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The Greatest of All Improvements: Roads, Agriculture, and Economic Development in Africa

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> Good roads, canals, and navigable rivers, by diminishing the expense of carriage, put the remote parts of the country more nearly upon a level with those in the neighborhood of the town. They are upon that account the greatest of all improvements. They encourage the cultivation of the remote, which must always be the most extensive circle of the country. They are advantageous to the town, by breaking down the monopoly of the country in its neighborhood.... They open many new markets to its produce.
>
> Adam Smith, *The Wealth of Nations*, I.xi.b.5

1. Introduction

In most poor countries, large fractions of the population earn their living from agriculture. This is widely understood as a central feature of the structural transformation that occurs as economies grow. But even among other poor countries, sub-Saharan Africa stands out as a region where vast majorities of the population live in rural areas and work in agriculture. Many live in semi-subsistence, growing most of their own food and only occasionally walking to markets to exchange (for example) a few stalks of sugar cane for some soap or salt or kerosene.[1]

This paper asks why so many people continue to live and work in subsistence agriculture in sub-Saharan Africa. There are many possible explanations, of course; we do not seek a single monocausal explanation. In this paper, however, we briefly discuss a few possible reasons for the persistence and ubiquity of subsistence agriculture, and we offer a simple model economy that allows us to analyze the relative importance of a few different explanations.

We focus on the role of transportation and rural infrastructure – what Smith refers to as “the greatest of all improvements”. In most African countries, rural transport infrastructure is notoriously poor, and the transaction costs of moving goods to market are extremely high. We explore the impact that high transaction costs may have on the allocation of resources across sectors – and in turn on the overall output of the economy. As Adam Smith pointed out more than two centuries ago, improvements in transportation infrastructure can have a dramatic impact on the

[1] Very few households in sub-Saharan Africa actually live in a literal subsistence state, such that they buy and sell nothing in markets. Almost all are integrated to some extent with the market economy and are aware of market opportunities. Even the most remote households typically buy and sell small quantities of goods. Thus, we view the term “subsistence agriculture” as somewhat misleading. However, in subsequent passages of this paper, we have used this term instead of the preferred -- but more cumbersome -- “semi-subsistence agriculture”.

allocations of resources across sectors and on the productivity of different geographic areas.

This paper uses Uganda as a benchmark country. In many ways, Uganda is typical of other sub-Saharan economies with large rural populations. We offer a detailed description of Uganda, to highlight the features that it shares in common with our model economy; we also readily acknowledge that Uganda is far more complicated (and far more interesting and enchanting) than our digital construct. But we believe that our model may offer some useful insights to policy debates already taking place in Uganda. More generally, we believe that our model can usefully inform our thinking about real-world developing economies, and especially a number of countries in sub-Saharan Africa.

Our strategy is to write down a simple static model in which we can think about allocations of productive resources across sectors. The model that we use is one that underlies the dynamic analysis of Gollin, Parente, and Rogerson (2004, 2007). In this paper, we forgo dynamics, but we enrich the model by adding intermediate goods and transportation costs.

The organization of the paper is as follows. Section 2 reviews the literature on Africa's low agricultural productivity and on the related transportation issues that we consider here. Section 3 discusses Uganda's current situation; for our modeling exercise, we will take Uganda as the real-world economy that we seek to represent. We will discuss some of the stylized features of the Ugandan economy that will be important in our modeling exercise. Section 4 introduces a simple static model in which resources are allocated across a food and non-food sector. We then add two complications: intermediate goods and transportation costs. Since our simple model relies on a strong assumption regarding preferences, we then show that the same intuition holds for a more general preference structure. Finally, we discuss possible interactions between intermediate goods and transportation costs in the model. Section 5 then reports on a quantitative exercise in which we assign parameter values and compute the model equilibrium. We do not claim that the resulting numbers are reliably representing the Ugandan economy, but we argue that the qualitative results of the model and robust and that they convey important information about the relative impacts of different changes in the benchmark economy. Section 6 offers some concluding thoughts.

2. Background

Agriculture plays a large role in most poor economies today, as it did historically in the countries that are now rich. In most of the world's poorest countries, agriculture accounts for more than half of measured GDP and as much as 80-90 percent of measured employment. Comparable figures applied in historical times to North America and Europe. The transition out of agriculture into manufacturing, services, and other activities is in fact one of the most robust features of long-run economic growth.

Figure 1 shows cross-section data relating real per capita income to the fractions of employment and output in agriculture. African countries are shown distinct from the other countries in the data. It is striking that both employment shares in agriculture and GDP shares in agriculture show a strong negative relationship with income per capita. It is also striking that African countries occupy a cluster on each graph: they are disproportionately poor, and agriculture accounts for very large fractions of employment and output in most African countries.

Another aspect of the data that is evident in Figure 1 is that in the sub-Saharan countries, agriculture accounts for much higher shares of the labor force than of output. As we have written in earlier work (Gollin, Parente and Rogerson 2004), and as others have also documented, this implies that output per worker is far higher in non-agriculture than in agriculture.

Figure 2 shows the ratio of the two sectoral labor productivity levels implied by the data. According to these data, averaging across the sub-Saharan countries with available data, labor in non-agriculture produced seven times more output than the labor in agriculture. For all countries outside this region, the gap was less than half as big. Thus, it appears as though sub-Saharan Africa has a great many workers employed in a sector where they are remarkably unproductive.

Admittedly, with both labor and output, measurement problems are severe. The labor figures used here do not measure hours worked in agriculture; they instead represent the fraction of the economically active population who report that agriculture is their primary source of income. To the extent that rural people are counted, by default, as working in agriculture, we may overestimate the labor used in agriculture.[2] Similarly, the data may do a poor job of accounting for the value of agricultural output. National income and product accounts in principle

[2] This is not, however, a problem unique to poor countries. In many rich countries, farmers may work in off-farm activities (e.g., holding a steady job "in town"), and it is not clear whether we are likely to overestimate agricultural labor more severely in rich countries or in poor ones.

include home consumed agricultural goods, so the problem is not one of theory. Implementation, however, can be tricky. Sectoral output is usually estimated from area and yield data, rather than from market sales, but it is not always straightforward to quantify the volume of output, nor is it obvious what prices should be used for valuing agricultural production.

Although the data may be imperfect, there is no doubt that there is a real transition in the size of the agricultural sector as part of the growth process; nor is there any doubt that there are big differences in living standards and productivity levels across sectors. Rural people in developing countries are visibly poor and often undernourished. Few goods are available in rural markets, and consumption levels are low. These observations are repeatedly supported in household survey data, as summarized recently by Ravallion et al. (2007).

We consider that these data pose a fundamental puzzle for thinking about African development. Why are so many people in sub-Saharan Africa “stuck” in the subsistence agricultural sector, using little improved technology, and essentially unable to benefit from the division of labor? Given the income and productivity differences across sectors, why do we not observe more people migrating out of subsistence agriculture and moving to cities?

We view the current allocation of people across sectors to be a long-term feature of African development, rather than the result of short-term crisis or disruption. Clearly the situation is not static; as Table 1 shows, the proportion of Africa’s population working in agriculture has been falling steadily. Yet these numbers remain stubbornly high for the region as a whole. Some individual countries (e.g., Burkina Faso, Mozambique, Rwanda) seem even more mired in this low-productivity equilibrium, with relatively little change in the agricultural share of labor over the past fifty years. And *within* countries, there are typically geographic pockets where almost the entire population remains in subsistence agriculture. For example, Uganda’s 2002 census showed that Kisoro, Kamwenge, Nebbi, Yumbe, Apac, Pader, Kabera-Maido, Katakwi, and Pallisa districts all had 85 percent or more of households living in subsistence. In many countries of sub-Saharan Africa, subsistence agriculture is not merely an anachronistic holdover confined to a few obscure hill towns; instead, it represents the predominant way of life for most of society.

