The Role of Energy Capital in Accounting for Africa's Recent Growth Resurgence

Stephie Fried[a] and David Lagakos[b]

[a]Carleton College, [b]UCSD and NBER

IMF Workshop on Macroeconomic Policy and Income Inequality
February 9-10, 2017

Energy as a Driver of Growth in Sub-Saharan Africa?

In Sub-Saharan Africa since 2000 we have seen:

1. Large increases in per capita GDP
2. Large increases in per capita energy consumption

Energy as a Driver of Growth in Sub-Saharan Africa?

In Sub-Saharan Africa since 2000 we have seen:

1. Large increases in per capita GDP
2. Large increases in per capita energy consumption

Our question

- How much of the growth was driven by energy investment?

Structural Macro Approach

Quantitative general equilibrium model

- Three goods: agriculture, non-agriculture, and energy
- Subsistence level of ag. consumption (e.g. Herrendorf et al)
- Non-agriculture production requires energy
- Most energy capital is financed by the government

Structural Macro Approach

Quantitative general equilibrium model

- Three goods: agriculture, non-agriculture, and energy
- Subsistence level of ag. consumption (e.g. Herrendorf et al)
- Non-agriculture production requires energy
- Most energy capital is financed by the government

Counterfactual experiment

- How much growth if Africa ↑ energy capital but nothing else?
- Six largest Sub-Saharan African countries

Contributions

1. Document new stylized facts on energy and growth

2. Energy investment explains $\approx$ one third of growth on average

Contributions

1. Document new stylized facts on energy and growth
   - Growth in GDP and energy consumption strongly correlated
   - UDI World Electric Power Plants Data Base

2. Energy investment explains $\approx$ one third of growth on average

Contributions

1. Document new stylized facts on energy and growth
   - Growth in GDP and energy consumption strongly correlated
   - UDI World Electric Power Plants Data Base
2. Energy investment explains $\approx$ one third of growth on average
   - Big per capita increases in energy use
   - Energy is an important input in non-agriculture production
   - Pre-2000 levels of energy use are very small

Related Literature

Micro studies: effects of energy investments on development

- e.g. Lipscomb, Mobarak, and Barham (2013); Rud (2012); Dinkelman (2011)

Macro studies: long-run effects of energy use

- e.g. Golosov, Hassler, Krusell, and Tsyvinski (2014); Hassler, Krusell, and Smith Jr. (2016); Hassler, Krusell, Olovsson (2015)

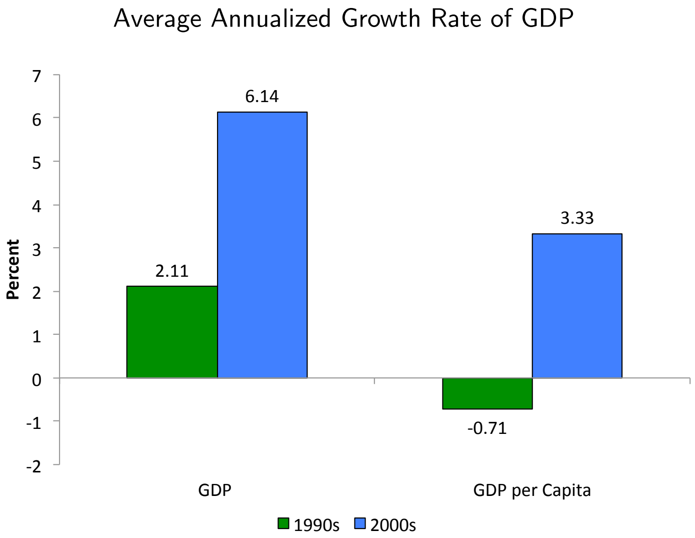
Growth and development accounting

- e.g. Klenow and Rodriguez-Clare (1997); Hall and Jones (1999); Caselli (2005); Young (1995)

