Ln (travel time to nearest 100K city)		–0.396***			–1.818***			–1.030***	
		(0.146)			(0.152)			(0.136)	
Ln (travel time to nearest 500K city)			–0.458			–3.946***			–2.175***
			(0.311)			(0.354)			(0.302)
Ln (potential production high-input)	1.137***	1.141***	1.139***						
	(0.020)	(0.020)	(0.020)						
Ln (potential production low-input)				0.695***	0.669***	0.695***			
				(0.023)	(0.023)	(0.024)			
Ln (potential production irrigated)							0.618***	0.629***	0.613***
							(0.013)	(0.013)	(0.014)
Ln (population)	0.169***	0.162***	0.165***	0.219***	0.201***	0.173***	0.135***	0.129***	0.118***
	(0.012)	(0.012)	(0.013)	(0.012)	(0.013)	(0.015)	(0.012)	(0.012)	(0.013)
Ln (neighbor population aggregate)	0.475***	0.399***	0.410***	0.306***	0.160***	–0.235***	–0.026	–0.105*	–0.362***
	(0.048)	(0.056)	(0.087)	(0.046)	(0.054)	(0.090)	(0.045)	(0.054)	(0.089)
Country dummies	yes	yes	yes	yes	yes	yes	yes	yes	yes
Constant	yes	yes	yes	yes	yes	yes	yes	yes	yes
Wald test of exogeneity	0.32	3.33	0.41	109.36	146.81	145.59	33.82	49.90	93.96
(p-value)	0.573	0.068	0.523	0.000	0.000	0.000	0.000	0.000	0.000
Left-censored observations	8,114	8,114	8,114	6,757	6,757	6,757	7,719	7,719	7,719
Uncensored observations	27,239	27,239	27,239	30,229	30,229	30,229	23,167	23,167	23,167
Total observations	35,353	35,353	35,353	36,986	36,986	36,986	30,886	30,886	30,886

Source: Own calculations.

Note: East Africa includes the following seven countries: Kenya, Uganda, Tanzania, Zambia, Malawi, Mozambique, and South Africa. Total crop production (value) is 20-crop aggregate using the medians of African country-level crop prices. Standard errors in parentheses.

* significant at 10 percent; ** significant at 5 percent; *** significant at 1 percent.

As for all Sub-Saharan Africa, reducing travel time significantly increases the adoption of high-input/high-yield technology in East Africa (table 4.6). The impacts are greater when roads are connected to larger cities. The semielasticity on share of high-input crop production is -0.07, -0.02, and -0.01 for travel time to the nearest city with a population of 500,000, 100,000, and 25,000 or more, respectively.

Table 4.5 Impacts of road connectivity on the production of different crops: East Africa

	(1)	(2)	(3)	(4)
Elasticity of travel time to nearest city with 100,000 people	High-input crop production	Low-input and subsistence crop production	Irrigated crop production	All combined
Estimation method	IV-Tobit	IV-Tobit	IV-Tobit	IV-Tobit
Total crops	–0.396***	–1.818***	–1.030***	–1.691***
	(0.146)	(0.152)	(0.136)	(0.086)
Cereals	–0.419**	–0.483***	–1.836***	–1.764***
	(0.185)	(0.162)	(0.198)	(0.130)
Cash crops	—	–1.824***	–1.043***	–1.219***
	—	(0.190)	(0.164)	(0.146)
Maize	1.939***	1.175***	–0.808***	–0.777***
	(0.406)	(0.326)	(0.212)	(0.222)

Source: Own calculations.

Note: East Africa includes the following seven countries: Kenya, Uganda, Tanzania, Zambia, Malawi, Mozambique, and South Africa. Total crops include 20 crops; cereals (6) are wheat, rice, maize, barley, millet, and sorghum; cash crops (3) are coffee, cotton, and groundnuts. All crops are aggregated using the medians of African country-level crop prices (US$). Standard errors in parentheses.

* significant at 10 percent; ** significant at 5 percent; *** significant at 1 percent.

The regression results for West Africa (table 4.7), however, show markedly different patterns. First, the coefficient estimates of travel time under high-input/rain-fed systems are positive, counter to our expectations. Second, the coefficient estimates of travel time under low-input/rain-fed systems are negative, as expected, but the coefficient is much smaller than that of East Africa. As in East Africa and all Sub-Saharan Africa, travel-time measures have similar elasticities across different travel-time measures: the coefficient estimates of travel time to the nearest city with a population of 25,000, 100,000, and 500,000 and more are -0.9, -1.1, and -1.0, respectively. The impacts of road connectivity on irrigated crop production in West Africa are of similar magnitude, but the impacts of road connectivity on the high-input/high-yield technology adoption in West Africa are insignificant (table 4.8).

One possible explanation for these differences across regions is that road connectivity may show decreasing marginal productivity in crop production: the more densely roads are connected, the smaller the marginal benefits. Since East Africa has less road infrastructure, the (marginal) impacts of new road construction (on crop production) can be higher than those in West Africa, which already has a relatively well-connected road network.

Table 4.6 Impacts of road connectivity on the adoption of high-input crop production system: East Africa

Equation	(1)	(2)	(3)
Dependent variable	Share of high-input crop production in total crop production		
Estimation method	IV–Tobit	IV–Tobit	IV–Tobit
Ln (travel time to nearest 25K city)	–0.012**		
	(0.006)		
Ln (travel time to nearest 100K city)		–0.019**	
		(0.008)	
Ln (travel time to nearest 500K city)			–0.067***
			(0.016)
Share of high-input potential production in total potential production of all crops	0.269***	0.268***	0.267***
	(0.008)	(0.008)	(0.008)
Ln (population)	–0.005***	–0.005***	–0.006***
	(0.001)	(0.001)	(0.001)
Ln (neighbor population aggregate)	0.012***	0.009***	–0.003
	(0.002)	(0.003)	(0.005)
Country dummies	yes	yes	yes
Constant	yes	yes	yes
Wald test of exogeneity	1.83	0.95	3.37
(p-value)	0.176	0.330	0.067
Left-censored observations	5,662	5,662	5,662
Uncensored observations	24,289	24,289	24,289
Total observations	29,951	29,951	29,951

Source: Own calculations.