<u>Possible explanations:</u>
A number of explanations have been offered for the persistence of subsistence agriculture, both in the policy literature and in academic studies. We consider here

three alternative viewpoints, although there are undoubtedly many other possibilities. Our starting point is the model of structural transformation presented in Gollin, Parente and Rogerson (2007). In this model of a closed economy (henceforward GPR), countries cannot begin to move resources out of agriculture into the non-agricultural sector until they can exceed the economy's requirements for food production. This in turn cannot occur until the country's agricultural technology becomes sufficiently productive. Countries with low inherent productivity in agriculture will begin their structural transformation late and will lag behind the world leaders for a long time.

Within the framework of GPR, a country might remain stuck in subsistence agriculture for at least three reasons. First, it might have very poor agricultural technology. Second, a price distortion in the non-agricultural sector might make it prohibitively expensive for most farmers to purchase non-agricultural inputs and correspondingly reduce their incentives to sell agricultural outputs. Finally, there might be other wedges, such as high intra-country transportation costs, that could slow the structural transformation.

All three of these explanations appear plausible in the sub-Saharan context, and the model presented below will allow us to consider each of these explanations in turn (or for multiple explanations acting in combination). For now, we will look briefly at the reasons for taking these explanations seriously.

Low Agricultural Productivity

The World Bank's recent *World Development Report 2008: Agriculture for Development* notes that sub-Saharan Africa has lagged behind other regions of the developing world in agricultural productivity levels and growth rates. Grain yields, a measure of land productivity, grew at 2.8 percent annually in East Asia between 1961 and 2004; in sub-Saharan Africa, they grew hardly at all. Africa has far lower levels of modern variety adoption than other regions of the developing world. (See Table 3 for illustrative data on four of Africa's major crops.) In addition, little land is irrigated, and many farmers use almost no fertilizer.

These facts do not, however, necessarily imply low intrinsic productivity in agriculture. Input use (and therefore yields) may be low because of poor technology that does not respond well to inputs. But low input use could also result from policy distortions or lack of effective demand. In other words, causation could flow from a poor overall economy to low agricultural productivity, as well as the other way around.

There are reasons, however, to believe that sub-Saharan Africa may in fact lag behind other regions of the world in agricultural technology. The staple foods of sub-Saharan Africa – tropical maize, cassava, cooking bananas and plantain, sweet potatoes, yams – are not crops that have been widely researched in the rich countries of temperate zones. Modern agricultural researchers found fewer useful raw materials to work with in Africa than in Asia or Latin America, and their efforts also began later – in the 1980s, rather than the 1960s, for a variety of political and economic reasons. As a result, few useful crop varieties have been developed to this day for sub-Saharan Africa, and research successes have been rare.

Compounding this problem, the production environments of the sub-Saharan region are so enormously heterogeneous that technologies developed for one locale do not necessarily have a very wide domain of usefulness. Where successful rice varieties in South Asia could be planted on many millions of hectares, a successful crop variety in Africa is unlikely to be planted on more than a few hundred thousand hectares.

Note that these explanations do not invoke pure geographic differences. There may in fact be soil or climate problems that make agriculture less productive in Africa than in other regions, but this is not obvious. Across the world and throughout history, farmers have overcome problems of poor land and rainfall by improving soils, managing water, and selecting new crops and farming systems. While there may in fact be important geographic differences in agricultural productivity across countries, these are not essential.

Input Price Distortions:

Agricultural inputs appear to have high farmgate prices in sub-Saharan Africa, even compared with other regions of the developing world. Partly in response, farmers use few chemical fertilizers or pesticides, even where these would appear to have high technical responses. Restuccia et al. (2008) suggest that high input prices are a significant explanation of the low agricultural productivity – and hence the low income levels – of many African countries.

Transportation and Market Access:

A United Nations report in 2007 noted that “Africa is lagging significantly behind in the development of regional trade, particularly because of the lack of reliable and adequate transport" (ECA 2007). By almost any measure, Africa's transportation infrastructure is poor by comparison to all other regions of the world. Transport prices are high along main corridors, and transportation along feeder and market roads into rural areas is particularly dreadful.

Overall, Africa has approximately half the road density (6.8 km of road length per 100 km^2 of land area) of Latin America (12 km/100 km^2) and about one-third the density of Asia (18 km/100 km^2). The quality of these roads is also poor by comparison to other regions. Few of the roads are paved, and fewer still are well maintained.

As a result, few people in sub-Saharan Africa have good market access. GIS data compiled by IFPRI suggest that only 20 percent of the rural population of sub-Saharan Africa lives within one hour of a market center (defined as a community of 5,000 people or more). Fully one-third of the rural population lives five hours or more from a market center. In a number of countries (e.g., Congo, Tanzania, Rwanda, Ethiopia), more than half the population lives five hours or more from a market center.

For households in these locations, the lack of transportation to market is a major impediment to buying and selling goods. For example, in Uganda, 30 percent of communities surveyed in the national household survey of 2005/06 did not have roads that were passable even in the dry season. Two-thirds of communities lacked any bus or taxi connections. As a result, markets (not to mention health clinics and other public services) are far and difficult to reach (Uganda National Household Survey 2006/06, p. 142).

A longstanding literature argues that high transport costs can pose a major impediment to development in Africa and other regions of the developing world. This includes theoretical papers along with a number of recent policy and empirical papers, such as Platteau (1996), Fan and Hazell (2001), Fan and Chan-Kang (2004), Torero and Chowdhury (2004), Renkow et al. (2004), Zhang and Fan (2004), and Minten and Stifel (2008). A recurring view in this literature is that African transport costs are so high that they alter incentives for agricultural investment and impede development. Numerous studies also suggest that transport costs are higher in sub-Saharan Africa than in other parts of the developing world, such as Asia and Latin America.

Literature review:

The agricultural transformation was first documented in the modern growth literature by Kuznets (1966) Chenery and Syrquin (1975), and others (e.g., Syrquin 1988). These authors, like most of the early growth and development economists, tended to view subsistence agriculture as a default source of employment and as a pool of reserve labor.

Influential scholars such as Rosenstein-Rodan (1943), Rostow (1960), and Lewis (1955) suggested that modern economic growth was essentially identifiable with industrialization. The challenge of development, in their view, was to create and expand employment in the modern industrial sector. This sector was seen as having high potential for growth, and it was assumed that industry (and to a lesser extent services) would gradually absorb workers from agriculture. Lewis (1955) and Fei and Ranis (1964) viewed the agricultural sector essentially as a pool of surplus labor, with a very low shadow wage.

In many dual economy models, such as those of Lewis, the labor market dynamics were somewhat ill defined. It was assumed that wage differences could and would arise between the modern sector and the traditional sector, with some kind of efficiency wage story (or alternatively, a price distorting minimum wage) accounting for the high wages paid in the modern sector. Harris and Todaro, among others, recognized that incentives would arise for rural to urban migration in this model, but they maintained the assumption that the modern sector would provide a limited number of jobs, with wages above the market-clearing level.

A number of recent papers in the growth economics revisit the dualism of Harris and Todaro. Temple (2005), Vollrath (2004) and Vollrath (2008), among others, have explored multi-sector models in which unemployment or underemployment is possible in the modern sector. In these papers, there may be fixed urban wages or other rigidities that prevent the urban labor market from clearing; other papers (e.g., Caselli and Coleman 2001) rely on transaction cost wedges that prevent the labor market from equalizing marginal products across sectors. These papers have the feature that the allocation of resources across sectors is inefficient; the social planner would allocate labor and capital differently.

Unlike these papers, ours focuses on a kind of dualism *within agriculture*; that is, we will differentiate between a subset of the agricultural sector which is “close” to market and the remainder of the agricultural sector, which is “remote” from the market. In this sense, our paper is close to recent work by Herrendorf, Schmitz, and Teixeira. It is also closely related to Adamopoulos (2005), who uses a model similar to ours to conduct a development accounting exercise.

Recent literature proposes several alternative explanations for the delayed sectoral transformation in contemporary Africa. Some have suggested that poor technology or institutions have delayed the onset of the structural transformation. For example, it is generally understood that agricultural research on staple food crops began later in sub-Saharan African than in other parts of the world; as a result, the development and diffusion of modern crop varieties has lagged far behind the trajectory of other developing regions.