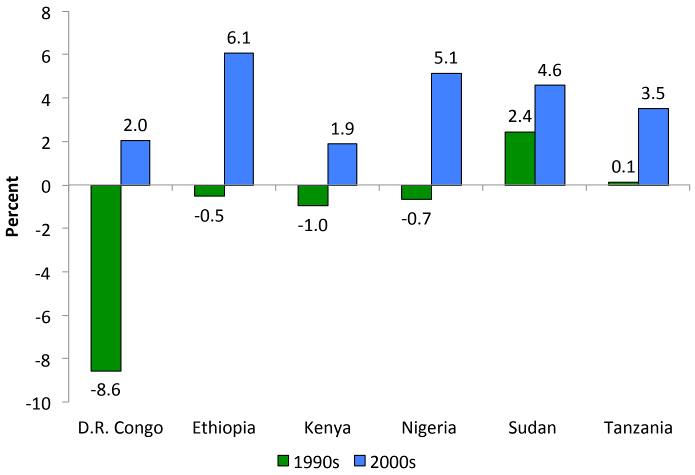
Outline of Talk

1. Stylized facts: energy and Africa's growth resurgence
2. General equilibrium model of structural change and energy
3. Calibrate model to match a pre-2000 steady state
4. Counterfactual: contribution of $\uparrow$ energy capital to growth

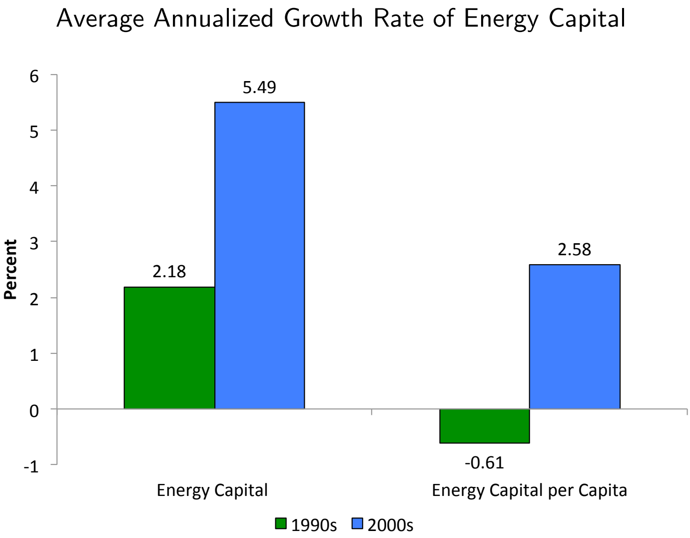
Large Increases in GDP in SSA Since 2000



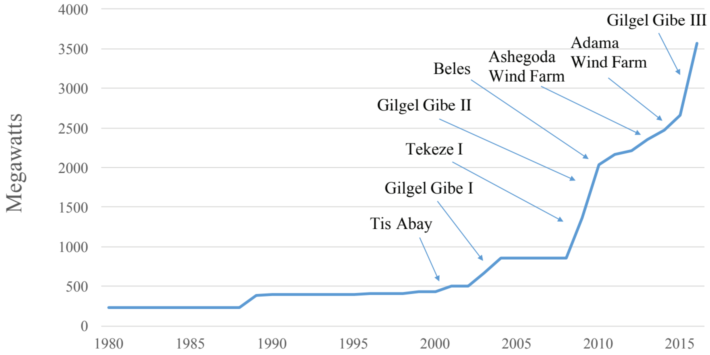
Annualized GDPPC Growth In The Biggest 6



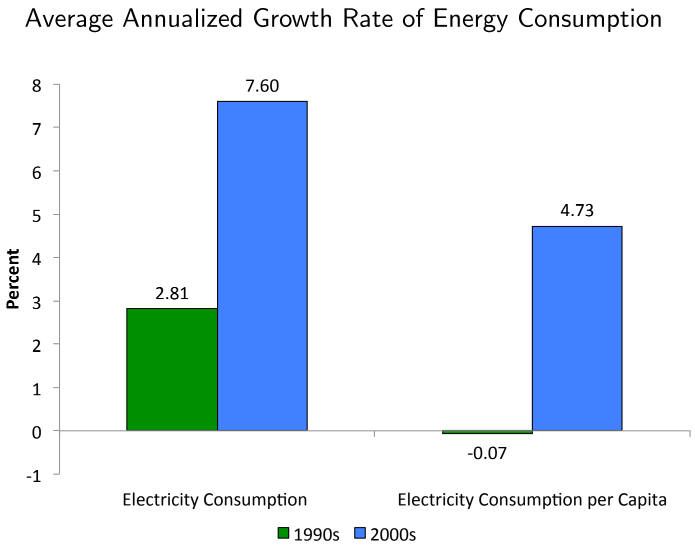
Large Increases in Energy Capital Since 2000 in SSA



