Agriculture, Roads, and Economic Development: Evidence from Uganda

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Agriculture, Roads, and Economic Development in Uganda

Background
Two-Region Model
Three-Region Model
Conclusions

Agriculture, Roads, and Economic Development

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Outline

1. Background and Motivation
2. Two-Region Model
3. Three-Region Model
4. Conclusions
Outline

1. Background and Motivation
   2. Two-Region Model
   3. Three-Region Model
   4. Conclusions
Large fractions of Uganda’s population live in rural areas (85%) and work in agriculture (73%).

Agricultural sector appears to have low productivity, relative to non-agriculture. Agriculture accounts for 20% of GDP, suggesting that output per worker in non-agriculture is greater by a factor of 12!

Poverty is relatively concentrated in rural areas (93%).

Poverty rates are much higher among rural households (34%) than urban households (14%).
Within rural Uganda, most individuals work in agriculture, although non-farm enterprises are also important. Farms primarily produce staple foods on small plots.

- Major crops are cooking bananas, cassava, maize, beans.
- Each of these is grown by approx. 75-85% of agricultural households.
- These four crops together account for 55% of crop area.
- Cash crops (coffee, tea, sugar, cotton) together account for less than 8% of cropped area.
Large-scale and smallholder agriculture

- A large-farm sector is found in tea, cotton, and sugar.
- Approximately 400 registered enterprises employing 28,000 workers.
- Smallholder farms account for almost all of agricultural employment and output.
- Approximately 4.2 million agricultural households employing approximately 8 million workers.
Semi-subsistence farming

- Most farms produce similar food crops on very small scale.
- Large fractions of output are consumed at home.
  - Banana (68%)
  - Cassava (77%)
  - Maize (48%)
  - Beans (84%)
- Households trade small amounts of their output, often selling in local markets to buy non-agricultural consumption goods and intermediate inputs: salt, soap, kerosene; farm tools and chemicals.
Puzzles:

- Why are so many people concentrated in a sector where they are so (relatively) unproductive?
- Within the sector, why do so many people live in semi-subsistence?
Possible explanations

- Low agricultural productivity in a landlocked economy: the “food problem” (Schultz 1955).
- Low non-agricultural productivity: non-agricultural consumption goods and manufactured inputs are very expensive, so many rural households do not seek to trade.
- High transportation costs: make food expensive in cities, limiting the size of urban populations; also make non-agricultural goods expensive in rural areas, reducing demand.
Evidence: Low agricultural productivity

- Uganda’s crop yields lag far behind world leaders in all crops but cassava.
- Maize yields only 30% of world average and 11% of world leaders.
- Yield deficits are large even relative to countries with similar agroecologies.
Crop yields are low

Uganda Crop Yields Relative to World Leaders

- Maize: 0.111
- Sorghum: 0.240
- Cassava: 0.692
- Beans: 0.161
- Coffee: 0.307
Evidence: Low non-agricultural productivity

- Average productivity is higher than in agriculture, but it is still low by world standards.
- Uganda exports very limited quantities of non-agricultural goods: some minerals (gold, cobalt, petroleum); soap; hand tools; and electric current.
Evidence: Remoteness and transportation

- Rural households are frequently remote:
  - Three-quarters live more than two hours from a market center.
  - One-quarter live more than five hours from a market center.

- Average distance to a health clinic was 7 km (including in cities); 77 percent of people report that they walk to get to clinics.
Transportation

- Roads are very bad, especially in rural areas.
- Measured transport costs are very high, and price wedges between different markets appear to be extremely high.
- The cost of moving 100 kg of agricultural goods 100 km was as high as $5.43 (trucking matoke from Mbarara to Lira), compared with $0.573 for corn in the US.
- Uganda’s paved road density in 2003 was 16,300 km in an area of 200,000 km².
- By contrast, Britain at the time the Romans left (AD 350) had 12-15,000 km of roads in an area of 240,000 km².
Bad roads
## Transport Costs