Another area of interest to researchers has been the high apparent price of intermediate inputs in sub-Saharan Africa. Agricultural development could be slowed by distortions in the cost of farm inputs (as in Restuccia, Yang, and Zhu 2007; Herrendorf and Teixera 2008), as well as by weak credit markets (Duflo and Banerjee 2005). Wedges in labor markets (Dekle and Vandenbroucke 2006) might also be sufficient to slow the agricultural transformation.

A particular source of interest is the relationship between high input costs, low output prices, and high transportation costs, as explored in Herrendorf, Schmitz, and Teixeira (2006).

3. Uganda

In many ways, Uganda offers a perfect case study of agriculture in sub-Saharan Africa, and it corresponds quite well to the model economy that we study. Because it is landlocked, Uganda's agricultural economy is effectively closed. Although the country exports small quantities of food to Sudan and Kenya, and while it exports large amounts of coffee (along with smaller amounts of sugar and cotton), it is largely a closed economy in food. The principal food crops are also very little traded on international markets: matoke (a kind of cooking banana) is one of the main staple foods, along with maize, cassava, yams, and other root crops. Of these, only maize is traded to any significant degree.

Uganda's net grain imports (including maize) are equivalent to about 10 percent of production; but since grain is only 21 percent of calorie consumption, imports of grain account for only 2.1 percent of Uganda's total food energy. (See Table 4.) Since Uganda is a net exporter of pulses, fish, and some other commodities that are domestically consumed, only 1.7 percent of total calorie consumption depends on imported foods. In essence, Uganda's food economy is self-contained.

Even though the country has a number of important agricultural exports (e.g., coffee), Uganda's food economy is effectively a closed economy.

About three-quarters of the population lives in rural areas, and most make their livings from subsistence agriculture (Uganda Bureau of Statistics 2007, pp. 16-17). It is common for households to pursue mixed cropping. Two-thirds of agricultural households had between 1 and 4 plots in 2002, and about 40 percent of the plots were themselves mixed stands, where multiple crops are grown together (Uganda Bureau of Statistics 2004, pp. 5-6). Ten crops account for over 90 percent of the plots under cultivation: bananas, beans, cassava, sweet potatoes, coffee, groundnuts, maize, millet, sorghum, and sesame. Almost 40 percent grow some beans, and approximately the same number report growing some cassava. Farms also typically include livestock. About 20 percent of farm households reported owning one or more cattle; 30 percent reported keeping goats; and 46 percent of households reported keeping chicken, mostly on a very small scale (Uganda Bureau of Statistics 2004).

Rural households in Uganda are very poor. In 2005/06, 93.2 percent of Uganda's poor households (using a headcount measure) were rural, somewhat higher than the 84.6 percent of households in rural areas. The poverty rate for rural households, using a headcount measure, was 34.2 percent (Uganda Bureau of Statistics 2006, p. 60). Rural households allocated about 50 percent of their total expenditure to food, drink, and tobacco – although the pricing of these goods is complicated, since much of consumption is home produced (Uganda Bureau of Statistics 2006, pp. 56-59). About 15 percent of rural households had fewer than two sets of clothes per household member, and only 43 percent reported that each member of the household had a pair of shoes in good condition. Most households outside Kampala owned their own homes and furnishings, including a radio or other electronic device. About 40 percent of rural households owned a bicycle, but very few owned any other mode of transportation (Uganda Bureau of Statistics 2006, pp. 94-95).

Rural households and communities have difficulties in accessing markets and infrastructure, as well as services. IFPRI's GIS data suggest that more than three-quarters of Uganda's population (78 percent) live two or more hours from a market center; 25 percent live five or more hours from a market. In 2005/06, only 9 percent of rural communities had any access to electricity. For the most part, people walk long distances to markets and other services, although bicycles and even motorcycle transport is available to a limited degree. For example, for the country as a whole (including urban areas), the average distance to a government health clinic was about 7 km, and 77 percent of people reported that they walked to these clinics.

Transport costs and marketing margins are very high. Table 5 shows the price dispersion across a number of staple food commodities for a single time period (July 2006), looking only at the six largest urban markets. Even across these market centers, the prices of most crops differed sharply, reflecting high transport costs. Not surprisingly, the biggest price difference was for matoke, the cooking banana that is a starch staple in Uganda. Here, prices differed across urban markets by more than a factor of three, which reflects the relative perishability of the commodity, compared with maize flour or cassava flour. Potatoes (known locally as "Irish") displayed a similarly large price dispersion, with a factor two difference between high and low prices. The absolute differences in price between high and low in these data are approximately 50 percent of the average prices at which the commodity is sold. Since these are pure transportation and transaction costs, this suggests that inter-city trade is quite costly.

By all accounts, however, the inter-city costs of transport and trade are small in comparison to the costs of bringing commodities to and from rural households. Most informants whom we interviewed suggested that retail prices for agricultural commodities in the nearest urban area frequently reach four times the farmgate prices of the same commodities. These price differentials do not involve any processing or quality grading; they simply reflect the costs of moving goods from one place to another.

Although spatial dispersion of prices may reflect policy barriers, market power, and other factors, in Uganda's case, the poor condition of roads is an immediate and striking feature of geography. Uganda's paved road density in 2003 of 16,300 km in a land area of 200,000 km^2 (CIA Factbook 2009) was not much greater than the paved road density found in Britain at the end of Roman rule in AD 350, which was 12-15,000 km in a land area of 242,000 km^2 (Lay 1992, p. 55 and CIA Factbook 2009). In this specific sense, then, Uganda lags Britain by almost two thousand years in the development of its road infrastructure.

4. Models

In this section we lay out several models that serve to motivate the final model that we develop.

The Static GPR Model

A. Benchmark Model

We begin with a static version of the model in GPR. The basic setup is as follows. Consider an economy with a measure one of identical agents. Each individual has preferences over two goods, which we label as agriculture (a) and manufacturing (m), given by[3]:

$$u(a-\bar{a})+v(m+\bar{m}) \tag{1}$$

where u and v are defined for non-negative values, are both increasing, strictly concave functions and $\bar{a}$ and $\bar{m}$ are both strictly positive. The key feature of these preferences is the presence of the $\bar{a}$ and $\bar{m}$ terms, which serve to make the income elasticity of the agricultural good less than one and that of the manufactured good greater than one.[4] GPR further considered the special case where the function u has the property that it is minus infinity if $a-\bar{a}$ is negative and equal to a constant for all nonnegative values of $a-\bar{a}$. The economy is endowed with one unit of land and each individual is endowed with one unit of time.

The technology for producing the manufactured good is given by:

$$m = A_m n_m \tag{2}$$

where n_m is the number of workers that work in the manufacturing sector, and the technology for producing the agricultural good is given by:

$$a = A_a L^{\theta} n_a^{1-\theta} \tag{3}$$

where n_a is the number of workers that work in the agricultural sector and L is land. While we could extend our definition of preferences so that allocations with $a<\bar{a}$ can be evaluated, and that individuals only value a in such situations, we will instead simply assume that the economy is able to produce sufficient amounts of a so as to provide all individuals with at least $\bar{a}$ units of the agricultural good. A sufficient condition for this is that $A_a > \bar{a}$. We assume that land ownership is equally distributed across the population.

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[3]While we refer to the nonagricultural good as the manufacturing good, it should be interpreted as representing both the manufacturing and the service sectors.

[4]It is sufficient that at least one of $\bar{a}$ or $\bar{m}$ be greater than zero for this property to hold. Having both positive allows for the possibility of a corner solution in which $m=0$.

We study the competitive equilibrium allocation for this economy, which can be obtained by solving the Social planner's problem of maximizing the utility of a representative household subject to the feasibility constraints. This turns out to be somewhat trivial given the extreme form of preferences that we have assumed. In particular, given that everyone needs to consume exactly $\bar{a}$ units of the agricultural good, but receives no benefit from consuming any additional amount, the optimal allocation is to allocate enough workers to the agricultural sector so as to produce $\bar{a}$ for each individual in the economy, and then to allocate all remaining workers to the manufacturing sector. It follows that the optimal value for n_a is given by:

$$n_a = [\frac{\bar{a}}{A_a}]^{1/(1-\theta)}. \quad (4)$$

The key implication of this model is that in an economy in which food is a necessity, there is a powerful negative relationship between agricultural TFP and employment in agriculture. In particular, a one percent decrease in agricultural TFP A_a will lead to an even larger percentage increase in employment in agriculture, equal to $1/(1-\theta)$.