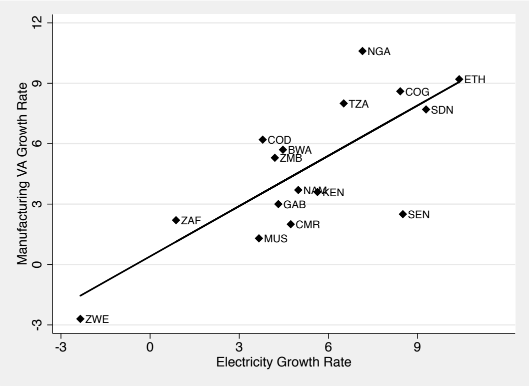
Especially Large Increases in Energy Capital in Ethiopia



Large Growth In Energy Consumption in SSA Since 2000



Correlated Growth Rates of Manufacturing and Energy



- Correlation coefficient: 0.76

Why Do We Need a Model?

Estimate the following regression instead?

$$\ln(Y_{i,t}) = \beta_0 + \beta_1 \ln(E_{i,t}) + \epsilon_{i,t}$$

Why Do We Need a Model?

Estimate the following regression instead?

$$\ln(Y_{i,t}) = \beta_0 + \beta_1 \ln(E_{i,t}) + \epsilon_{i,t}$$

Dual causality

- $\uparrow$ energy $\Rightarrow \uparrow$ GDP
- $\uparrow$ GDP $\Rightarrow \uparrow$ energy demand
- Empirical analysis requires a country-level instrument

Why Do We Need a Model?

Estimate the following regression instead?

$$\ln(Y_{i,t}) = \beta_0 + \beta_1 \ln(E_{i,t}) + \epsilon_{i,t}$$

Dual causality

- $\uparrow$ energy $\Rightarrow \uparrow$ GDP
- $\uparrow$ GDP $\Rightarrow \uparrow$ energy demand
- Empirical analysis requires a country-level instrument

Our approach: structural macro model

- Counterfactual in which all growth is from energy investment

Outline of Talk

1. Stylized facts: energy and Africa's growth resurgence
2. General equilibrium model of structural change and energy
3. Calibrate model to match a pre-2000 steady state
4. Counterfactual: contribution of $\uparrow$ energy capital to growth

Overview of the Model

Households

- Consume agriculture, non-agriculture, and energy
- Save physical capital

Perfectly competitive firms

- Produce agriculture, non-agriculture, and energy
- Labor and capital are perfectly mobile across sectors

Government

- Finances energy capital
- Lump-sum taxes on the household

Households

Households choose:

- Consumption: C_a, C_n, C_e
- Saving

Utility

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

Capital accumulation

$$K_{t+1} = (1 - \delta)K_t + qI_t$$

Agricultural Production

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

- Production of the agricultural good does not use energy

Non-Agricultural Production

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

Energy Production

Aggregate energy input

$$E_t = E_{o,t}^{\rho} E_{g,t}^{1-\rho}$$

Two types of energy

- Off-grid energy: $E_{o,t}$
- Grid energy: $E_{g,t}$

Energy Production

Aggregate energy input

$$E_t = E_{o,t}^{\rho} E_{g,t}^{1-\rho}$$

Two types of energy

- Off-grid energy: $E_{o,t} = A_{o,t} {K_{o,t}}^{\phi} N_{o,t}^{1-\phi}$
- Grid energy: $E_{g,t} = A_{g,t} {K_{g,t}}^{\phi} N_{g,t}^{1-\phi}$

Government

- Provides grid-capital

$$K_{g,t+1} = (1-\delta)K_{g,t} + qI_{g,t}$$

- Finances investment through lump-sum taxes

General Equilibrium

Agents optimize

- Households choose labor allocation, consumption, and saving
- Firms choose production quantities