<table>
<thead>
<tr>
<th>Dried Cassava Marketing Costs</th>
<th>Ush/100 Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Farm Gate Price</strong></td>
<td></td>
</tr>
<tr>
<td>· Transport (Farm gate to primary market)</td>
<td>1000</td>
</tr>
<tr>
<td>· Market dues/local tax</td>
<td>200</td>
</tr>
<tr>
<td>· Capital costs and operating surplus</td>
<td>800</td>
</tr>
<tr>
<td><strong>Primary Market Price</strong></td>
<td>6000</td>
</tr>
<tr>
<td>· Bagging materials</td>
<td>500</td>
</tr>
<tr>
<td>· Labour costs (loading/unloading, sorting, weighing)</td>
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</tr>
<tr>
<td>· Transport (rural to urban market)</td>
<td>3500</td>
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<tr>
<td>· Market dues/local tax</td>
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<tr>
<td>· Trading Licence &amp; security</td>
<td>200</td>
</tr>
<tr>
<td>· Capital costs and operating surplus</td>
<td>1600</td>
</tr>
<tr>
<td><strong>Wholesale Market Price</strong></td>
<td>13000</td>
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</table>

Specific questions

- How would the economy respond to each of the following?
  - Improvements in agricultural productivity
  - Improvements in non-agricultural productivity
  - Reductions in transportation costs
  - Population growth

- How would these interventions alter the allocation of workers across sectors?

- How would they affect the prevalence of semi-subsistence agriculture?

- How would they affect welfare?
Outline

1. Background and Motivation
2. Two-Region Model
3. Three-Region Model
4. Conclusions
To answer these questions, we need a general equilibrium model with at least two sectors and with explicit transportation costs.

We also need to distinguish between agriculture that is “semi-subsistence” and more commercially oriented agriculture.
Related literature

- Also related to work on transportation and growth in Herrendorf, Schmitz, and Teixeira (2006, 2008); Adamopoulos (2005).
- Most similar to models of structural transformation in Gollin, Parente, and Rogerson (2004, 2007)
How to Drive an Economy into Subsistence
The Food Problem Bites...

- Closed economy.
- Food is essential.
- Labor productivity in agriculture is low and farmers cannot produce much surplus.
  \[\Rightarrow\] Large fractions of the labor force will be devoted to agriculture.
  \[\Rightarrow\] Increases in agricultural productivity will have a large impact on the proportion of people in agriculture.
Simplest Two-Sector Model

- Simplified static version of Gollin, Parente, and Rogerson (2002).
- Preferences given by: \( u(a - \bar{a}) + v(m + \bar{m}) \)
- Suppose in particular that 
  \[
  u(a - \bar{a}) = \begin{cases} 
  -\infty & \text{if } (a - \bar{a}) \leq 0 \\
  \tilde{a} & \text{if } (a - \bar{a}) > 0 
  \end{cases}
  \]
- Then individuals will seek to consume exactly \( \bar{a} \) units of food.
Technology

- Suppose manufacturing technology is given by $m = A_m n_m$.
- Agricultural technology is given by $a = A_a L^\theta n_a^{1-\theta}$.
- Let $A_a > \bar{a}$.
- Assume that the economy has one unit of land, equally distributed across the population, and that there is one unit of labor.
Equilibrium

- Solve for the competitive equilibrium by solving the Social Planner’s problem of allocating labor across sectors to maximize the utility of a representative household subject to feasibility constraints.

- In equilibrium, the number of workers in agriculture will be exactly enough to produce $\bar{a}$ units of food; i.e.,

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

- In this environment, a one percent increase in agricultural TFP $A_a$ will lead to an even larger percentage decrease in employment in agriculture, equal to $\frac{1}{1-\theta}$. 
In the simplest model, productivity gains in non-agriculture have no effect. How do we allow for that causal possibility?