Note: East Africa includes the following seven countries: Kenya, Uganda, Tanzania, Zambia, Malawi, Mozambique, and South Africa. Total crop production (value) is 20-crop aggregate using the medians of African country-level crop prices. Standard errors in parentheses.

* significant at 10 percent; ** significant at 5 percent; *** significant at 1 percent.

Table 4.7 Impacts of road connectivity on crop production: West Africa

Equations	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dependent variable	Ln (total crop production, high-input)			Ln (total crop production, low-input/subsistence)			Ln (total crop production, irrigated)		
Estimation method	IV–Tobit	IV–Tobit	IV–Tobit	IV–Tobit	IV–Tobit	IV–Tobit	IV–Tobit	IV–Tobit	IV–Tobit
Ln (travel time to nearest 25K city)	0.700***			–0.921***			–0.693***		
	(0.182)			(0.116)			(0.219)		
Ln (travel time to nearest 100K city)		0.463**			–1.102***			–0.573**	
		(0.213)			(0.136)			(0.278)	
Ln (travel time to nearest 500K city)			4.056***			–1.033***			–1.952***
			(0.351)			(0.199)			(0.422)
Ln (potential production high-input)	1.725***	1.729***	1.578***						
	(0.032)	(0.032)	(0.038)						
Ln (potential production low-input)				0.420***	0.406***	0.440***			
				(0.018)	(0.018)	(0.019)			
Ln (potential production irrigated)							0.069***	0.068***	0.068***
							(0.021)	(0.021)	(0.022)
Ln (population)	0.271***	0.242***	0.217***	–0.009	0.002	0.063***	–0.158***	–0.132***	–0.107***
	(0.029)	(0.028)	(0.028)	(0.018)	(0.018)	(0.016)	(0.035)	(0.035)	(0.028)
Ln (neighbor population aggregate)	0.340***	0.338***	1.846***	0.793***	0.645***	0.566***	0.263***	0.231**	–0.375**
	(0.061)	(0.080)	(0.152)	(0.039)	(0.052)	(0.085)	(0.065)	(0.096)	(0.175)
Country dummies	yes	yes	yes	yes	yes	yes	yes	yes	yes
Constant	yes	yes	yes	yes	yes	yes	yes	yes	yes
Wald test of exogeneity	18.21	1.90	171.60	44.17	47.90	14.26	9.61	4.64	23.81
(p-value)	0.000	0.168	0.000	0.000	0.000	0.000	0.002	0.031	0.000
Left-censored observations	1,831	1,831	1,831	104	104	104	3,427	3,427	3,427
Uncensored observations	13,730	13,730	13,730	15,446	15,446	15,446	9,709	9,709	9,709
Total observations	15,561	15,561	15,561	15,550	15,550	15,550	13,136	13,136	13,136

Source: Own calculations.

Note: West Africa includes five countries: Nigeria, Benin, Togo, Ghana, and Côte d'Ivoire. Total crop production (value) is 20-crop aggregate using the medians of African country-level crop prices. Standard errors in parentheses.

* significant at 10 percent; ** significant at 5 percent; *** significant at 1 percent.

Table 4.8 Impacts of road connectivity on the adoption of high-input crop-production systems: West Africa

Equations	(10)	(11)	(12)
Dependent variable	Share of high-input crop production in total crop production		
Estimation method	IV–Tobit	IV–Tobit	IV–Tobit
Ln (travel time to nearest 25K city)	0.013		
	(0.010)		
Ln (travel time to nearest 100K city)		0.012	
		(0.013)	
Ln (travel time to nearest 500K city)			0.040*
			(0.021)
Share of high-input potential production in total potential production of all crops	0.072***	0.073***	0.067***
	(0.008)	(0.008)	(0.009)
Ln (population)	0.006***	0.006***	0.005***
	(0.002)	(0.002)	(0.001)
Ln (neighbor population aggregate)	0.013***	0.014***	0.026***
	(0.003)	(0.004)	(0.009)
Country dummies	yes	yes	yes
Constant	yes	yes	yes
Wald test of exogeneity	0.16	0.99	0.03
(p-value)	0.688	0.320	0.852
Left-censored observations	1,248	1,248	1,248
Uncensored observations	11,875	11,875	11,875
Total observations	13,123	13,123	13,123

Source: Own calculations.

Note: West Africa includes five countries: Nigeria, Benin, Togo, Ghana, and Côte d'Ivoire. Total crop production (value) is the 20-crop aggregate using the medians of African country-level crop prices. Standard errors in parentheses.

* significant at 10 percent; ** significant at 5 percent; *** significant at 1 percent.

5 Interpretation of results and implications for spatial investment

The coefficients of the variables for travel time to the nearest city would seem to imply a very large potential response of agricultural production to infrastructure investments and policy changes that reduce travel times. For example, if marketing margins account for 50 percent of the urban price (for example, 100 shillings of a 200-shilling urban consumer price) and if 80 percent (80 shillings) of the marketing costs are due to factors that are proportional to travel time, then a 10 percent reduction in travel time would reduce the marketing margin by 8 percent (8 shillings in this example). If consumer prices are unchanged (due to a perfectly price-elastic demand), then producers reap the entire benefit of the lower transport costs and producer prices rise by 8 percent (from 100 to 108 shillings).

