The Role of Electricity Investments in Africa's Growth: A Macroeconomic Analysis

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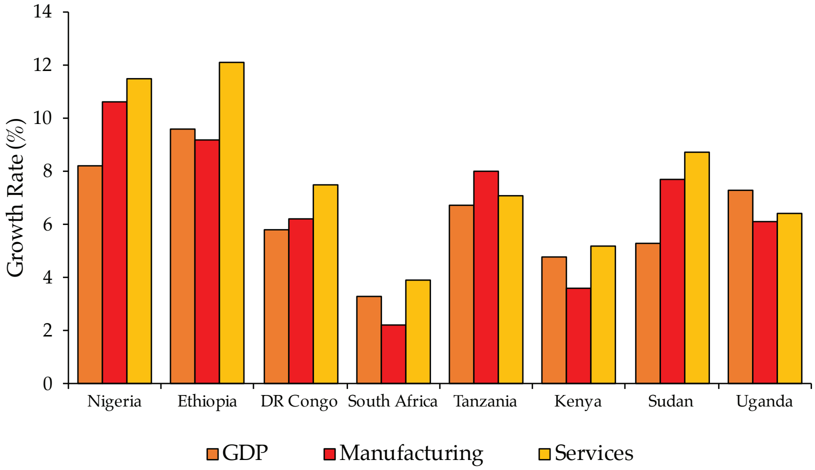
June 2, 2016

Sub-Saharan Africa's Dramatic Growth Since 2000

	1990s	Since 2000
Annualized GDP Growth Rate	2.5	6.0
Countries with GDP Growth $\geq 5\%$	5	16
% of Population in Country w/ Growth $\geq 5\%$	14	66

Countries with 5% annualized growth doubled their GDP since 2000.

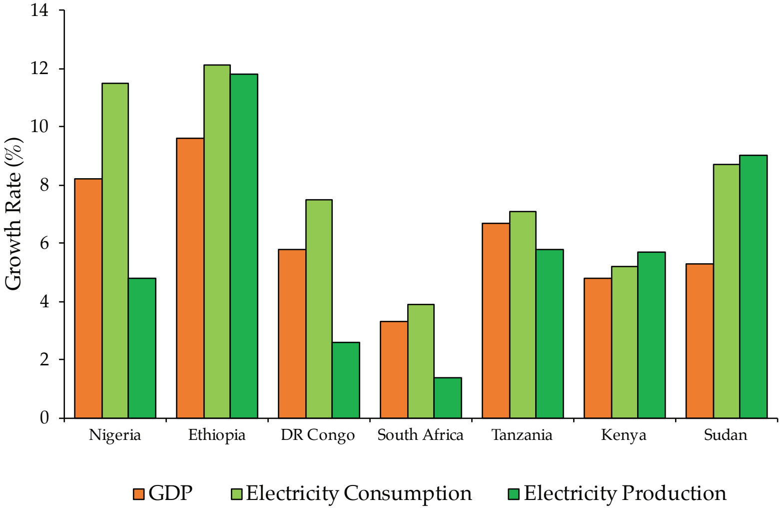
Africa's Growth in Manufacturing and Services Since 2000



Africa's Sources of Growth

- Many potential sources; relative importance not yet well understood
- This paper focuses on role of electricity investments
- Many African countries have made massive investments in electric power
- Hard to imagine robust non-agricultural growth without electricity

Africa's Electricity Growth Since 2000



Much of Electricity Growth is Hydropower

Figure: Gilgel Gibe III Dam in Ethiopia

Much of Electricity Growth is Hydropower

- Hydropower $\sim$ around 70% of total in Sub-Saharan Africa, excluding South Africa (Eberhard et al, 2011)

- Exceptions like South Africa (coal), Nigeria (gas), Senegal (Oil)

- Enormous future potential, e.g. Inga 3 project at mouth of Congo River

GDP Growth Strongly Correlated with Electricity Growth

Correlation with Electricity Growth, 18 SSA countries

	Correlation Coefficient	*p*-value
GDP growth	0.63	0.007
Manufacturing GDP growth	0.76	0.001
Services GDP growth	0.63	0.008