In the next section we will consider how this finding extends to a model that does not have such an extreme preference structure, but before moving to consider that generalization we want to consider two additional economic mechanisms that are potentially important determinants of the allocation of labor to agriculture.

B. Intermediate Goods in Agriculture

We modify the GPR model by assuming that the output of the manufacturing sector can be used either for consumption or as an input in the production of the agricultural good. Let x denote the input of the manufactured good used in the agricultural sector. To simplify the exposition we restrict attention to an agricultural production function which is of the Cobb-Douglas variety:

$$a = A_a L^{(1-\theta_x-\theta_n)} x^{\theta_x} n_a^{\theta_n}. \quad (5)$$

The social planner problem for this economy is no longer as trivial as in the GPR model, since there is a nontrivial decision about the input mix that is used to produce the required amount of agricultural output. Specifically, the social planner seeks to solve:

$$\max_{n_a, x} v(A_m(1-n_a) - x + \bar{m})$$

subject to:

$$\bar{a} = A_a x^{\theta_x} n_a^{\theta_n}$$

Letting λ_a be the Lagrange multiplier on the constraint, the first order conditions for an interior solution are given by:

$$v'(A_m(1-n_a)-x+\bar{m})A_m = \lambda_a\theta_n A_a x^{\theta_x} n_a^{\theta_n-1} \tag{6}$$

$$v'(A_m(1-n_a)-x+\bar{m}) = \lambda_a\theta_x A_a x^{\theta_x-1} n_a^{\theta_n} \tag{7}$$

Dividing the two equations by each other yields:

$$A_m = \frac{\theta_n}{\theta_x}\frac{x}{n_a} \tag{8}$$

which implies that the optimal choice of x for a given choice of n_a satisfies:

$$x = A_m \frac{\theta_x}{\theta_n} n_a \tag{9}$$

It follows that we could rewrite the social planner's problem as:

$$\max_{n_a} v(A_m(1-n_a) - A_m \frac{\theta_x}{\theta_n} n_a + \bar{m})$$

subject to:

$$\bar{a} = A_a A_m^{\theta_x} (\theta_x / \theta_n)^{\theta_x} n_a^{\theta_n+\theta_x}$$

Because n_a is the only choice variable it follows that the constraint effectively determines the value of n_a, just as in the GPR model, with the solution given by:

$$n_a = B[\frac{\bar{a}}{A_a A_m^{\theta_x}}]^{1/(\theta_n+\theta_x)} \tag{10}$$

where $B = [\frac{\theta_n}{\theta_x}]^{1/(\theta_n+\theta_x)}$. The key result is that in this extended version of GPR low productivity in either the agricultural or the manufacturing sector can give rise to increased employment in the agricultural sector. It is important to note that the elasticity of n_a with respect to A_m is smaller than the elasticity of n_a with respect to A_a by a factor of θ_x.

While we do not develop it in any detail, we note that while the above argument stressed low productivity in the manufacturing sector as a factor leading to high employment in agriculture, the exact same analysis shows that policies that increase the relative price of the intermediate good used in the agricultural sector would have the same effects.

C. Adding Transportation Costs

In this subsection we abstract from intermediate inputs in agricultural production, but consider a different extension of the basic model described above. In particular, we consider a model in which production of agriculture and manufacturing goods takes place in different locations and it is costly to transport these goods between locations. Specifically, the two production technologies are as in the simple model that we described initially:

$$a = A_a L^\theta n_a^{1-\theta} \tag{11}$$

$$m = A_m N_m \tag{12}$$

Workers reside in the location in which they work, and must consume goods delivered to that location. For simplicity, we assume that transportation costs take the form of iceberg costs and are symmetric, i.e., the cost of transporting m from one location to the other is the same as transporting a from one region to the other. We denote this cost by q. Letting a_m and a_a denote the consumption of agricultural goods of workers in region m and a respectively, and similarly for m_a and m_m, feasibility now requires the following:

$$n_a a_a + (1-n_a)\frac{a_m}{(1-q)} = A_a L^\theta n_a^{1-\theta} \tag{13}$$

$$(1-n_a)m_m + n_a \frac{m_a}{(1-q)} = A_m n_m \tag{14}$$

We again consider the social planner's problem for this economy. For simplicity we abstract from moving costs for individuals and hence do not need to specify the initial location of workers. The presence of the location decision gives rise to a nonconvexity in this economy, which means that optimal allocations will not necessarily equate utilities across individuals in different locations. We assume that the transfers across individuals that are part of supporting such an allocation as an equilibrium are taken care of within the family, so that we are implicitly thinking that the economy can be thought of as consisting of many families each of which have many members. This assumption serves to simplify the analysis by allowing us to better focus on the role of transportation costs for goods, and is not critical for our results. Our main result is that transportation costs also have the effect of inducing a larger allocation of workers to the agricultural sector, and if we were to assume that all individuals begin in the agricultural location and it is costly for an individual to move to the other location, this would simply reinforce this result.

It remains true that the social planner needs to allocate workers so that each worker obtains $\bar{a}$ units of the agricultural good. From the feasibility condition for the agricultural good it follows that there is a unique value of n_a that is consistent with this outcome. Specifically, setting a_a and a_m equal to $\bar{a}$ in this expression yields:

$$n_a \bar{a} \frac{q}{1-q} = \frac{\bar{a}}{1-q} - A_a n_a^{1-\theta} \tag{15}$$

From this expression it follows that decreases in A_a and increases in q both lead to increases in n_a. Considering the case in which $\theta = 0$ provides some additional insight. In this case we obtain:

$$n_a = \frac{\bar{a}}{\bar{a}q + (1-q)A_a} \tag{16}$$

From this expression there are three results of interest. First, as in the GPR model, a decrease in A_a leads to an increase in n_a. Second, whereas in the case of no transportation costs (i.e., $q = 0$) this elasticity is equal to negative one, in this case it is less than this in absolute value. Third, an increase in transportation costs leads to an increase in n_a, since we had assumed earlier that $A_a > \bar{a}$. The elasticity of n_a with respect to q is given by $(A_a - \bar{a})/(\bar{a}n_a)$. The intuition for these results is straightforward. Transportation costs imply that it takes agricultural production in excess of $\bar{a}$ in order to support an individual who resides in the manufacturing sector. It follows that if transportation costs increase, that holding the labor allocation fixed will result in a shortage of agricultural production, thereby necessitating an increase in labor allocated to agricultural production. Therefore, holding all else constant, an economy with greater transportation costs will have a greater fraction of its employment in the agricultural sector. The effect of changes in A_a is also muted by the presence of transportation costs. When $\theta = 0$ and there are no transportation costs, a one percent increase in A_a leads to a one percent decrease in n_a since the same amount of food can now be produced by one percent fewer workers. In an economy with transportation costs it remains true that the same amount of output can be produced by one percent fewer workers, but when more individuals move from the agricultural sector to the manufacturing sector, it is necessary to transport more food, and therefore the decrease in n_a is necessarily less.

D. Summary

The key message from the above analysis is to note three channels which can lead to greater allocation of labor to the agricultural sector in an economy with a fixed requirement for the consumption of agricultural output. The first channel is low TFP in agriculture. The second channel is low TFP in the production of an intermediate good used in the agricultural sector, or equivalently, a policy that raised the relative price of this input. The third channel is higher transportation costs. Two results of interest emerge from the above analysis concerning the size of these effects. First, the magnitude of the second channel is likely to be much smaller than the first channel, since the second channel is reduced relative to the first by a factor equal to the factor share of the intermediate good. Second, the presence of transportation costs tends to decrease the magnitude of the first channel.

<u>Extension to More General Preferences</u>

The previous analysis assumed an extreme form of Stone-Geary preferences. The benefit of doing this was that it made the analysis much more transparent. But it is also of interest to examine whether the qualitative results depend on this extreme specification. We explore this issue in this section.