Assuming an elasticity of supply of 0.3, production in this hypothetical scenario would increase by 2.3 percent, and the elasticity of production with respect to travel time would be 0.023/–0.10 = –0.23 (table 5.1). But if the product faces demand constraints (simulated using an own-price elasticity of demand of –0.4), the urban price falls by 3.6 percent and the rural price increases by only 0.8 percent. In this scenario, production rises by only 0.2 percent, so that the elasticity of production with respect to travel time is –0.02.

Table 5.1 Travel-time elasticities with endogenous market price effects

Own-price elasticity of supply
Own-price elasticity of demand
Urban price (% change)
Rural price (% change)
Production (% change)
Travel time (% change)
Elasticity of supply with respect to travel time

Source: Own calculations.
Note: Calculations assume that initially marketing margins account for 50 percent of the urban price and that 80 percent of the marketing margins are due to factors th

Both of these travel-time elasticities are significantly below the estimates for various crops for all Sub-Saharan Africa or East Africa. The estimated travel time elasticities in Sub-Saharan Africa (all cropping systems) are –2.0 for the six-cereal aggregates and –3.3 for maize (table 4.2); the corresponding elasticites for East Africa are smaller in absolute magnitude (–1.8 and –0.8, respectively, table 4.5), but still much larger than the estimates using an elasticity of supply with respect to price of 0.3. To approximate even the relative small magnitude of the travel time elasticity for maize in East Africa (–

0.78, table 4.5) requires a very high own-price elasticity of supply of 0.8 and perfectly elastic demand (–0.63, table 5.1).

The regression results for choice of technology may give a truer picture of realistic short- to medium-term elasticities of production relative to reductions in travel time, one that does not implicitly involve increases in area cultivated (which might require movements of people or reductions in fallow times). The regressions on the share of high-input technology suggest more modest estimates of the elasticity of supply. For example, in East Africa, the coefficients of -0.019 on the logarithm of travel time to the nearest city with 100,000 people or more (table 4.6), suggests that a 10 percent reduction in travel time leads to a 0.19 percent increase in the share of high-input crop production out of total crop production. Assuming that new technology leads to a 50 percent increase in yields, production would increase by 0.1 percent. The Elasticity of supply with respect to travel time would be 0.001/–0.10 or –0.01, within the range of travel-time elasticities implied for an overall supply elasticity of 0.3 and alternative elasticities of demand (as seen in table 5.1).

Note, though, that the regression coefficients of the variables for travel time to nearest cities do not reflect elasticities of the supply or technology adoption of farmers, but elasticities of supply of locations, which in general are not 100 percent covered with crops, and reallocation of crop production across locations. These large travel-time elasticities capture a long-term relationship involving the location of population centers (markets) and the location of crop output, in which marketing constraints (that is, demand constraints) are implicit and important. Indeed, in the absence of a marketing constraint, very large elasticities of supply from investment in roads that open up new areas of production are possible (for example, consider the “vent for surplus” models of development where introduction of new export crops, in part made possible by investments and the opening up of the marketing chain, allowed massive expansion of cocoa and coffee production in West Africa). In the long run, crop production can readily be increased in many regions through increases in area cultivated.

But aggregate marketing constraints are extremely important for African agricultural products, since demand for food crops is price inelastic. With abundant suitable area for production, but facing a limited market, areas closer to markets do have a sizeable advantage as possible sites for production than do distant areas. When reductions in travel time bring large additional supplies into the market, market prices are likely to fall, dampening the incentives for production and possibly resulting in a reduction in output in areas for which travel time did not decrease. Thus, the aggregate supply response (across all regions) is likely to be less than implied by the results for individual locations. The econometric results for individual locations cannot simply be aggregated to derive elasticities of supply for wider regions.[21]

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[21] There are other reasons why the estimated production/travel-time elasticities may overstate the supply response. Because much of production is consumption, location of production and population tend to be spatially correlated, even though in the short run there is no direct causality between travel times and production. Moreover, in the short run, other constraints on production may be binding, including price distortions arising from trade and other country-level policies and insufficient availability of labor (especially during peak labor demand seasons), fertilizer, and credit.

Implications of investment: corridors versus rural roads in Mozambique

The above approach can be used to estimate the effects of alternative road infrastructure investments on agricultural production in Mozambique, a country with one of the most detailed road infrastructure spatial data sets in Sub-Saharan Africa. Rather than using the estimated parameters from East Africa or all of Sub-Saharan Africa, we conduct a separate regression analysis for Mozambique and then use the parameters to estimate the impact on agricultural productivity due to changes in travel time brought about by alternative road investments.[22]

The regression results indicate considerably greater sensitivity of production to differences in travel times in Mozambique than in East Africa overall. For example, the elasticity of total crop production with respect to travel time to cities with 100,000 people or more in East Africa overall is - 1.7 (and -0.8 for maize). For Mozambique, the elasiticity of total crop production with respect to travel time to cities of 50,000 or more is -2.8 for all crops (-1.6 for maize) (see tables 5.2 and 5.3).[23]

We use these parameters to analyze two different scenarios: (a) an investment in the five major international corridor roads in northern Mozambique and (b) in addition to the investment in corridors, the upgrading of all existing rural and feeder road networks to gravel, good-condition surfaces, raising speed attainable on these roads to 60 km/hr.