- Suppose manufacturing goods can be used as intermediate inputs in agriculture.
- Let $x$ denote the input of the manufactured good used in the agricultural sector.
- Agricultural technology is now $a = A_a l^{(1 - \theta_x - \theta_n)} x^{\theta_x} n_a^{\theta_n}$. 

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Social Planner’s Problem

- Social Planner now solves:

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

\[
s.t. \quad \bar{a} = A_a x^{\theta_x} n_\theta ^{\theta_n}
\]

- Solution gives: \( n_a = B \left[ \frac{1}{A_a A_m^{\theta_x \theta_n}} \right]^{1/(\theta_n + \theta_x)} \).

- Increases in either \( A_a \) or \( A_m \) will reduce the labor in agriculture, but agricultural productivity will have a slightly higher impact.
How do we allow for the possibility that transportation costs may affect allocations?

- Assume that there are iceberg transportation costs associated with moving any goods from one region to another.
- A fraction $q$ is lost when agricultural goods are moved from the rural area to the city.
- Symmetrically, a fraction $q$ is lost when manufactured consumption goods are moved from the city to the rural area.
Technology

- Technologies are the same as initial model:
  - $a = A_a l^\theta n_a^{1-\theta}$
  - $m = A_m n_m$
Feasibility

- Market clearing in agriculture requires:
  \[ n_a a_a + (1 - n_a) \frac{a_m}{(1-q)} = A_a l^\theta n_a^{1-\theta} \]

- Market clearing in non-agriculture:
  \[ (1 - n_a) m_m + n_a \frac{m_a}{(1-q)} = A_m n_m \]
Assuming the restrictive specification for preferences, we get
\[ n_a \bar{a} q \frac{q}{1-q} = \bar{a} \frac{q}{1-q} - A_a n_a^{1-\theta}. \]

If we further impose \( \theta = 1 \), so that agricultural production is linear in labor, we get: \( n_a = \frac{\bar{a}}{\bar{a}q + (1-q)A_a}. \)

An increase in \( A_a \) leads to a decrease in \( n_a \).

Since (by assumption) \( A_a > \bar{a} \), a decrease in \( q \) will also lead to a decrease in \( n_a \).
Transport Costs and Intermediate Inputs

- Transport costs by themselves lead to more workers in agriculture, simply because they imply that more agricultural output is required to support a given number of workers in the city.
- But transport costs also have an important interaction with intermediate inputs.
- A transport cost that makes it expensive to move manufactured goods from the city to rural areas will function like a price distortion or barrier, and will reduce the demand for manufactured inputs in agriculture.
- This in turn reduces the number of people who are needed in cities.
A Complete Two-Sector Model

- Preferences more general: $\alpha \log(a - \bar{a}) + (1 - \alpha) \log(m + \bar{m})$
- Agricultural technology: $a = A_a F(l, x, n_a) = A_a l^{1-\theta_x-\theta_n} x^{\theta_x} n^{\theta_n}$
- Manufacturing technology: $m = A_m n_m$. 
Markets for agriculture and non-agriculture clear, net of iceberg costs.

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

\[
(1 - n_a) m_m + n_a \frac{m_a}{(1 - q)} + \frac{x}{(1 - q)} = A_m (1 - n_a)
\]
Closed form solutions are obtainable for this model.

Allocations of agricultural goods:

\[ a_a = A_a F(1, x, n_a) - (1 - n_a) \bar{a} \frac{q}{1 - q} \]

\[ a_m = (1 - q) A_a F(1, x, n_a) + n_a q \bar{a} \]
Allocations of manufactured consumption:

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

\[ m_m = \max \{A_m (1 - n_a) - \frac{x}{1 - q} + n_a \bar{m} \frac{q}{1 - q}, A_m - \frac{x}{(1 - n_a)(1 - q)}\}\]
Intermediate goods allocation (assuming interior solution):

\[
\frac{(1 - \alpha)}{\alpha} \frac{(a_a - \bar{a})}{(m_a + \bar{m})} = A_a F_2
\]
Quantitative Experiment

- Choose parameters to match some observations from Ugandan economy.