Markets clear

- $(w_{at}, w_{nt}, w_{gt}, w_{ot})$ clear the labor market
- $(p_{at}, p_{nt}, p_{gt}, p_{ot}, p_{et})$ clear the goods market
- (r_{at}, r_{nt}, r_{ot}) clear the capital market

Government budget balances

- Lump-sum taxes equal grid-energy investment

Outline of Talk

1. Stylized facts: energy and Africa's growth resurgence
2. General equilibrium model of structural change and energy
3. **Calibrate model to match a pre-2000 steady state**
4. Counterfactual: contribution of $\uparrow$ energy capital to growth

Calibration: Two Steps

1. Calibrate some parameters directly from data series

2. Calibrate remaining parameters using a method of moments

Direct Calibration

Parameter	Value	Source
Capital share in agriculture: θ	0.33	Capital's share of income
Capital share in energy: ϕ	0.9	Capital's share of energy (U.S.)
Depreciation rate: δ	0.04	Penn World Tables
Elasticity of substitution: ϵ	0.05	Hassler et. al (2012)
Utility weight on ag: ω_a	0.02	Herrendorf et al. (2014)
Utility weight on energy: ω_e	0.04	U.S. CPI importance weight

Direct Calibration

Parameter	Value	Source
Capital share in agriculture: θ	0.33	Capital's share of income
Capital share in energy: ϕ	0.9	Capital's share of energy (U.S.)
Depreciation rate: δ	0.04	Penn World Tables
Elasticity of substitution: ϵ	0.05	Hassler et. al (2012)
Utility weight on ag: ω_a	0.02	Herrendorf et al. (2014)
Utility weight on energy: ω_e	0.04	U.S. CPI importance weight

Direct Calibration

Parameter	Value	Source
Capital share in agriculture: θ	0.33	Capital's share of income
Capital share in energy: ϕ	0.9	Capital's share of energy (U.S.)
Depreciation rate: δ	0.04	Penn World Tables
Elasticity of substitution: ϵ	0.05	Hassler et. al (2012)
Utility weight on ag: ω_a	0.02	Herrendorf et al. (2014)
Utility weight on energy: ω_e	0.04	U.S. CPI importance weight

Direct Calibration

Parameter	Value	Source
Capital share in agriculture: θ	0.33	Capital's share of income
Capital share in energy: ϕ	0.9	Capital's share of energy (U.S.)
Depreciation rate: δ	0.04	Penn World Tables
Elasticity of substitution: ϵ	0.05	Hassler et. al (2012)
Utility weight on ag: ω_a	0.02	Herrendorf et al. (2014)
Utility weight on energy: ω_e	0.04	U.S. CPI importance weight

Method of Moments

Parameters: $\{q, A_o, I_g, \mu, \rho, \bar{a}\}$

Moments

Moment	Empirical value
Capital-output ratio: $\frac{K}{Y}$	1.9
Price of off-grid to grid electricity: $\frac{p_o}{p_g}$	5
Grid-electricity-investment-output ratio: $\frac{I_g}{Y}$	0.008
Energy share of GDP: $\frac{p_e E}{Y}$	0.10
Fraction of off-grid capital: $\frac{K_o}{K_o+K_g}$	0.06
Share of employment in agriculture: $\frac{N_a}{N}$	0.67

Method of Moments

Parameters: $\{q, A_o, I_g, \mu, \rho, \bar{a}\}$

Moments

Moment	Empirical value
Capital-output ratio: $\frac{K}{Y}$	1.9
Price of off-grid to grid electricity: $\frac{p_o}{p_g}$	5
Grid-electricity-investment-output ratio: $\frac{I_g}{Y}$	0.008
Energy share of GDP: $\frac{p_e E}{Y}$	0.10
Fraction of off-grid capital: $\frac{K_o}{K_o+K_g}$	0.06
Share of employment in agriculture: $\frac{N_a}{N}$	0.67