A. GPR Model

We now consider the more general case in which the function u is strictly increasing for nonnegative values of its argument. The Social planner's problem now exhibits a nondegenerate trade-off in terms of the allocation of labor to the two production activities. The Social planner's problem can be written as:

$$\max_{n_a} u(A_a n_a^{1-\theta} - \bar{a}) + v(A_m(1-n_a) + \bar{m})$$

It is possible that the optimal allocation of time will be at the corner $n_a = 1$. If the solution is interior, then straightforward manipulation of the first order condition gives:

$$u'(A_a n_a^{1-\theta} - \bar{a}) A_a (1-\theta) n_a^{n-\theta} = v'(A_m(1-n_a) + \bar{m}) A_m \tag{17}$$

The left hand side of this equation is decreasing in n_a while the right hand side is increasing in n_a, so an interior solution can be represented as the intersection of two curves, one of which is upward sloping and the other of which is downward sloping. Two simple comparative static results of interest concern the effect of changes in the two TFP terms, A_a and A_m on n_a. In general one cannot sign these effects, due to the fact that there are income and substitution effects that work in opposing directions. The presence of the $\bar{a}$ and $\bar{m}$ terms implies that a positive income effect tends to move resources toward the manufacturing sector. It follows that an increase in A_a should results in a decrease in n_a as long as the substitution effect is not too large. In particular, if we assume a constant elasticity of substitution specification of preferences, i.e.,

$$u(a-\bar{a}) + v(m+\bar{m}) = \frac{\alpha}{\eta}(a-\bar{a})^{\eta} + \frac{(1-\alpha)}{\eta}(m+\bar{m})^{\eta} \tag{18}$$

then it follows that an increase in A_a leads to a decrease in n_a as long as $\eta \leq 0$. A special case of the above specification is the limiting case as η tends to zero, which gives log-log preferences. In this case a proportional increase in both A_a

and A_m will also lead to a lower value of h_a. Put somewhat differently, from a development perspective, assuming that $\eta \le 0$, sustained improvements in technology lead to the movement of resources out of agriculture as long as the improvements in the agricultural sector are at least as large as the improvements in the nonagricultural sector.

GPR emphasized the fact that many poor countries are both relatively unproductive in agriculture yet devote most of their labor allocation to the production of agriculture. In the context of their preference specification, it followed that agricultural TFP was the key factor that led to this resource allocation. The above analysis shows that this result generalizes to a wider class of preferences. However, while the more general form of preferences preserves the result that an increase in A_a leads to a decrease in n_a, the generalization tends to reduce the magnitude of this effect. To see this, consider the special case in which $\theta = 0$ and preferences are log-log. The first order condition for this case becomes:

$$\frac{A_a}{A_a n_a - \bar{a}} = \frac{A_m}{A_m(1-n_a)+\bar{m}} \tag{19}$$

With the extreme form of preferences studied by GPR, n_a reduced by an amount that kept $A_a n_a$ constant. From the above expression it should be clear that if A_a increases, then $A_a n_a$ must also increase, so that with these preferences the elasticity of n_a with respect to A_a is smaller in absolute value.

B. Intermediate Inputs

In this section we extend the previous model to allow for intermediate goods that are produced by the manufacturing sector but used in the production of agricultural output. For simplicity, we will assume that the utility specification features a unitary elasticity of substitution between a and m, i.e., preferences are given by:

$$\alpha \log(a-\bar{a}) + (1-\alpha)\log(m+\bar{m}) \tag{20}$$

We also specialize the agricultural technology to be of the CES variety:

$$a = A_a F(L, M, H_a) = A_a[(1-\theta_x-\theta_n)L^\varepsilon + \theta_x x^\varepsilon + \theta_n n_a^\varepsilon]^{1/\varepsilon} \tag{21}$$

where x is the input of intermediate inputs from the manufacturing sector in the agricultural sector. The manufacturing technology is as before, but output from this sector can now be used either as consumption or as an input into the agricultural sector, so the feasibility constraint is now:

$$m + x = A_m h_m. \tag{22}$$

As before, there is an endowment of land that is set at unity.
Once again we solve the social planner's problem for this economy. It is now possible to have corner solutions for either one or both of consumption of the manufactured good and input of the intermediate good produced in the manufacturing sector. For simplicity, in what follows we focus on the case in which all solutions are interior, though the points being made carry over to the other cases as well. Writing the social planner's problem as:

$$\max_{n_a,x} \alpha \log(A_a F(1,x,n_a) - \overline{a}) + (1-\alpha)\log(A_m(1-n_a) - x + \overline{m})$$

we get two first order conditions:

$$\frac{\alpha[(1-\theta_x-\theta_n)L^\varepsilon + \theta_x x^\varepsilon + \theta_n n_a^\varepsilon]^{\frac{1}{\varepsilon}-1} A_a \theta_n n_a^{\varepsilon-1}}{A_a F(1,x,n_a) - \overline{a}} = \frac{(1-\alpha)A_m}{A_m(1-n_a) - x + \overline{m}} \tag{23}$$

$$\frac{\alpha[(1-\theta_x-\theta_n)L^\varepsilon + \theta_x x^\varepsilon + \theta_n n_a^\varepsilon]^{\frac{1}{\varepsilon}-1} A_a \theta_x x^{\varepsilon-1}}{A_a F(1,x,n_a) - \overline{a}} = \frac{(1-\alpha)}{A_m(1-n_a) - x + \overline{m}} \tag{24}$$

Dividing the two first-order conditions by each other yields:

$$\frac{\theta_n n_a^{\varepsilon-1}}{\theta_x x^{\varepsilon-1}} = A_m \tag{25}$$

which yields the equation:

$$x = [\frac{\theta_n}{A_m \theta_x}]^{1/(\varepsilon-1)} n_a \tag{26}$$

i.e., the optimal choice of x is a linear function of n_a. This result is basically a statement about optimal input use, and hence is the same result that we derived in the previous section. Proceeding as before, we can use this relationship to eliminate M from the Social planner's problem and reduce it to a problem of simply choosing n_a. For the special case of a Cobb-Douglas production function (i.e., the limiting case as ε tends to 0), then the social planner's Problem can be written as:

$$\max_{n_a} \alpha \log(B_1 A_a A_m^{\theta_x} n_a^{\theta_x+\theta_n} - \overline{a}) + (1-\alpha)\log(A_m(1+\frac{\theta_x}{\theta_n})(1-n_a) - B_2 - \overline{m}) \tag{27}$$

The key result that emerges is that the TFP in the manufacturing sector implicitly affects measured TFP in the agricultural sector when output is expressed in terms of labor and land. The key result is that in this model, a relatively low productivity in agriculture coupled with a large allocation of labor to the agricultural sector could be the result of either a low value of A_a or a low value of A_m. As in the previous analysis, because A_m enters the reduced form production function for agriculture with the exponent θ_x whereas the term A_a enters with a unit exponent, it follows that the effect of a change in A_a is larger, with the extent of the difference depending on the size of θ_x. The key point of this analysis was to show that the previous analysis about the effects of intermediate inputs carries over exactly to the case of more general preferences.

C. A Model with Transportation Costs

We now consider the case of transportation costs in the model with more general preferences. As in the last section, we consider the log-log specification of preferences. Because consumption must be indexed by location, the Social planner's problem for this economy is somewhat more complicated than the ones that we have studied previously, but it can be written as:

$$\max_{a_j, m_j, n_a} n_a[\alpha \log(a_a - \bar{a}) + (1-\alpha)\log(m_a + \bar{m})]$$
$$+ (1-n_a)[\alpha \log(a_m - \bar{a}) + (1-\alpha)\log(m_m + \bar{m})]$$

subject to:

$$n_a a_a + (1-n_a)\frac{a_m}{(1-q)} = A_a F(1, n_a)$$

$$(1-n_a)m_m + n_a \frac{m_a}{(1-q)} = A_m(1-n_a)$$

Once again there is the possibility of corner solutions for one or both of m_m and m_a, though as we will see soon, m_m cannot be zero if m_a is positive.