  - $A_a = A_m = 1$
  - $\theta_x = .2$, $\theta_n = .4$
  - $\alpha = .20$
  - $\bar{m} = 0$
  - $\bar{a} \Rightarrow n_a = 0.80$
  - $q = 0.5$
Benchmark equilibrium allocations:

<table>
<thead>
<tr>
<th>$n_a/\text{Pop}$</th>
<th>$a_m$</th>
<th>$a_a$</th>
<th>$m_m$</th>
<th>$m_a$</th>
<th>$x$</th>
</tr>
</thead>
<tbody>
<tr>
<td>.800</td>
<td>.454</td>
<td>.458</td>
<td>.045</td>
<td>.023</td>
<td>.077</td>
</tr>
</tbody>
</table>
Comparative Statics

- Consider three scenarios:
  - 10% increase in agricultural TFP
  - 10% increase in manufacturing TFP
  - 10% reduction in transport cost

- Welfare comparison: Ask how by what fraction the benchmark consumption bundle would need to be increased in order to yield the same utility as each scenario.
## Comparative Statics Results

### Two-Sector Model

<table>
<thead>
<tr>
<th>Channel</th>
<th>$n_a/Pop$</th>
<th>$a_m$</th>
<th>$a_a$</th>
<th>$m_m$</th>
<th>$m_a$</th>
<th>$x$</th>
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<tbody>
<tr>
<td>Benchmark</td>
<td>.800</td>
<td>.454</td>
<td>.458</td>
<td>.045</td>
<td>.023</td>
<td>.077</td>
<td>-</td>
</tr>
<tr>
<td>$A_a = 1.1$</td>
<td>.736</td>
<td>.460</td>
<td>.469</td>
<td>.103</td>
<td>.052</td>
<td>.081</td>
<td>.33</td>
</tr>
<tr>
<td>$A_m = 1.1$</td>
<td>.787</td>
<td>.455</td>
<td>.460</td>
<td>.063</td>
<td>.031</td>
<td>.086</td>
<td>.045</td>
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<tr>
<td>$q = .45$</td>
<td>.747</td>
<td>.457</td>
<td>.463</td>
<td>.080</td>
<td>.044</td>
<td>.095</td>
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<tr>
<td>$A_a = 1.1, q = .45$</td>
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<td>.463</td>
<td>.474</td>
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<td>.079</td>
<td>.097</td>
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## The Effects of Population Growth

<table>
<thead>
<tr>
<th></th>
<th>$n_a/Pop$</th>
<th>$a_a$</th>
<th>$a_m$</th>
<th>$m_a$</th>
<th>$m_m$</th>
<th>$x$</th>
<th>$\Delta$</th>
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<tbody>
<tr>
<td>Benchmark</td>
<td>.800</td>
<td>.454</td>
<td>.458</td>
<td>.045</td>
<td>.023</td>
<td>.077</td>
<td>–</td>
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<tr>
<td>Pop = 1.1</td>
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<td>.452</td>
<td>.454</td>
<td>.023</td>
<td>.011</td>
<td>.084</td>
<td>–.009</td>
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<tr>
<td>Pop = 1.1, $A_a = 1.038$</td>
<td>.800</td>
<td>.454</td>
<td>.458</td>
<td>.045</td>
<td>.023</td>
<td>.085</td>
<td>.000</td>
</tr>
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</table>
## Development Paths