Method of Moments

Parameters: $\{q, A_o, I_g, \mu, \rho, \bar{a}\}$

Moments

Moment	Empirical value
Capital-output ratio: $\frac{K}{Y}$	1.9
Price of off-grid to grid electricity: $\frac{p_o}{p_g}$	5
Grid-electricity-investment-output ratio: $\frac{I_g}{Y}$	0.008
Energy share of GDP: $\frac{p_e E}{Y}$	0.10
Fraction of off-grid capital: $\frac{K_o}{K_o+K_g}$	0.06
Share of employment in agriculture: $\frac{N_a}{N}$	0.67

Method of Moments

Parameters: $\{q, A_o, I_g, \mu, \rho, \bar{a}\}$

Moments

Moment	Empirical value
Capital-output ratio: $\frac{K}{Y}$	1.9
Price of off-grid to grid electricity: $\frac{p_o}{p_g}$	5
Grid-electricity-investment-output ratio: $\frac{I_g}{Y}$	0.008
Energy share of GDP: $\frac{p_e E}{Y}$	0.10
Fraction of off-grid capital: $\frac{K_o}{K_o+K_g}$	0.06
Share of employment in agriculture: $\frac{N_a}{N}$	0.67

Method of Moments

Parameters: $\{q, A_o, I_g, \mu, \rho, \bar{a}\}$

Moments

Moment	Empirical value
Capital-output ratio: $\frac{K}{Y}$	1.9
Price of off-grid to grid electricity: $\frac{p_o}{p_g}$	5
Grid-electricity-investment-output ratio: $\frac{I_g}{Y}$	0.008
Energy share of GDP: $\frac{p_e E}{Y}$	0.10
Fraction of off-grid capital: $\frac{K_o}{K_o+K_g}$	0.06
Share of employment in agriculture: $\frac{N_a}{N}$	0.67

Method of Moments

Parameters: $\{q, A_o, I_g, \mu, \rho, \bar{a}\}$

Moments

Moment	Empirical value
Capital-output ratio: $\frac{K}{Y}$	1.9
Price of off-grid to grid electricity: $\frac{p_o}{p_g}$	5
Grid-electricity-investment-output ratio: $\frac{I_g}{Y}$	0.008
Energy share of GDP: $\frac{p_e E}{Y}$	0.10
Fraction of off-grid capital: $\frac{K_o}{K_o+K_g}$	0.06
Share of employment in agriculture: $\frac{N_a}{N}$	0.67

Method of Moments

Parameters: $\{q,\ A_o,\ I_g,\ \mu,\ \rho,\ \bar{a}\}$

Moments

Moment	Empirical value
Capital-output ratio: $\frac{K}{Y}$	1.9
Price of off-grid to grid electricity: $\frac{p_o}{p_g}$	5
Grid-electricity-investment-output ratio: $\frac{I_g}{Y}$	0.008
Energy share of GDP: $\frac{p_e E}{Y}$	0.10
Fraction of off-grid capital: $\frac{K_o}{K_o+K_g}$	0.06
Share of employment in agriculture: $\frac{N_a}{N}$	0.67

Method of Moments: Parameter Values

Parameter	Value
Investment technology: q	0.52
TFP in off-grid energy: A_o	0.05
Grid-energy investment: I_g	0.01
Distribution parameter: μ	1.46e-14
Off-grid energy share: ρ	0.01
Subsistence consumption: $\bar{a}$	0.83

Model Fit: 3 Non-Targeted Moments

1. Energy share of expenditure: $\frac{p_e C_e}{p_a C_a + C_n + p_e C_e} = 0.01$

2. Agriculture consumption share of GDP: $\frac{p_a C_a}{Y} = 0.72$

3. Subsistence requirement $\approx$ \$1.82/day at PPP

Model Fit: 3 Non-Targeted Moments

1. Energy share of expenditure: $\frac{p_e C_e}{p_a C_a + C_n + p_e C_e} = 0.01$
   - Eberhard et. al (2001): Ethiopia in 2000 ≈ 0.02

2. Agriculture consumption share of GDP: $\frac{p_a C_a}{Y} = 0.72$

3. Subsistence requirement $\approx$ \$1.82/day at PPP

Model Fit: 3 Non-Targeted Moments

1. Energy share of expenditure: $\frac{p_e C_e}{p_a C_a + C_n + p_e C_e} = 0.01$
   - Eberhard et. al (2001): Ethiopia in 2000 ≈ 0.02
2. Agriculture consumption share of GDP: $\frac{p_a C_a}{Y} = 0.72$
   - Herrendorf et al. (2014): avg. low income countries: 0.6
3. Subsistence requirement $\approx$ \$1.82/day at PPP