For now we proceed to characterize an interior solution, though it is easy to incorporate the possibility of corner solutions into the analysis. Let λ_a and λ_m be the Lagrange multipliers associated with the two constraints in the Social planner's problem. The first order conditions for the allocations of m and a can be written as:

$$\frac{\alpha}{a_a - \bar{a}} = \lambda_a \tag{28}$$

$$\frac{\alpha}{a_m - \bar{a}} = \frac{\lambda_a}{(1-q)} \tag{29}$$

$$\frac{(1-\alpha)}{m_a - \bar{a}} = \frac{\lambda_m}{(1-q)} \tag{30}$$

$$\frac{\alpha}{m_m - \bar{a}} = \lambda_m \tag{31}$$

It follows that:

$$a_m - \bar{a} = (1-q)(a_a - \bar{a}) \tag{32}$$

$$m_m + \bar{m} = \frac{(m_a + \bar{m})}{(1-q)} \tag{33}$$

These conditions imply that in an optimal allocation $a_a > a_m$ and $m_m > m_a$, which is intuitive, since it says that the presence of transportation costs leads individuals to consume relatively more of the good that is produced in their location. It is also true that the consumption allocation for the individuals in the manufacturing location are linear functions of the consumption allocation for the individuals in the agricultural location.

Given that the consumption allocations are linear functions of each other it turns out that it is very easy to solve for the optimal consumption allocations for a given allocation of workers across the locations. In particular, given a value of N_a, simple algebra gives:

$$a_a = A_a F(1, n_a) - (1-n_a)\bar{a}(1 - \frac{1}{1-q}) \tag{34}$$

$$m_a = (1-q)A_m(1-n_a) - \bar{m}(1-n_a) \tag{35}$$

With these expressions in hand we can now consider the decision of how to optimally allocate workers between the two sectors. Specifically, letting the allocations now all be considered as functions of n_a, we can consider the unconstrained solution to maximizing the objective function of the social planner's problem that has these functions substituted in:

$$\max_{n_a} n_a[\alpha \log(a_a(n_a) - \bar{a}) + (1-\alpha)\log(m_a(n_a) + \bar{m})] + (1-n_a)[\alpha \log(a_m(n_a) - \bar{a})$$
$$+ (1-\alpha)\log(m_m(n_a) + \bar{m})]$$

Defining U_a and U_m as the utility levels attained by individuals in the agricultural sector and the manufacturing sector respectively, the first order condition for an interior solution to this problem is:

$$U_a - U_m + \frac{n_a \alpha}{a_a - \bar{a}} a_a^{'} + \frac{n_a(1-\alpha)}{m_a + \bar{m}} m_a^{'} + \frac{(1-n_a)\alpha}{a_m - \bar{a}} a_m^{'} + \frac{(1-n_a)(1-\alpha)}{m_m + \bar{m}} a_a^{'} = 0 \tag{36}$$

Using the expression relating the consumption allocations we can show that:

$$U_a - U_m = (1-2\alpha)\log(1-q) \tag{37}$$

This expression implies that whether the workers in the agricultural sector or the manufacturing sector end up with the highest utility depends on the relative weights attached to the two different consumption goods in the utility function. If $\alpha > 1/2$, implying that the agricultural good has a greater weight, then $U_a > U_m$. Given that $\alpha < .5$ would seem to be the relevant empirical case based on expenditure shares in rich countries, it follows that $U_m > U_a$ would hold.

Also, from the expressions for the consumption allocations it follows that:

$$\frac{a_a^{'}}{a_a - \bar{a}} = \frac{a_m^{'}}{a_m - \bar{a}} \tag{38}$$

and

$$\frac{m_a^{'}}{m_a + \bar{m}} = \frac{m_m^{'}}{m_m + \bar{m}} \tag{39}$$

so that the first order condition can be written as:

$$(1-2\alpha)\log(1-q) + \frac{\alpha}{a_a - \bar{a}} a_a^{'} + \frac{(1-\alpha)}{m_a + \bar{m}} m_a^{'} = 0 \tag{40}$$

Assuming that $\theta = 0$, substitution for $a_a^{'}$ and $m_a^{'}$ leads to:

$$(1-2\alpha)\log(1-q) + \frac{\alpha}{n_a - [\frac{\bar{a}q/(1-q)}{A_a + \bar{a}q/(1-q)}]} = \frac{(1-\alpha)}{(1-n_a) - \frac{\bar{m}}{q\bar{m}-(1-q)A_m}} \tag{41}$$

It follows that the left hand side is decreasing in n_a while the right hand side is increasing in n_a, so that once again the optimal solution for n_a can be depicted as the intersection of two curves, one of which is upward sloping and one of which is downward sloping. In terms of comparative statics results, the effect of A_a on n_a remains the same: an increase in A_a leads to a downward shift of the downward sloping curve that represents the left hand side of the above equation, thereby leading to a decrease in n_a. The effect of an increase in q on n_a is somewhat more involved in this model. Intuitively, an increase in transportation costs leads to both substitution and income effects. Because an increase in transportation costs implies that more resources are used up in moving goods across locations they are associated with a negative income effect. As discussed previously, one effect of the terms $\bar{a}$ and $\bar{m}$ in preferences is to create a mechanism by which lower income leads to a greater allocation of labor to the agricultural sector. But changes in transportation costs also imply substitution effects, having a larger effect on the good that is being transported more heavily. These effects can be seen in the above expression.

To begin with, consider the case in which $\bar{a} = \bar{m} = 0$. In this case the terms involving q in the second and third terms disappear, so that the only term containing q is the first term. The effect of an increase in q on this term is determined by the sign of $(1-2\alpha)$. Specifically, if $\alpha > .5$, which means that the allocation of resources is biased toward the agricultural sector, then an increase in q leads to an increase in n_a. In contrast, if $\alpha < .5$, which means that the allocation of resources is biased toward the manufacturing good, then an increase in q leads to a decrease in n_a. In the case in which $\alpha = .5$, the allocation of labor is the same across sectors and an increase in q has no impact on the allocation of labor across locations. It should be noted that even though the allocation of labor is not affected, individual consumption allocations are affected, with consumers in each location receiving a consumption allocation that is more heavily biased toward the good that is produced in their location.

Loosely speaking, when $\bar{a} = \bar{m} = 0$, the effect of an increase in transportation costs is to create greater dispersion in the two labor allocations. This illustrates the substitution effects. To see the income effects, consider the case when $\alpha = .5$, in which case the first term in the above expression is equal to zero. Straightforward calculation shows that if $\bar{a}$ and $\bar{m}$ are strictly positive then the right hand side shifts down whereas the left hand side shifts up. The effect of each of these shifts is to increase n_a.

The result that emerges is that for an economy which allocates the majority of its labor to the agricultural sector and in which $\bar{a}$ and $\bar{m}$ are strictly positive, the effect of an increase in q is to increase the allocation of labor to the agricultural sector.

D. The Interaction of Intermediate Inputs and Transportation Costs

To simplify exposition we have thus far considered intermediate inputs and transportation costs in isolation from each other. However, there is in fact a simple interaction between the two which is important to point out. The key intuitive result from the extension to considering intermediate inputs was that low use of intermediate inputs leads to an effective reduction in agricultural productivity. In a model in which low agricultural productivity leads to higher employment in agriculture, use of intermediate inputs is an alternative channel influencing the allocation of workers to agriculture. In our analysis of the intermediate input case, we showed that low productivity in the production of intermediates acted in a similar fashion (though with a smaller magnitude) to low productivity in agriculture in terms of how it influences the allocation of labor. We commented at the end of that section that a policy distortion that serves to increase the relative price of the intermediate good would have the same effects. In this section we show that the introduction of transportation costs into a model with intermediate inputs in agriculture necessarily creates an effect of this sort.

The intuition is simple: if intermediate goods need to be transported to the agricultural region, then increases in transportation costs serve to increase the cost of intermediates, thereby lessening their use and leading to a reduction in labor productivity in that sector. In this section we quickly show this formally, in the simplest setting possible. Specifically, our starting point will be the intermediate good model studied in the previous subsection, with log-log preferences and a Cobb-Douglas production function, extended to assume that there is a cost associated with transporting intermediate goods for use in agriculture. To facilitate exposition, we abstract from transportation costs associated with moving the final goods between locations.