This Paper: Quantify Role of Electricity in Africa's Growth

- How much of Africa's growth was caused by electricity investments?
- Challenge: reverse causality: growth increases the demand for electricity, and non-agricultural goods, which use more electricity
- Direct econometric approach – instruments at country level – very hard

This Paper: Quantify Role of Electricity in Africa's Growth

- Our approach: use "structural" macro approach

- Measure electricity supply increases directly

- Discipline demand side using (known) income elasticities of demand

  - for electricity

  - for non-agricultural goods, which use electricity intensively

  $\Rightarrow$ Constrains magnitude of "reverse causality" story

Results So Far

- Focus on Africa's 6 largest economies, excluding South Africa, since 2000
- Electricity accounts for $\sim$ one third of growth in GDP/capita
- Range: 23% to 48% for Nigeria, Ethiopia, Kenya, Tanzania and Sudan; Just 2% in DR Congo
- Quantitative conclusions depend on labor/capital being poor substitutes for electricity in model

Model

Households and Preferences

Preferences

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U(C_{a,t}, C_{n,t}, C_{e,t})$$

where

$$U(C_{a,t}, C_{n,t}, C_{e,t}) = \omega_a \log(C_{a,t} - \bar{a}) + \omega_n \log(C_{n,t}) + \omega_e \log(C_{e,t})$$

– $C_{a,t}$, $C_{n,t}$, $C_{e,t}$: consumption of agriculture, non-agriculture and electricity

– $\bar{a}$ is a "subsistence need"; relative demand for C_n and C_e rise with income

– follow structural change lit., i.e. Herrendorf, Valentinyi, Rogerson (2014)

Production Technologies

Agriculture sector:

$$Y_{a,t} = A_t K_{a,t}^{\theta} N_{a,t}^{1-\theta}$$

Non-agriculture sector:

$$Y_{n,t} = A_t \left[\mu (K_{n,t}^{\theta} N_{n,t}^{1-\theta})^{\frac{\epsilon-1}{\epsilon}} + (1-\mu) E_{n,t}^{\frac{\epsilon-1}{\epsilon}} \right]^{\frac{\epsilon}{\epsilon-1}}$$

– $E_{n,t}$ is electric power input

– ϵ is elasticity of substitution between E and K-N aggregate input

– less substitutability when $\epsilon \to 0$

– follows macro-energy literature, e.g. Hassler, Krussell and Olavsson (2015)

Electric Power Sector

Production Function

$$E_t = \chi K_{e,t}^{\phi} N_{e,t}^{1-\phi}$$

Electricity capital and labor inputs

- K_e is "electricity capital" e.g. hydroelectric dams, power lines
- Law of motion: $K_{e,t+1} = K_{e,t}(1-\delta) + I_{e,t}$
- $I_{e,t}$ financed through taxation, chosen by government
- $N_{e,t}$ hired competitively in labor market
- Resource contraint: $E_t = E_{n,t} + C_{e,t}$

Household Budget Constraint and Capital Accumulation

Budget constraint

$$C_{n,t} + p_{a,t} C_{a,t} + p_{e,t} C_{e,t} + I_t \leq w_t + r_t K_t + \Pi_{e,t} - T_t$$

where

- w_t is labor income, $r_t K_t$ is capital income
- $\Pi_{e,t}$ is profits from electricity sector
- T_t is tax bill (equal to $I_{e,t}$)
- Law of Motion for (non-energy) capital: $K_{t+1} = K_t(1-\delta) + I_t$

Sources of Growth in Model

- Two exogenous sources of growth in model

    1. Increases in total-factor productivity, A_t

    2. Investments in electricity, $I_{e,t}$

- Both also lead endogenously to more private investment/capital, K_t

- Through lens of model, all GDP per capita growth ultimately due to $I_{e,t}$ increases (which we measure directly), or A_t increases (the residual)

Quantifying Sources of Growth using Model

- Focus on two steady states of model: "before 2000" and "after 2000"