Model Fit: 3 Non-Targeted Moments

1. Energy share of expenditure: $\frac{p_e C_e}{p_a C_a + C_n + p_e C_e} = 0.01$
   - Eberhard et. al (2001): Ethiopia in 2000 ≈ 0.02
2. Agriculture consumption share of GDP: $\frac{p_a C_a}{Y} = 0.72$
   - Herrendorf et al. (2014): avg. low income countries: 0.6
3. Subsistence requirement $\approx$ \$1.82/day at PPP
   - World Bank thresholds on extreme poverty: 1-2 dollars per day

Outline of Talk

1. Stylized facts: energy and Africa's growth resurgence
2. General equilibrium model of structural change and energy
3. Calibrate model to match a pre-2000 steady state
4. Counterfactual: contribution of ↑ energy capital to growth

Computational Experiment: Steady-State Analysis

Year 2000 steady state

- Normalize TFP to unity: A^{2000}

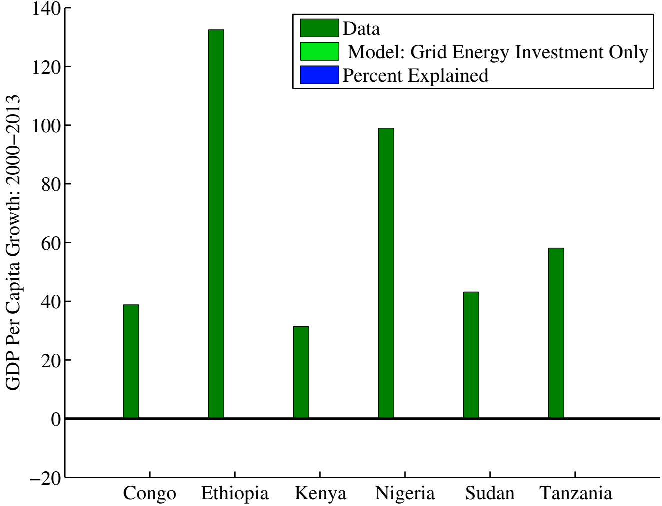
Year 2013 steady state

- Change TFP and energy investment: A^{2013} and I_g^{2013}
- Match increase in energy consumption and GDP per capita

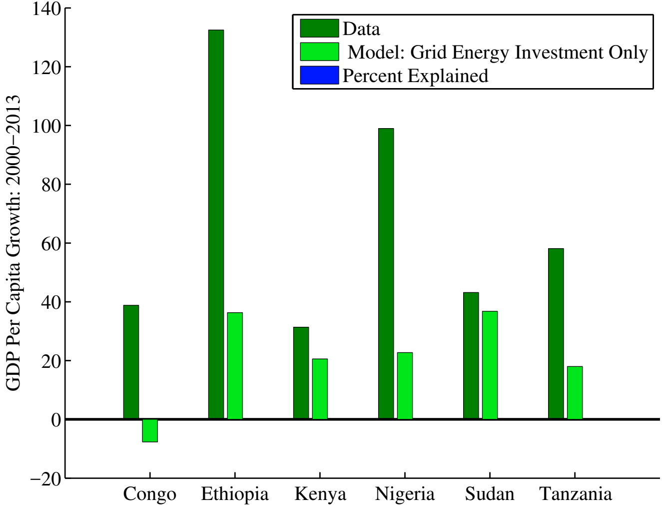
Hypothetical steady state

- All growth comes from energy investment
- $A = A^{2000}$ and $I_g = I_g^{2013}$

