Electricity and Firm Productivity: A General Equilibrium Approach

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The views in this paper are those of the authors and do not represent the views of the Federal Reserve System or its staff.

Electricity in the Developing World

There's very little

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- Lack of electricity near the top of developing world firms' list of obstacles to success (World Bank, 2017)
- Most modern production requires electricity

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This paper: effects of outages on firm productivity

Few Existing Studies Find Small Effects

Partial equilibrium, short run

Allcott, Collard-Wexler, and O'Connell (2016)

- Indian manufacturing firms
- Outages decrease revenues by 5% and have no effect on TFP

Fisher-Vanden, Mansur, and Wang (2015)

- Similar analysis and findings for Chinese firms

This paper: long run, general equilibrium

What We Do: General Equilibrium Model of Electrification

GE mechanisms through which outages affect productivity

1. Firm expansion: scale up production
2. Firm entry: use more-productive electricity-using technologies
3. Idle resources

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Simulate effects of eliminating outages on output per worker

- 5 major Sub-Saharan African economies
- Small short-run partial-equilibrium effects (like micro studies)
- Long-run general-equilibrium effects $\approx 4\times$ larger

Literature

Macro-development in GE

- Buera, Kaboski, and Shin (2019); Brooks and Donovan (Forthcoming); Lagakos, Mobarak, and Waugh (2020); Akcigit, Alp, and Peters (Forthcoming)

Macro literature on weak links

- Jones (2011); Atalay (2017); Baqaee and Farhi (2019); Bartelme and Gorodinchenko (2015)

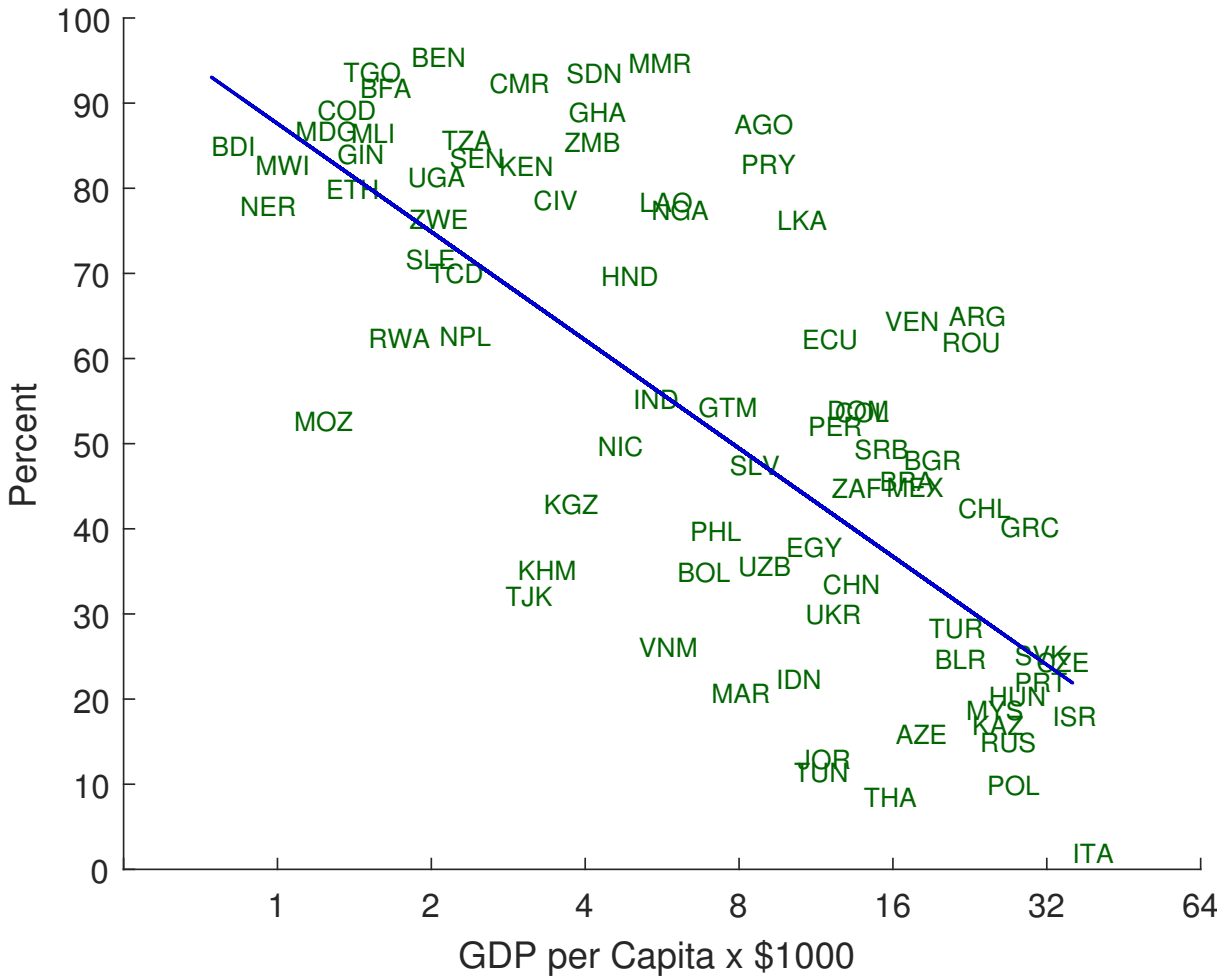
Micro literature on household and regional effects of electrification