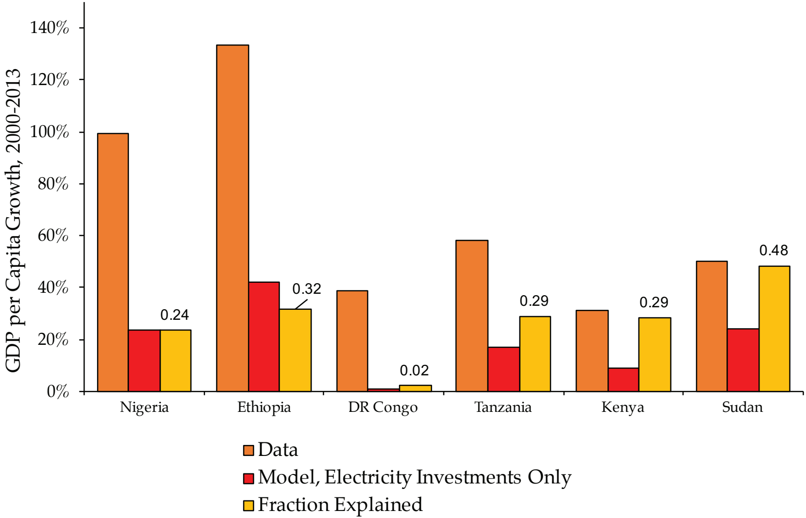
- Calibrate model to Ethiopia before 2000; match agriculture employment share (73%), energy investments/GDP (1%), GDP per capita ($621), electricity per capita (21 kwh / capita)

- Pick $\epsilon = 0.4$, following Krusell, Hassler, Olavsson (2015)

- Increase electricity investments, $I_{e,t}$ to match electricity growth since 2000; increase total-factor productivity, A_t, to match GDP per capita growth

- Repeat for Nigeria, Kenya, DR Congo, Tanzania and Sudan

Quantitative Results: Growth of GDP per Capita



Preliminary Conclusions and Future Work

- Africa since 2000: high GDP/capita growth & large electricity investments

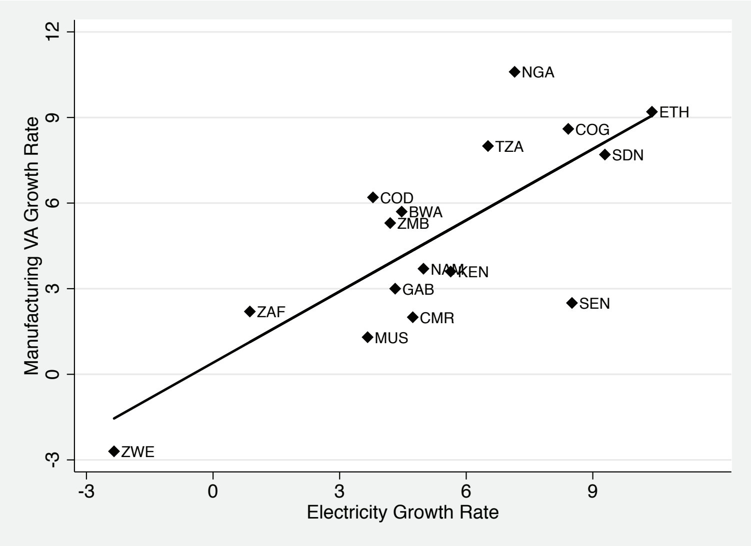
- Structural macro model: electricity investments explain $\sim$ one third of growth in six large African countries

- Conclusions depend on electricity and other inputs being poor substitutes

- Future work: better identification of elasticity of substitution; solve full transition; add other African countries; internal evidence from Ethiopia

Extra Slides

Growth Strongly Correlated with Change in Electricity



Decomposing Growth Since 2000 Using Model

- First compute steady state with fixed levels of $\{A_a, A_n, I_e\}$
- Do so by calibrating to match levels in 1990
- Then compute steady state with higher levels $\{A'_a, A'_n, I'_e\}$
- Pick values of $\{A'_a, A'_n, I'_e\}$ to match data in 2016
- Model matches all growth by construction
- Decompose growth into three sources; ask what fraction due to electricity

Parameterization

– Pick $\omega_a = 0.02$, $\omega_n = 0.97$ and $\omega_e = 0.01$ to match U.S. ("long-run") expenditures shares

– Standard macro choices of $\beta = 0.96$, $\delta = 0.07$, and $\theta = 0.33$ to match returns on capital, depreciation and capital income share in GDP