Using the estimated regression coefficients and the simulated changes in travel times to cities of 50,000 people or more per pixel, improvements in the national corridor raise total crop production by 24 percent and maize production by 33 percent (table 5.4). The investments in rural feeder roads in scenario 2 raise national crop production by a further 131 percent and maize production by a further 146 percent. These simulated production gains are extremely high, reflecting (a) the huge potential for increased production (as reflected in the difference between actual and potential production); (b) the reduced-form estimation procedure used, which provides measures of the elasticity of crop-supply locations (including reallocation of crop production across locations); and (c) the underlying assumption of completely price-elastic demand (that is, that expansions in crop production and sales do not lead to a fall in crop prices). This latter assumption is particularly unrealistic for domestic staple food crops, although a high elasticity may be appropriate for some exported agricultural products. Nonetheless, this analysis, done for more microscale investments where increases in production would not greatly affect the total market supply, could suggest the potential gains of alternative road investments on agricultural productivity and farm incomes.

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[22] Note that because large-scale flooding severely damaged crops in Mozambique, the IFPRI SPAM used regional production figures from 2006 instead of 2000 as an input into the calculation of spatial crop allocations.

[23] We use a smaller city-size cutoff (50,000 as opposed to 100,000) for Mozambique to reflect cities in which major wholesale markets are located. Consistent data on cities of 50,000 to 100,000 are not available for all of Sub-Saharan Africa.

Table 5.2 Impacts of road connectivity on crop production: Mozambique

Equations	(1)	(2)	(3)	(4)
Dependent variable	Ln (total crop production, high-input)	Ln (total crop production, low-input/subsistence)	Ln (total crop production, irrigated)	Share of high-input crop production in total crop production
Estimation method	IV-Tobit	IV-Tobit	IV-Tobit	IV-Tobit
Ln (travel time to nearest 50K city)	–2.269***	–2.728***	–2.147***	0.009
	(0.191)	(0.181)	(0.253)	(0.008)
Ln (potential production, high-input)	0.323***			
	(0.049)			
Ln (potential production, low-input)		–0.240***		
		(0.055)		
Ln (potential production, irrigated)			0.440***	
			(0.037)	
Share of high-input potential production in total potential production of all crops				0.035***
				(0.013)
Ln (population)	0.202***	–0.085**	0.242***	0.017***
	(0.044)	(0.042)	(0.055)	(0.002)
Ln (neighbor population, aggregate)	–0.525***	–0.442***	0.058	–0.007*
	(0.084)	(0.079)	(0.115)	(0.003)
Constant	yes	yes	yes	yes
Wald test of exogeneity	152.85	200.43	18.10	0.66
(p-value)	0.000	0.000	0.000	0.418
Left-censored observations	839	440	1,955	399
Uncensored observations	5,449	5,864	3,867	5,057
Total observations	6,288	6,304	5,822	5,456

Source: Own calculations.

Note: Total crop production (value) is a 20-crop aggregate using the medians of African country-level crop prices. Standard errors in parentheses.

* significant at 10 percent; ** significant at 5 percent; *** significant at 1 percent.

The benefits of improved road networks, however, extend past simply increasing agricultural production. These investments also spur rural nonfarm activity and perhaps, more importantly, reduce rural remoteness, increasing access of households to health, education, and other opportunities. In this case, the investment in the main corridor roads significantly reduces travel time between cities on the corridors but does not greatly affect access to markets by northern Mozambican households (table 5.5 and figure 5.1).[24] Rural remoteness in northern Mozambique (defined as greater than 5 hours travel time to a city of at least 50,000 people) is dramatically reduced, though, in the second scenario (upgrading all existing roads to gravel, good-condition surfaces). This investment would reduce the number of people in northern Mozambique living in remote areas from the current 3.5 million to 0.8 million.

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[24] For details of the calculations, see Dorosh and Schmidt (2008).

Table 5.3 Impacts of road connectivity on the production of different crops: Mozambique

	(1)	(2)	(3)	(4)
Elasticity of travel time to nearest city with 50,000 people	High-input crop production	Low-input and subsistence crop production	Irrigated crop production	All combined
Estimation method	IV–Tobit	IV–Tobit	IV–Tobit	IV–Tobit
Total crops	–2.269***	–2.728***	–2.147***	–2.762***
	(0.191)	(0.181)	(0.253)	(0.185)
Cereals	–2.456***	–2.262***	–1.629***	–2.062***
	(0.179)	(0.198)	(0.220)	(0.174)
Cash crops	–2.916***	–2.341***	–	–2.531***
	(0.611)	(0.244)	–	(0.270)
Maize	–	–2.527***	–1.042***	–1.552***
	–	(0.354)	(0.205)	(0.203)

Source: Own calculations.

Note: Total crops include 20 crops; cereals (6) are wheat, rice, maize, barley, millet, and sorghum; cash crops (3) are coffee, cotton, and groundnuts. All crops are aggregated using the medians of African country-level crop prices (US$). Standard errors in parentheses.

* significant at 10 percent; ** significant at 5 percent; *** significant at 1 percent.

Table 5.4 Simulated impacts of road improvement on crop production: Mozambique

	(a) Baseline (mn $)	(b) Scenario 1: Improving northern corridors to 80km/hr (mn $)	(c) Scenario 2: Improving all rural roads to 60km/hr (mn $)	(b) vs (a) % change	(c) vs (a) % change
Total crops					
All systems	1,506	1,869	3,486	24	131
High-input	169	204	356	20	110
Low-input and subsistence	1,246	1,549	2,896	24	132
Irrigated	91	104	176	15	95
Cereals	338	441	886	31	162
Cash crops	266	364	708	37	167
Maize	222	295	546	33	146

Source: Own calculations.

Note:

1. Baseline values are computed from the estimation results of tables 5.2 and 5.3. Specifically, $\sum_i \hat{y}_i = \sum_i \exp\left(\ln X_i \cdot \hat{\beta}\right)$. We select only statistically significant parameter estimates in computation. The fitted values are then normalized to make the national total the same as the actual, such that $baseline = \sum_i \omega \hat{y}_i,\ \omega \equiv \sum_i y_i / \sum_i \hat{y}_i$.