- Vidart (2019); Lee Miguel and Wolfram (2016); Dinkelman (2011); Gertler, Shelef, Wolfram, and Fuchs (2016); Dinkelman and Schulhofer-Wohl (2015); Fried and Lagakos (2020); Dzansi, Puller, Street, and Yebuah-Dwamena (2018); Jack and Smith (2015); Ryan (2014); Rud (2012); Lipscomb, Mobarak, and Barham (2013)

Four Facts on Electricity and Firms in the Developing World

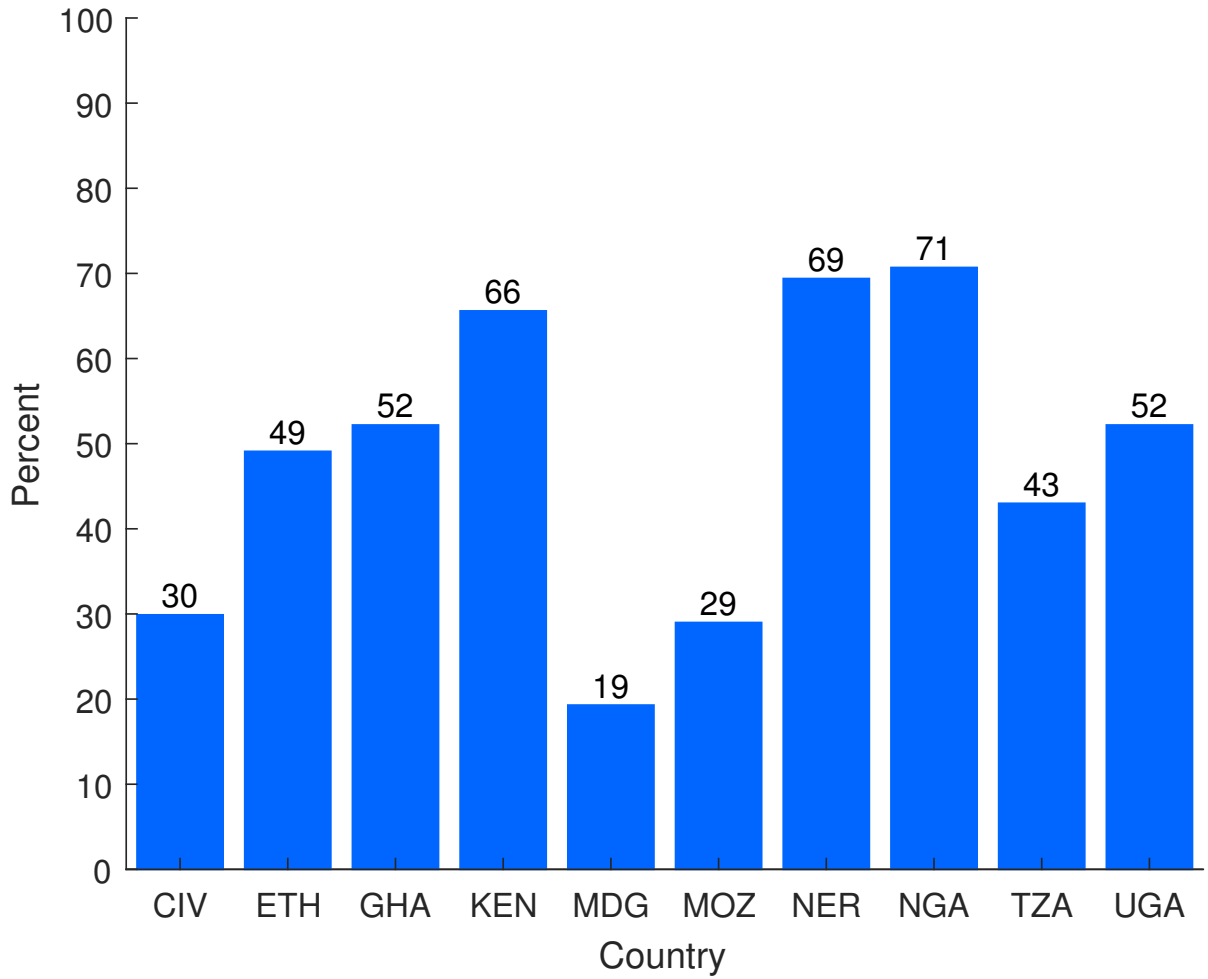
1. Frequent, unpredictable power outages
2. Some firms have access to generators
3. Self-generated electricity costs firms more than grid electricity
4. The electricity price is below the market-clearing level