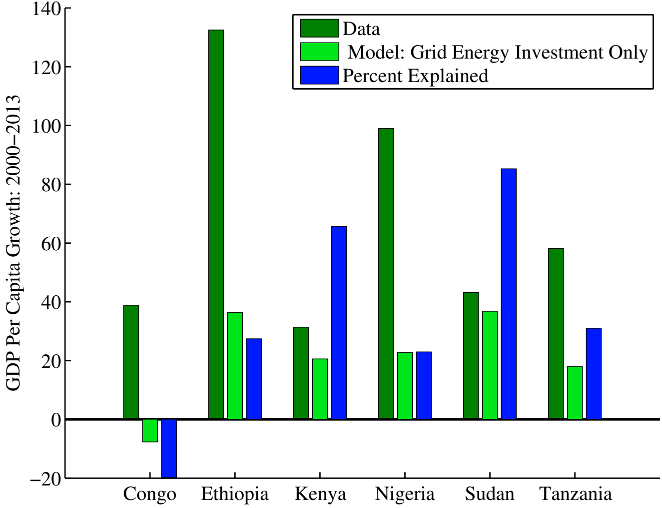
Role of Energy Capital



Role of Energy Capital



Energy Investment Explains ≈ $\frac{1}{3}$ of Growth on Average



Large Effects Due to Three Main Features of the Data

1. Large increases in energy per capita between 2000-2013

2. Energy is an important input in non-agriculture production

3. Grid-energy consumption per capita in 2000 is very low

Large Effects Due to Three Main Features of the Data

1. Large increases in energy per capita between 2000-2013
    - Avg. annualized growth rate of 4.7%
2. Energy is an important input in non-agriculture production
3. Grid-energy consumption per capita in 2000 is very low

Large Effects Due to Three Main Features of the Data

1. Large increases in energy per capita between 2000-2013
   - Avg. annualized growth rate of 4.7%
2. Energy is an important input in non-agriculture production
   - Energy share in manufacturing is approximately 10%
3. Grid-energy consumption per capita in 2000 is very low

Large Effects Due to Three Main Features of the Data

1. Large increases in energy per capita between 2000-2013
   - Avg. annualized growth rate of 4.7%
2. Energy is an important input in non-agriculture production
   - Energy share in manufacturing is approximately 10%
3. Grid-energy consumption per capita in 2000 is very low
   - Avg. per capita energy consumption in our study: 67 kwh
   - Avg. per capita energy consumption in U.S.: 13,671 khw

Decomposition Exercise

Experiment	Avg. % Explained
Baseline	35.4
Halve grid-energy investment growth	24.8
Halve pre-2000 energy share	13.1
Double pre-2000 grid-energy investment	10.0

Decomposition Exercise

Experiment	Avg. % Explained
Baseline	35.4
Halve grid-energy investment growth	24.8
Halve pre-2000 energy share	13.1
Double pre-2000 grid-energy investment	10.0

Decomposition Exercise

Experiment	Avg. % Explained
Baseline	35.4
Halve grid-energy investment growth	24.8
Halve pre-2000 energy share	13.1
Double pre-2000 grid-energy investment	10.0

Decomposition Exercise

Experiment	Avg. % Explained
Baseline	35.4
Halve grid-energy investment growth	24.8
Halve pre-2000 energy share	13.1
Double pre-2000 grid-energy investment	10.0

Energy Is An Important Driver of Recent African Growth

1. Big increases in energy use since 2000

2. Energy increases account for $\approx \frac{1}{3}$ of African growth

Energy Is An Important Driver of Recent African Growth

1. Big increases in energy use since 2000
   - Avg. growth rate of energy consumption per capita: 4.7%
   - Avg. growth rate of energy capital per capita: 2.6%

2. Energy increases account for $\approx \frac{1}{3}$ of African growth

Energy Is An Important Driver of Recent African Growth

1. Big increases in energy use since 2000
   - Avg. growth rate of energy consumption per capita: 4.7%
   - Avg. growth rate of energy capital per capita: 2.6%

2. Energy increases account for $\approx \frac{1}{3}$ of African growth
   - Magnitude varies by country
   - Results driven by the large increases in energy, the importance of energy in production, low initial levels of energy

Energy Is An Important Driver of Recent African Growth

1. Big increases in energy use since 2000
   - Avg. growth rate of energy consumption per capita: 4.7%
   - Avg. growth rate of energy capital per capita: 2.6%

2. Energy increases account for $\approx \frac{1}{3}$ of African growth
   - Magnitude varies by country
   - Results driven by the large increases in energy, the importance of energy in production, low initial levels of energy

Thank You!