2. Scenario 1 and 2 values are computed in the same way as the baseline after substituting corresponding improved travel times in each pixel.

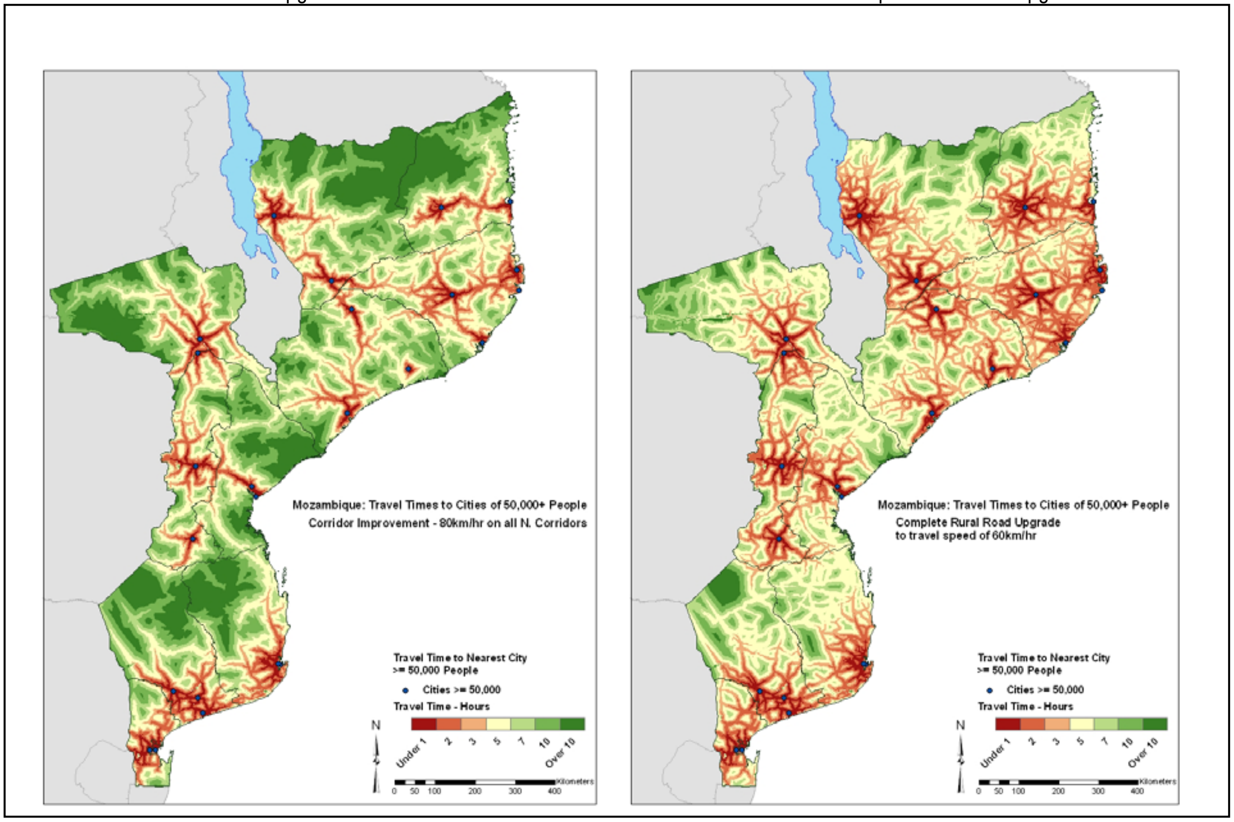
Table 5.5 Estimated costs of road network improvements in Mozambique

	Additional improved roads (kms)	Total population north remote	(a) Marginal cost (mn $)	(b) Change in remoteness (mn people)	(c) = (b)/(a) ('000 people per mn $)
Current	—	3.50	—	—	—
Corridor improvement only	2,206	2.79	314	0.71	2.27
Corridor improvement and rural roads	16,800	0.81	672	1.98	2.95

Source: Own calculations.

Note: Remoteness defined as greater than 5 hours of travel time to a city of 50,000 people or more. Assumes cost of $40,000/km to upgrade a one-lane gravel road to all-weather.

Figure 5.1 Effects of comprehensive rural road upgrade on estimated travel time



Estimated travel time: Corridor upgrade

Estimated travel time: Complete rural road upgrade

Source: Own calculations..

But the estimated financial costs of these road investments are substantial. Based on average road-improvement costs for various types of roads in Sub-Saharan Africa developed by the Africa Infrastructure Country Diagnostic, the estimated cost of improving the 2,206 km of road necessary to complete the major national and international corridors is $314 million. Upgrading 16,800 km of existing rural roads in Mozambique (mainly in the north) to a travel speed of 60 km/hr (the speed for a gravel road of very good quality) would require an estimated $672 million—more than twice the cost of corridor upgrading but about 30 percent more effective in reducing remoteness in terms of the marginal reduction in remoteness per million dollars invested.[25] Thus, even though reducing the time distance to major markets is critical for development, resources are limited and prioritization is necessary.

Finally, it should be noted that corridors and rural roads may affect producer incentives more by connecting rural roads to ports than to cities of a given size. Likewise, the relevant city size for calculation of travel times may vary by crop or even by country or region depending on market structures. There may also be other important impacts of road connectivity in the medium term that are not well captured in this analysis, including potential effects on rural-urban and rural-rural migration. In addition, the impacts of corridor investments will be broader and more diverse and could include increased productivity in urban areas. Further systematic research on these issues is needed for definitive conclusions.

6 Summary and policy implications

Agricultural production and proximity (as measured by travel time) to urban markets are highly correlated in Sub-Saharan Africa, even after taking agroecology into account. Likewise, adoption of high-input technology is negatively correlated with travel time to urban centers, although adoption rates are low throughout most of the subcontinent. The correlations between the location of population centers and road infrastructure (as reflected in travel time) and the location of production suggest a long-run relationship in which land is typically not a binding constraint on aggregate production but in which demand constraints that vary over space are important.