Given there is no cost associated with moving final goods between locations, the social planner will allocate the same final consumption to all individuals. As a result the social planner's problem now becomes:

$$\max_{n_a, x} \alpha \log(A_a x^{\theta_x} n_a^{\theta_n} - \bar{a}) + (1-\alpha)\log(A_m(1-n_a) - \frac{x}{1-q} + \bar{m})$$

Note that the presence of transportation costs for the intermediate good implies that $x/(1-q)$ good must be sacrificed in terms of consumption in order to have x units of intermediate input in the agricultural sector. Proceeding as before we get two first order conditions:

$$\frac{\alpha A_a \theta_n x^{\theta_x} n_a^{\theta_n - 1}}{A_a x^{\theta_x} n_a^{\theta_n} - \bar{a} - \bar{a}} = \frac{(1-\alpha)A_m}{A_m(1-n_a) - x/(1-q) + \bar{m}} \tag{42}$$

$$\frac{\alpha A_a \theta_x x^{\theta_x - 1} n_a^{\theta_n}}{A_a x^{\theta_x} n_a^{\theta_n} - \bar{a} - \bar{a}} = \frac{(1-\alpha)/(1-q)}{A_m(1-n_a) - x/(1-q) + \bar{m}} \tag{43}$$

Dividing the two first-order conditions by each other yields:

$$\frac{\theta_n n_a}{\theta_x x} = A_m(1-q) \tag{44}$$

which yields the equation:

$$x = \frac{\theta_x}{\theta_n} A_m(1-q) n_a \tag{45}$$

From this point on the analysis is exactly as before. In particular, this expression shows that from the perspective of the allocation of labor to agriculture, adding transportation costs that apply to the intermediate good acts just as if we were to reduce productivity of producing intermediates by a factor of $(1-q)$. That is, this model reduces to one in which there are no intermediate goods or transportation costs, and there is a linear technology for producing the agricultural good with TFP equal to $A_a[A_m(1-q)]^{\theta_x}$. It follows that in a model with transportation costs and intermediate inputs, increases in transportation costs necessarily produce effects along two channels.

5. Quantitative Analysis

The previous analysis has formally demonstrated three different channels that influence the allocation of labor to the agricultural sector in a setting in which some minimal amount of food is required. The goal of this section is to carry out a quantitative analysis to provide some information regarding the relative magnitudes of these effects, as well as to measure the welfare effects associated with these three channels.

In this section we consider a two sector model along the lines of the ones considered in the previous section, allowing for both intermediate goods as inputs into the agricultural sector, as well as symmetric transport costs that apply to movement of both final and intermediate goods across locations. Specifically, we assume as before that preferences are given by:

$$\alpha \log(a-\bar{a})+(1-\alpha)\log(m+\bar{m}) \tag{46}$$

We assume that output in the agricultural sector is given by a CES production function defined over land (L), intermediates (x) and labor (n_a):

$$a = A_a F(L,x,n_a) = A_a[(1-\theta_x-\theta_n)L^{\varepsilon}+\theta_x x^{\varepsilon}+\theta_n n_a^{\varepsilon}]^{\frac{1}{\varepsilon}} \tag{47}$$

Feasibility is determined by the two constraints:

$$n_a a_a + (1-n_a)\frac{a_m}{(1-q)} = A_a F(1,x,n_a) \tag{48}$$

$$(1-n_a)m_m + n_a\frac{m_a}{(1-q)} + \frac{x}{(1-q)} = A_m(1-n_a) \tag{49}$$

We study the social planner's problem for this economy, which as noted earlier, can be understood as the competitive equilibrium allocation that would emerge if we interpret our model as consisting of a large number of households each with a large number of members, where households maximize the average utility of their members. As noted earlier, the presence of the nonconvexity associated with the discrete location choice coupled with transportation costs implies that not all household members will end up with the same utility. This implies that households are implicitly making transfers across family members.

Many of the results that we derived in the previous section continue to hold in this model that features both intermediates and transportation costs. In particular, given an allocation of labor across the two locations and a choice of x that is feasible given the choice of n_a, we can derive closed form solutions for the consumption allocations. In particular, we have:

$$a_a = A_a F(1, x, n_a) - (1-n_a)\bar{a}\frac{q}{1-q} \tag{50}$$

$$a_m = (1-q)A_a F(1, x, n_a) + n_a q\bar{a} \tag{51}$$

As noted earlier, when $\bar{m} > 0$, it is possible that the solution for m_a will be zero even when there is positive production of the manufacturing good net of inputs into the agricultural sector. This is easily incorporated into the analysis. Specifically, we have:

$$m_a = \max\{(1-q)[A_m(1-n_a) - \frac{x}{1-q}] - (1-n_a)\bar{m}q, 0\} \tag{52}$$

$$m_m = \max\{A_m(1-n_a) - \frac{x}{1-q} + n_a\bar{m}\frac{q}{1-q}, A_m - \frac{x}{(1-n_a)(1-q)}\} \tag{53}$$

It follows that our previous results about consumption allocations continue to hold, namely that consumption in each location is biased toward consumption of the good produced in that location.

For a given value of n_a, and using the above allocation rules, increasing x shifts the overall consumption bundle as well as production from the manufacturing good toward the agricultural good. The optimal choice of x will equate the marginal rate of substitution between consumption of agriculture and manufacturing to the marginal rate of transformation between the two, taking into account transportation costs and the rule for allocating consumption within the family. A simple calculation shows that if all solutions are interior, then the choice of x should be such that the following holds:

$$\frac{(1-\alpha)}{\alpha}\frac{(a_a - \bar{a})}{(m_a + \bar{m})} = A_a F_2 \tag{54}$$

when the solutions for a_a and m_a are those derived above. If the marginal product of x is not equal to infinity when $x=0$ then it is possible that the solution for x may be interior. It is also possible that the optimal solution may be to allocate all of the output of the manufacturing sector as intermediate inputs in the agricultural sector, in which case both m_a and m_m will be zero.

We now turn to the quantitative analysis. We choose parameters so that the model captures some features of the Ugandan economy. The technology parameters A_a and A_m can be set to one without loss of generality, as this simply amounts to a choice of units. We also normalize the size of the population to equal one.

For our benchmark results we assume that the production function in the agricultural sector is Cobb-Douglas, and set $\theta_x = .2$ and $\theta_n = .4$, implying a share for land that is also equal to $.4$. The preference parameter α is set to $.20$. If $\bar{a}$ and $\bar{m}$ were zero, then expenditure shares would provide information on α. The parameters $\bar{a}$ and $\bar{m}$ become less relevant as a country becomes richer, so looking at expenditure shares for rich countries does provide information about α if we assume that preferences are the same across countries. If we were interpreting the agricultural sector output exclusively as food, then expenditure shares in a rich country such as the US would suggest that our value of α is somewhat on the high side, but we think it is reasonable to have a broader notion of agricultural output to include some clothing for example, thereby motivating the somewhat higher value for α.

In terms of how they influence labor allocations, the parameters $\bar{a}$ and $\bar{m}$ have the same effect, which is to lead to a greater allocation of labor to agriculture holding all else constant. In view of this we set $\bar{m}=0$ in our benchmark specification and rely on $\bar{a}$ to achieve the desired allocation of labor. In particular, we will choose $\bar{a}$ so that roughly 80% of the population works in the agricultural sector. The final parameter to be set is the transportation cost parameter q. For our benchmark results we set $q=.5$. Table 6 displays the equilibrium allocation that results from our calibrated economy.

Table 6: Allocations in the Benchmark Equilibrium

n_a / Pop	a_m	a_a	m_m	m_a	x
.800	.454	.458	.045	.023	.077

We now consider the effects of changes in several of the model's parameters for the equilibrium allocations and welfare. Our measure of welfare is standard. Specifically, let the benchmark equilibrium has n_a^* workers in the agricultural sector and a consumption allocation to be $(a_a^*, m_a^*, a_m^*, m_m^*)$ and suppose that the new allocation that emerges from a particular change in the economy is given by $n_a', a_a', m_a', a_m', m_m'$. We then ask what proportional change in the consumption bundle $(a_a^*, m_a^*, a_m^*, m_m^*)$, holding the labor allocation n_a fixed, would yield the same average utility as generated by the new allocation.
In our qualitative analysis we considered three key driving forces for the allocation of labor to agriculture: TFP in agriculture, TFP in manufacturing and transportation costs. We begin by exploring the impact of a ten percent improvement in each of these variables in isolation. Table 7 presents the results.