<table>
<thead>
<tr>
<th>Development Paths</th>
<th>$n_a/Pop$</th>
<th>$a_a$</th>
<th>$a_m$</th>
<th>$m_a$</th>
<th>$m_m$</th>
<th>$x$</th>
<th>$\Delta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benchmark</td>
<td>.800</td>
<td>.454</td>
<td>.458</td>
<td>.045</td>
<td>.023</td>
<td>.077</td>
<td>–</td>
</tr>
<tr>
<td>$A_a = A_m = 2$</td>
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<td>.525</td>
<td>.599</td>
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<td>.50</td>
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<td>10.45</td>
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<tr>
<td>$A_a = A_m = 2, q = .25$</td>
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<td>.614</td>
<td>.668</td>
<td>1.31</td>
<td>.980</td>
<td>.176</td>
<td>17.14</td>
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</tbody>
</table>
Outline

1. Background and Motivation
2. Two-Region Model
3. Three-Region Model
4. Conclusions
Next, we consider a three-region version of the model. Why? Not so much for the theoretical contribution...

In Uganda, many questions from policy makers about quasi-subsistence agriculture.

- Why are so many households located in this sector?
- How might the size of this sector respond to increases in productivity or reductions in transportation costs?
- Should improvements be targeted to this sector or others?
To address these questions, we introduce a third region to our model.

The new region also produces agricultural goods.

The two agricultural regions differ in that one is “close” to the city and the other is “remote.”
Background
Two-Region Model
Three-Region Model
Conclusions

Schematic Representation

Remote Agriculture

Region 2

Near Agriculture

Region 1

City Manufacturing

Region 0

\[
\text{Cost } q_1 \quad \text{Cost } q_2
\]

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Three-Region Model

Endowments

- $l_1 = 0.1$
- $l_2 = 0.9$
- Labor is allocated endogenously.
Feasibility Conditions

\[ n_0 m_0 + n_1 \frac{m_1 + x_1}{1 - q_1} + n_2 \frac{m_2 + x_2}{(1 - q_1)(1 - q_2)} = A m n_0 \]

\[ n_0 \frac{a_0}{(1 - q_1)} + n_1 a_1 + n_2 (1 - q_2) a_2 = \frac{A}{a} l_1^{1-\theta_x-\theta_n} x_1^{\theta_x} n_1^{\theta_n} + (1 - q_2) A l_2^{1-\theta_x-\theta_n} x_1^{\theta_x} n_1^{\theta_n} \]
Equilibrium Allocations

- For interior solution:

\[
m_0 + \bar{m} = \frac{m_1 + \bar{m}}{(1 - q_1)} = \frac{m_2 + \bar{m}}{(1 - q_1)(1 - q_2)}
\]

\[
\frac{a_0 - \bar{a}}{(1 - q_1)} = a_1 - \bar{a} = (1 - q_2)(a_2 - \bar{a})
\]

- Corner solutions are plausible under some specifications. We solve for them and check for them computationally.
Most parameter values are the same as in the two-sector model. Exception: need two transport costs.

- $A_a = A_m = 1$
- $\theta_x = .2, \theta_n = .4$
- $\alpha = .20$
- $\bar{m} = 0$
- $\bar{a} \Rightarrow n_1 + n_2 = 0.80$
- $q_1 = 0.1, \ q_2 = 0.6$
Benchmark Allocations

<table>
<thead>
<tr>
<th>Consumption Allocations: Three Region Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n_1$</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>.096</td>
</tr>
</tbody>
</table>

- Individuals in the “near” agricultural region consume bundles quite similar to urban residents.
- Individuals in the “remote” agricultural region seem to be in quasi-subsistence.
Agriculture Production: Three Region Model

<table>
<thead>
<tr>
<th>(l_1/n_1)</th>
<th>(l_2/n_2)</th>
<th>(x_1/n_1)</th>
<th>(x_2/n_2)</th>
<th>(y_{a1}/n_1)</th>
<th>(y_{a2}/n_2)</th>
<th>(y_{a1}/l_1)</th>
<th>(y_{a2}/l_2)</th>
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</thead>
<tbody>
<tr>
<td>1.04</td>
<td>1.27</td>
<td>.187</td>
<td>.066</td>
<td>.73</td>
<td>.64</td>
<td>.70</td>
<td>.50</td>
</tr>
</tbody>
</table>