In terms of agronomic potential, there is substantial scope for increasing agricultural production in Sub-Saharan Africa, particularly in more remote areas. Total crop production relative to potential production is approximately 45 percent for areas within 4 hours travel time from a city of 100,000 people. In contrast, total crop production relative to agronomic potential is only about 5 percent for areas more than 8 hours travel time from a city of 100,000 people. These differences in actual versus potential production arise mainly because of the relatively small share of land cultivated out of total arable land in more remote areas.

For these remote regions, demand constraints in terms of low population densities and large travel times to urban centers sharply constrain production. (Low population densities also limit local labor availability.) Reducing transport costs (travel time) to these areas would expand the feasible market size for these regions, easing the demand constraint on production. To the extent that the expansion in production from these areas is small in terms of the relevant regional, national, or subnational market, average market prices outside the formerly remote region would be unaffected and significant aggregate production increases could result. For large remote regions, however, production increases arising from improved connectivity would potentially lead to lower average market prices and reduced production in already-connected areas.

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[25] This calculation assumes a cost of $40,000/km to upgrade a one-lane gravel road to an all-weather road, reflecting actual road costs in South Africa and other southern African countries.

More important, however, is the possibility that improved connectivity will not only affect access to markets, but in the medium term lead to increased migration from remote areas to areas near urban centers. In this scenario, local demand in the remote region decreases and production in the region may actually fall as a result of reduced travel times. Even so, average per capita incomes could rise in the remote region. Thus, it is crucial to evaluate not only impacts on agricultural costs and potential markets but impacts on the broader rural economy and household behavior.

References

Center for International Earth Science Information Network (CIESIN), International Food Policy Research Institute (IFPRI), and World Resources Institute (WRI). 2000. Gridded Population of the World (GPW), Version 2. Palisades, NY: CIESIN, Columbia University. http://sedac.ciesin.columbia.edu/plue/gpw.

Chamberlin, Jordan, Muluget Tadesse, Todd Benson, and Samia Zakaria. 2007. “An Atlas of the Ethiopian Rural Economy: Expanding the Range of Available Information for Development Planning.” Information Development 23 (2–3): 181–92.

Deichmann, U. 1997. “Accessibility Indicators in GIS.” Mimeo. New York: Department of Economic and Social Information and Policy Analysis, Statistics Division.

Diao Xinshen, Peter Hazell, Danielle Resnick and James Thurlow. 2006. “The Role of Agriculture in Development: Implications for Sub-Saharan Africa.” DGSD Discussion Paper, No. 29. IFPRI. Washington D.C.

Dorosh, Paul, and Emily M. Schmidt. 2008. “Mozambique Corridors: Implications of Investments in Feeder Roads.” Spatial and Local Development Team (processed), World Bank, Washington, D.C.

Environmental Systems Research Institute (ESRI). 1993. “Digital Chart of the World.” Vector Map (VMap) Level 0 Database 1:1,000,000-Scale Global Vector Basemap.

Fan, Shenggen, and Peter Hazell. 2001. “Returns to Public Investments in the Less-Favored Areas of India and China.” American Journal of Agricultural Economics 83 (5): 1217–22.

Food and Agriculture Organization (FAO). 2003. World Agriculture Towards 2015/2030: An FAO Perspective. Rome: FAO and EarthScan.

________. 1981. Report of the Agro-Ecological Zones Project. World Soil Resources Report 48 (1–4). Rome: FAO.

FAO, IFPRI, SAGE. 2006. Agro-Maps. A Global Spatial Database of Agricultural Land-Use Statistics Aggregated by Subnational Administrative Districts. http://www.fao.org/landandwater/agll/agromaps/interactive/index.jsp.

Fischer, Gunther, M. Shah, H. Velthuizen, and F. Nachtergaele. 2001. Global Agro-ecological Assessment for Agriculture in the 21st Century. Laxenburg, Austria: International Institute for Applied Systems Analysis (IIASA).

Greene, W. 2003. Econometric Analysis. Fifth Edition. Upper Saddle River, New Jersey: Pearson Education, Inc.

Henderson, J. V., Z. Shalizi, and A. J. Venables. 2001. “Geography and Development.” Journal of Economic Geography 1: 81–105.

Miller, J. 2001. “Using GIS for Global Food and Water Balance Process Modeling.” Proceedings of the ESRI International User Conference 2001, (On-line). http://www.esri.com/library/userconf/proc01/professional/papers/pap556/p556.htm.

Murray, S. 2007. “Africa Infrastructure Country Diagnostic Inception Report: Creation of a GIS Database to Support AICD Study.” Mimeo. Washington, D.C.: World Bank.

Nelson, Andy. November 2007. “Global 1 km Accessibility (Cost Distance) Model Using Publicly Available Data.” Mimeo. Washington, D.C.: World Bank.

———. “United Nations Environment Programme (UNEP) Road Map.” Africa Population Database, IV Version. UNEP.

Siebert, Stefan, P. Döll, and J. Hoogeveen. 2001. Global Map of Irrigated Areas Version 2.0. Germany: Center for Environmental Systems Research, University of Kassel/Rome, Italy: FAO.

Stifel, David, and Bart Minten. 2008. “Isolation and Agricultural Productivity.” Agricultural Economics 39 (1): 1–15.

Thomas, T. 2007. “Notes on Making Africa Access Map.” Mimeo. Washington, D.C.: World Bank.

You, L., and S. Wood. 2006. “An Entropy Approach to Spatial Disaggregation of Agricultural Production.” Agricultural Systems 90 (1–3): 329–47.