Table 7: Comparison of the Three Channels

Scenario	n_a / Pop	a_m	a_a	m_m	m_a	x	Δ
Benchmark	.800	.454	.458	.045	.023	.077	-
$A_a = 1.1$	.736	.460	.469	.103	.052	.081	.330
$A_m = 1.1$	.787	.455	.460	.063	.031	.086	.045
$q = .45$	.747	.457	.463	.080	.044	.095	.173
$A_a = 1.1$, $q = .45$	.681	.463	.474	.143	.079	.097	.769

Several points are worth noting. First, consistent with our theoretical analysis, all three changes result in a decline in the fraction of the population in the agricultural sector. Moreover, the ratio of θ_x to $\theta_x + \theta_n$ is 1/3 and the effect of a 10 percent increase in manufacturing TFP on labor allocated to agriculture is roughly 1/3 the size of the effect from a 10 percent increase in A_a. The effect of a ten percent improvement in transportation has an impact on labor allocated to agriculture that is roughly 80% as large as the ten percent increase in agricultural TFP. At least in this parameterization, the effects of improvements in transportation technology seem to be of roughly similar importance to equivalent improvements in agricultural TFP. Both are more important than improvements in the TFP for producing intermediate goods. This last result was predicted by our theoretical analysis, since we saw in the previous section that one of the effects of a 10 percent improvement in transportation is to mimic a ten percent improvement in the TFP for producing intermediates, but with some additional effects.

The welfare effects associated with these changes are huge–for example, a ten percent increase in A_a leads to a welfare increase of more than 30%. From a mechanical perspective, note that the source of this large increase is largely attributable to the fact that although the increase in the consumption levels is small, it represents a large percentage change m which is key to the welfare effect. Specifically, for the case of the increase in A_a, the value of m more than doubles for workers in both locations. To understand why a 10% improvement in technology in only one sector can have such a large effects, it is important to note that the welfare effect is highly nonlinear due to the presence of the $\bar{a}$ term. For example, if we considered the welfare increase associated with changing A_a by ten percent starting from a value of 2 instead of 1, and holding all other parameters fixed, then the welfare increase is only about half as large. Aside from noting the large welfare increases associated with small improvements in technology at low levels of development, it is also worth noting that the welfare effects associated with the increase in A_a are the largest in this economy, but that the welfare gain from a decrease in q is also very substantial.

Given that the economy devotes 80% of its labor to the agricultural sector, it should not be surprising that the welfare effect of a change in A_m is substantially lower than that associated with a change in A_a.

There are two different channels through which changes in q influence welfare. One effect is that fewer resources are used in transportation. A second effect is that consumption allocations are smoother across locations. It is of interest to know what the relative importance of these two effects is. It turns out that the second effect is extremely small: if we compute the utility gain associated with smoothing consumption across locations, keeping total consumption constant, then the welfare gain is only $.003$.

It is also instructive to notice how the consumption allocation changes to better appreciate the different mechanisms at work. Table 7 shows that in each case the consumption allocation increases along all dimensions, with the increase in consumption being the greatest for the increase in A_a. However, the increase in intermediates used in agriculture is actually smallest for this case. As noted earlier, the cases of increases in A_m and decreases in q both serve to decrease the relative price of intermediates, and therefore lead to a larger increase in intermediate usage relative to the case of an increase in A_a.

The last row of Table 7 reports the effects of having two of the changes occur simultaneously. The effect on the allocation of labor is roughly the sum of the two individual effects, but the improvement in welfare is much larger than the sum of the effects.

We next consider the effects of an increase in population size. It turns out that in a model with a fixed factor and food requirements, an increase in population pushes not only *more people* into agriculture but also a *greater fraction of the population* into this sector. This suggests that population increases (relative to available land) are also potentially an important factor in understanding the dynamics of labor allocation and productivity. Table 8 reports the results.

Table 8: The Effects of Population Growth

	n_a / Pop	a_a	a_m	m_a	m_m	x	Δ
Benchmark	.800	.454	.458	.045	.023	.077	-
$\text{Pop} = 1.1$	.826	.452	.454	.023	.011	.084	-.009
$\text{Pop} = 1.1,\ A_a = 1.038$	.800	.454	.458	.045	.023	.085	.000

The first row of Table 8 reports the results for a ten percent increase in population. We note that not only does this lead to a lower fraction of people in the manufacturing sector, but also that the absolute size of the population in this sector also decreases. There is also a modest decrease in welfare associated with a ten percent increase in population. Note that although fewer workers are working in the manufacturing sector, use of intermediate inputs in agriculture actually increases as a result of the population increase – a classic Boserupian effect.

The next row asks what increase in agricultural productivity would be required in order to restore the benchmark fraction of the population in agriculture. The answer turns out to be an increase of 3.8 percent. As this row shows, in this case the rest of the consumption allocation is also identical to that in the benchmark specification so that there is no net change in welfare either. But this table illustrates an important finding, which is that in the presence of a fixed amount of land, population increases require fairly substantial improvements in agricultural productivity just to maintain a constant share of the workforce devoted to agriculture.

The next issue we examine is how improvements in transportation (or lack thereof) influence a develop path. Table 9 reports the results.

Table 9: Development Paths

	n_a / Pop	a_a	a_m	m_a	m_m	x	Δ
Benchmark	.800	.454	.458	.045	.023	.077	-
$A_a = A_m = 2$	.344	.525	.599	1.01	.500	.150	10.45
$A_a = A_m = 2$, $q = .25$	.229	.614	.668	1.31	.980	.176	17.14

The second row shows that consequences of a doubling of TFP in both of the productive sectors. As the table shows, this had dramatic effects on the allocation of labor, the level of consumption and on welfare. In particular, the share of labor devoted to agriculture is more than cut in half, and the welfare increase is roughly a factor of ten. As in standard models, large improvements in TFP lead to large improvements in welfare.

The third row shows how the development path is altered if we assume that the large improvements in TFP in the two productive sectors are accompanied by an equivalent improvement in the transportation technology. The results are quite dramatic. In addition to producing an additional decline in the agricultural share of the workforce by roughly a third, we see that the welfare gain is almost doubled. Comparing the second and third rows, one can conclude that the consequences for development of neglecting transportation are very substantial.

A simple calculation that serves to quantify this is the following. Taking the third row of Table 9 as a benchmark, we can ask how large would the improvements in the TFP parameters A_a and A_m need to be in order to achieve the same movement of labor out of agriculture if there were no associated improvements in transportation. The answer is that they would have to increase to 2.8 in order to achieve this same outcome.

Conclusions

The analysis reported here begins with the somewhat obvious point that in a relatively closed economy in which food is an essential consumption good (and in which food must be produced domestically), agricultural productivity is linked directly to the fraction of the population working in the agricultural sector. If we observe a large number of people in this sector, with low productivity levels, we should not view the result as a paradox; instead, it is a natural implication of a simple model with subsistence food production.

Next, this paper shows that the presence of high transportation costs can exacerbate the effects of low agricultural productivity. In an economy where it is costly both to produce and to transport food, we should expect to find lots of people living in rural areas and producing their own food.

Finally, we explore in both a theoretical and quantitative sense the relative importance of changes in agricultural productivity, non-agricultural productivity, transportation costs, and population levels. We find that transportation costs have a large impact on allocations across sectors and on social welfare.

Does this paper offer much direct policy insight into Uganda's development needs? Our representation of transportation costs is highly abstract, and we do not consider the costs of building roads (i.e., reducing transportation costs), so we cannot offer any policy prescriptions about the amount of road building or transportation infrastructure that should be produced. However, at a practical level, it is difficult to imagine any development trajectory for Uganda that will not involve major investments in infrastructure. Whether this is carried out by the public sector or the private sector, and how it is financed, are questions beyond the scope of this paper. But our paper does suggest that Uganda is unlikely to see a large reduction in the size of its subsistence agricultural sector unless we see either an increase in agricultural productivity or a reduction in transport costs, or more likely both.

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