- Labor intensity is greater in near region.
- Far greater use of intermediates in near region.
- Output per unit of land (yield) is 40% higher in the near region.
- Differences in output per worker are not large.
### Equilibrium Scenarios

#### Experiments in the Three Region Model: Consumption Allocations

<table>
<thead>
<tr>
<th></th>
<th>$n_1$</th>
<th>$n_2$</th>
<th>$a_0$</th>
<th>$a_1$</th>
<th>$a_2$</th>
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<th>$m_2$</th>
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<tr>
<td>$A_a$, $A_m$, $q$</td>
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### Experiments in the Three Region Model: Agricultural Production

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<tr>
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<th>$y_{a1}/n_1$</th>
<th>$y_{a2}/n_2$</th>
<th>$y_{a1}/l_1$</th>
<th>$y_{a2}/l_2$</th>
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<tr>
<td>Benchmark</td>
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<td>.70</td>
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<td>.77</td>
<td>.86</td>
<td>.53</td>
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<tr>
<td>$A_m = 1.1$</td>
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<td>.66</td>
<td>.75</td>
<td>.51</td>
</tr>
<tr>
<td>$q = .9q$</td>
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<td>.51</td>
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<td>$A_a, A_m, q$</td>
<td>.77</td>
<td>.91</td>
<td>.95</td>
<td>.54</td>
</tr>
<tr>
<td>$A_a, q$</td>
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<td>.86</td>
<td>.88</td>
<td>.54</td>
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<tr>
<td>$l_1 = .2$</td>
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<td>.75</td>
<td>.78</td>
<td>.47</td>
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<tr>
<td>Pop 1.1</td>
<td>.71</td>
<td>.59</td>
<td>.70</td>
<td>.53</td>
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</table>
### Experiments in the Three Region Model: Agricultural Production

<table>
<thead>
<tr>
<th></th>
<th>$l_1/n_1$</th>
<th>$l_2/n_2$</th>
<th>$x_1/n_1$</th>
<th>$x_2/n_2$</th>
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<td>.066</td>
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<td>1.44</td>
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<td>.080</td>
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<td>.200</td>
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<td>.097</td>
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<td>1.68</td>
<td>.254</td>
<td>.137</td>
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<tr>
<td>$A_a, q$</td>
<td>.88</td>
<td>1.59</td>
<td>.225</td>
<td>.115</td>
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<tr>
<td>$l_1 = .2$</td>
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<tr>
<td>$Pop 1.1$</td>
<td>1.02</td>
<td>1.11</td>
<td>.176</td>
<td>.058</td>
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</tbody>
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Findings

- Improvements in agricultural TFP have a pronounced negative impact on the number of people working in quasi-subsistence.
- Improvements in agricultural TFP may actually lead to an increase in the number of people working in commercial agriculture.
- Decreases in transportation cost lead to decreases in the total agricultural population and in particular the proportion of people in quasi-subsistence.
- Crop yields in remote areas do not change very much with interventions. There may be little feasible way to affect these yield levels, even if agricultural TFP increases, because of compensating changes in labor allocations.
Environmental Impacts to Note

- Very low input use in subsistence sector.
- Population growth drives up the number of people in subsistence sector; places pressure on extensive margins.
- Improvements in transportation alleviate pressure on the extensive margin and add people to cities.
Outline

1. Background and Motivation
2. Two-Region Model
3. Three-Region Model
4. Conclusions
In an effectively closed economy, with agricultural goods displaying high income elasticities of demand, improvements in agricultural productivity necessarily matter.

Agricultural productivity increases will release labor (and potentially other resources) to other sectors.

High transportation costs will tend to keep people “stuck” in rural areas.
Caveats

- Lots of things missing from the model...
- If transportation improvements involve road construction, keep in mind that:
  - Road building is expensive.
  - Environmental impacts of roads may be large and negative.
  - Political and social costs may be substantial.
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Gollin and Rogerson in Uganda