You, L., S. Wood, and U. Wood-Sichra. 2007a. “Generating Plausible Crop Distribution and Performance Maps for Sub-Saharan Africa Using a Spatially Disaggregated Data Fusion and Optimization Approach.” IFPRI Discussion Paper 725, IFPRI, Washington, D.C.

You, L., S. Wood, U. Wood-Sichra, and J. Chamberlin. 2007b. “Generating Plausible Crop Distribution Maps for Sub-Saharan Africa Using a Spatial Allocation Model.” Information Development 23 (2/3): 151–9.

Appendixes

Table A.1 Countries in the sample

Country	No. pixels	Country	No. pixels
Angola	13,246	Lesotho	410
Benin	1,214	Liberia	1,121
Botswana	1,720	Madagascar	3,371
Burkina Faso	2,706	Malawi	1,031
Burundi	292	Mali	3,779
Cameroon	2,550	Mauritania	1,004
Central African Republic	2,835	Mozambique	7,309
Chad	5,303	Namibia	3,045
Congo	119	Niger	2,474
Congo, Dem. Rep. of	11,015	Nigeria	9,970
Côte d'Ivoire	2,434	Rwanda	296
Djibouti	159	Senegal	1,410
Equatorial Guinea	131	Sierra Leone	804
Eritrea	301	South Africa	9,094
Ethiopia	10,391	Sudan	16,217
Gabon	600	Swaziland	220
Gambia	121	Tanzania	10,064
Ghana	1,684	Togo	681
Guinea	2,492	Uganda	1,854
Guinea Bissau	399	Zambia	7,015
Kenya	2,283	Zimbabwe	4,518

Source: Calculated from output of the IFPRI SPAM.

Table A.2 African crop prices: the medians of country-level crop prices in year 2000

Crop	$/ton	Crop	$/ton
Wheat	157.6	Soybean	213.7
Rice	260.5	Dry beans	335.8
Maize	140.6	Other pulses	262.8
Barley	169.9	Sugarcane	16.9
Millet	156.3	Sugar beets	38.3
Sorghum	185.6	Coffee	1,190.7
Potato	221.5	Cotton	954.8
Sweet potato	157.3	Other fibers	458.6
Cassava	87.3	Groundnuts	402.3
Plantain and banana	258.9	Other oil crops	504.5

Source: IFPRI, calculated from FAO price data.

Table A.3 Road type and total road length in Africa

Road type		Total length		Estimated travel speed, km/hr
		km	Share (%)	
1	Motorway/major road	132,000	11	50
2	All weather/improved	282,000	22	35
3	Partially improved/earth roads	839,000	67	25

Source: Calculated from UNEP data.

Table A.4 Decay function and distance-weighted population aggregate to define local market size

Radius, km	Average distance, km (a)	Distance weight $\left(w_{ik} = 1/a^{0.3}\right)$	Distance-weighted population at location k (base: 1,000,000)
1–2	1.5	0.885	885,467
2–5	3.5	0.687	686,720
5–10	7.5	0.546	546,363
10–20	15	0.444	443,785
20–50	35	0.344	344,175
50–100	75	0.274	273,830

Source: Own calculations.

Note: $\text{local market size}_i = \sum_k w_{ik} \cdot pop_k$

Table A.5 Value of crop production by farming system

		Share (%)		
	Crop production (mn $)	High-input rain-fed	Low-input rain-fed	Irrigated
Wheat	776.0	41.8	29.3	28.9
Rice	2,726.0	9.8	39.7	50.6
Maize	4,980.9	35.0	59.3	5.7
Barley	165.4	0.0	99.2	0.8
Millet	1,666.8	23.4	76.3	0.2
Sorghum	2,681.4	19.4	76.5	4.1
Potato	1,261.3	34.8	64.2	1.0
Sweet potato	6,547.4	16.3	58.2	25.5
Cassava	7,075.0	13.0	87.0	0.0
Plantain and banana	7,449.4	20.7	79.0	0.3
Soybean	279.2	29.0	68.2	2.8
Dry beans	770.3	48.6	50.5	0.9
Other pulses	902.8	19.8	79.9	0.3
Sugarcane	1,016.4	14.5	19.3	66.2
Coffee	1,189.6	35.0	64.3	0.7
Cotton	6,039.5	17.3	21.9	60.8
Other fibers	47.6	0.0	100.0	0.0
Groundnuts	2,862.0	19.0	66.3	14.7
Other oil crops	4,385.6	22.9	77.1	0.0

Source: IFPRI SPAM.

Table A.6 Crop surplus and shortage, country aggregates

Country	Sum of crop surplus or shortage[1]	Country	Sum of crop surplus or shortage[1]	Country	Sum of crop surplus or shortage[1]
Large shortage		*Balanced*		*Moderate surplus*	
Ethiopia	–12,657.8	Mali	–171.3	Burundi	208.0
Tanzania	–3,330.7	Djibouti	–131.1	Gabon	212.1
Kenya	–3,316.8	Gambia	–80.9	Cameroon	318.0
Sudan	–3,035.8	Guinea Bissau	–74.2	Madagascar	464.5
South Africa	–3,017.1	Swaziland	–21.8	Benin	1,414.9
Zambia	–1,638.8	Guinea	–17.4	Malawi	1,528.4
		Chad	–6.3		
Moderate shortage		Mauritania	–4.6	*Large surplus*	
Angola	–1,139.4	Congo, Dem. Rep. of	1.4	Ghana	2,024.0
Burkina Faso	–966.1	Equatorial Guinea	11.5	Nigeria	2,445.0
Mozambique	–896.4	Central African Republic	18.1	Rwanda	2,462.6
Niger	–795.5	Togo	100.5	Côte d'Ivoire	5,855.0
Sierra Leone	–579.1	Senegal	132.4	Uganda	7,122.3
Liberia	–353.4	Congo	142.8	Zimbabwe	8,951.1
Eritrea	–337.9				
Lesotho	–336.7				
Botswana	–287.3				
Namibia	–247.5				

Source: Own calculations.