– Pick $\phi = 0.99$ to get 1% labor income share in electricity VA

– Pick $\mu = 0.97$ to get 3% VA share of energy in non-agriculture

– Pick $\epsilon = 0.5$ as benchmark value; sensitivity analysis later

– Pick $A_n = A_a$ for now and $A_n = 1$, $\chi = 1$ as normalization on units

– Calibrate $\bar{a}$ and I_e to match Ethiopia's 2000 steady state: (1) agriculture employment share of 75%, (2) electricity investment to GDP of 0.5%

Model's Other Quantitative Predictions

- Model predicts large movements of workers from agriculture to non-agriculture with electricity investments

- Data: movements out of agriculture, but not as large as model

- Likely to be frictions to worker reallocation that are not in model

Solution to Model

Steady State Solution to Model

From steady state Euler Equation

$$r = 1/\beta + \delta - 1 \tag{1}$$

From FOC for K_a

$$\frac{K_a}{N_a} = (p_a A_a \theta r^{-1})^{\frac{1}{1-\theta}} \tag{2}$$

From FOC for N_a

$$w = p_a A_a \left(\frac{K_a}{N_a}\right)^{\theta} (1-\theta) \tag{3}$$

Steady State Solution to Model

From FOC for K_n

$$A_n\left[\mu(K_n^{\theta}N_n^{1-\theta})^{\frac{\epsilon-1}{\epsilon}}+(1-\mu)E_n^{\frac{\epsilon-1}{\epsilon}}\right]^{\frac{1}{\epsilon-1}}(K_n^{\theta}N_n^{1-\theta})^{\frac{-1}{\epsilon}}\mu\theta\left(\frac{K_n}{N_n}\right)^{\theta-1}=r \quad (4)$$

From FOC for K_a

$$A_n\left[\mu(K_n^{\theta}N_n^{1-\theta})^{\frac{\epsilon-1}{\epsilon}}+(1-\mu)E_n^{\frac{\epsilon-1}{\epsilon}}\right]^{\frac{1}{\epsilon-1}}(K_n^{\theta}N_n^{1-\theta})^{\frac{-1}{\epsilon}}\mu(1-\theta)\left(\frac{K_n}{N_n}\right)^{\theta}=w \quad (5)$$

Ratio of (5) to (4)

$$\frac{1-\theta}{\theta}\frac{K_n}{N_n}=\frac{w}{r} \quad (6)$$

Steady State Solution to Model

From FOC for E

$$A_n\left[\mu(K_n^\theta N_n^{1-\theta})^{\frac{\epsilon-1}{\epsilon}} + (1-\mu)E_n^{\frac{\epsilon-1}{\epsilon}}\right]^{\frac{1}{\epsilon-1}} E_n^{\frac{-1}{\epsilon}}(1-\mu) = p_e \tag{7}$$

Instead of (7), ratio of (4) to (7)

$$\frac{(K_n^\theta N_n^{1-\theta})^{\frac{-1}{\epsilon}}\mu\theta(\frac{K_n}{N_n})^{\theta-1}}{(1-\mu)E_n^{-1/\epsilon}} = \frac{r}{p_e} \tag{8}$$

Reshuffling the above

$$N_n = x^{-\epsilon}(\frac{K_n}{N_n})^{-\theta} \tag{9}$$

where $x = (K_n^\theta N_n^{1-\theta})^{\frac{-1}{\epsilon}}$, and can be backed out from (8)

Steady State Solution to Model

From energy producer's FOC for N_e

$$N_e = (\chi p_e(1-\phi)w^{-1})^{\frac{1}{\phi}} K_e \tag{10}$$

From energy producer's profit function

$$\Pi_e = p_e E - w N_e \tag{11}$$

Notice that energy producer has profits because has fixed energy capital stock with which to produce

Steady State Solution to Model

Household FOC for C_a and C_n

$$C_a = p_a^{-1} C_n \frac{\omega_a}{\omega_n} + \bar{a} \tag{12}$$

Budget constraint in steady state

$$C_n = \omega_n [w + k(r - \delta) + \Pi_e - T - p_a \bar{a}] \tag{13}$$

Household FOC for C_e and C_n

$$C_e = p_e^{-1} C_n \frac{\omega_e}{\omega_n} \tag{14}$$