Note: Country-level aggregates of crop surplus/shortage in each pixel. Crop surplus/shortage in each pixel is defined as the difference between crop production (normalized by the average crop production in Sub-Saharan Africa) and population (normalized by the average population in Sub-Saharan Africa).

Table A.7 Comparison between East and West African regions

Variable	Sub-Saharan Africa average	East African average (a)	West African average (b)	(a)/(b), %
Population density, count/km^2	42.73447	47.61777	110.0893	43.3
Neighbor population, weighted aggregate, count	300,468.5	311,382.5	783,711.3	39.7
Distance to type-1 roads, km	35.09281	36.29334	38.15682	95.1
Distance to type-2 roads, km	32.63724	33.60026	19.19981	175.0
Distance to type-3 roads, km	15.47335	24.49986	12.86423	190.4
Travel time to city of 25,000 people, hrs	6.979	8.038234	3.327162	241.6
Travel time to city of 100,000 people, hrs	8.902497	9.806253	4.381306	223.8
Travel time to city of 500,000 people, hrs	12.72767	13.81543	6.250211	221.0
Total crop production, $	357,676.8	355,495.7	1,197,939	29.7
Total crop production, high-input, $	74,534.54	81,917.64	236,960.1	34.6
Total crop production, low-input/subsistence, $	225,634.3	250,914.2	805,665.4	31.1
Total crop production, irrigated, $	57,510.19	22,665.09	155,311.2	14.6
Suitable area, total crops, ha	135,630.7	142,002.5	153,262	92.7
Suitable area, high-input, total crops, ha	54,814.58	55,535.08	67,913.87	81.8
Suitable area, low-input, total crops, ha	43,139.12	53,367.45	52,231.28	102.2
Suitable area, irrigated, total crops, ha	26,105.78	19,382.56	29,522.27	65.7
Potential (maximum) production, high-input, total crops, $	4,629,393	4,917,712	5,522,684	89.0
Potential (maximum) production, low-input, total crops, $	405,565.1	542,016.2	431,718	125.5
Potential (maximum) production, irrigated, total crops, $	2,935,211	2,321,953	3,015,315	77.0

Source: Own calculations.

Note: 1. East African countries are Kenya, Uganda, Tanzania, Zambia, Malawi, Mozambique, and South Africa.

2. West African countries are Nigeria, Benin, Togo, Ghana, and Côte d'Ivoire.

Table A.8 Friction grid classification for travel-time calculation

Number of 3-second intervals*	Time	Speed (km/hr)	Road type
6	18 secs	100	
7	21 secs	85.7	
8	24 secs	75	Road 1 of 3 or 1 of 5
9	27 secs	66.7	
10	30 secs	60	Road 2 of 5
12	36 secs	50	Road 2 of 3 or 3 of 5
15	45 secs	40	
16	48 secs	37.5	
20	1 min	30	Road 4 of 5
30	1.5 mins	20	
60	3 mins	10	Road 3 of 3 or 5 of 5
75	3.75 mins	8	
100	5 mins	6	
120	6 mins	5	
150	7.5 mins	4	Former model off-road
200	10 mins	3	Off-road
300	15 mins	2	
600	30 mins	1	International boundary

Source: Thomas, 2007.

Note: * Number of 3-second intervals to cross a 500-meter grid cell.

About AICD

This study is a product of the Africa Infrastructure Country Diagnostic (AICD), a project designed to expand the world's knowledge of physical infrastructure in Africa. AICD will provide a baseline against which future improvements in infrastructure services can be measured, making it possible to monitor the results achieved from donor support. It should also provide a better empirical foundation for prioritizing investments and designing policy reforms in Africa's infrastructure sectors.

AICD is based on an unprecedented effort to collect detailed economic and technical data on African infrastructure. The project has produced a series of reports (such as this one) on public expenditure, spending needs, and sector performance in each of the main infrastructure sectors—energy, information and communication technologies, irrigation, transport, and water and sanitation. *Africa's Infrastructure—A Time for Transformation*, published by the World Bank in November 2009, synthesizes the most significant findings of those reports.

AICD was commissioned by the Infrastructure Consortium for Africa after the 2005 G-8 summit at Gleneagles, which recognized the importance of scaling up donor finance for infrastructure in support of Africa's development.

The first phase of AICD focused on 24 countries that together account for 85 percent of the gross domestic product, population, and infrastructure aid flows of Sub-Saharan Africa. The countries are: Benin, Burkina Faso, Cape Verde, Cameroon, Chad, Côte d'Ivoire, the Democratic Republic of Congo, Ethiopia, Ghana, Kenya, Lesotho, Madagascar, Malawi, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, South Africa, Sudan, Tanzania, Uganda, and Zambia. Under a second phase of the project, coverage is expanding to include as many other African countries as possible.

Consistent with the genesis of the project, the main focus is on the 48 countries south of the Sahara that face the most severe infrastructure challenges. Some components of the study also cover North African countries so as to provide a broader point of reference.

The World Bank is implementing AICD with the guidance of a steering committee that represents the African Union, the New Partnership for Africa's Development (NEPAD), Africa's regional economic communities, the African Development Bank, the Development Bank of Southern Africa, and major infrastructure donors.

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The data underlying AICD's reports, as well as the reports themselves, are available to the public through an interactive Web site, www.infrastructureafrica.org, that allows users to download customized data reports and perform various simulations. Inquiries concerning the availability of data sets should be directed to the editors at the World Bank in Washington, DC.