Percent of Firms Experiencing Electricity Outages



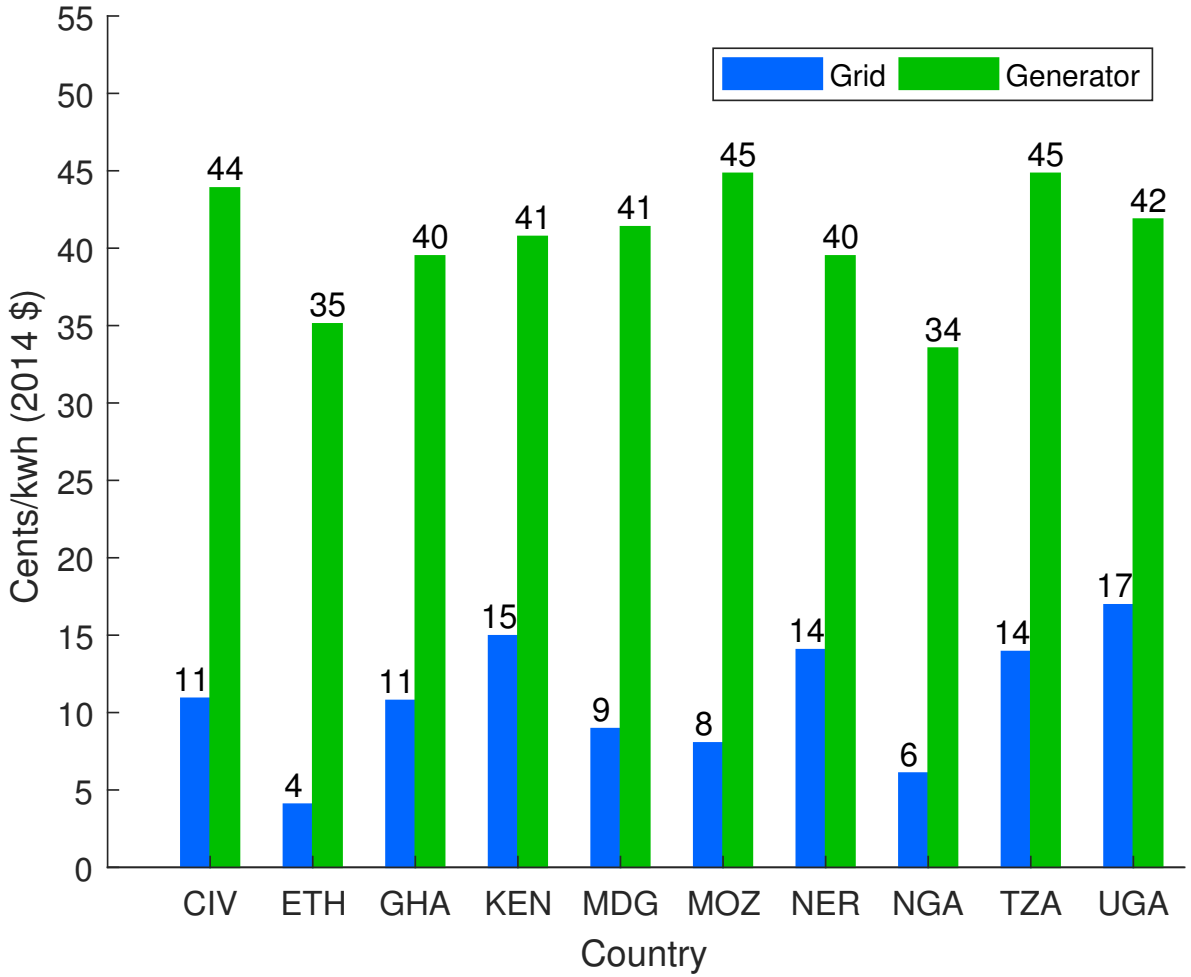
Power outages are very common

Percent of Firms Owning or Sharing a Generator



Some but not all firms have access to generators

Average Cost of Electricity: Grid vs. Generator



Self-generated electricity is 3-7 times as expensive

Electricity Prices Are Below Market-Clearing Levels

- Regulation keeps official electricity prices low (Trimble, Kojima, Arroyo, and Momhammadzadeh 2016; Burgess, Greenstone, Ryan and Sudarshan 2019)
- Effective prices even lower due to non-payment (Jack and Smith, 2015)
- One reason for widespread outages (Burgess, Greenstone, Ryan and Sudarshan 2019; McRae 2015)

Simple Model of Electricity and Firm Productivity

Purpose

- Characterize GE effects of electricity on firm productivity

Simplifying assumptions (all relaxed later)

- No labor
- Exogenous outages
- Price of grid electricity is zero

Composition of the Economy

Unit measure of identical households

- Consume final good and save

Unit measure of heterogeneous entrepreneurs

- Produce final good using either
  - Traditional technology: low productivity, no electricity
  - Modern technology: high productivity, requires electricity

Entrepreneurs

Draw productivity from Pareto distribution

$$G(z) = 1 - \left(\frac{1}{z}\right)^{\lambda}$$

Modern sector entry

- Pay cost Ω to operate in the modern sector
- Otherwise, operate in the traditional sector

Traditional Sector

Production

$$y_t^T = A^T z^{1-\eta} (k_t^T)^{\eta}$$

Profits

$$\pi_t^T = y_t^T - R_t k_t^T$$

Modern Sector

Power outages

- Divide period into a continuum of instants, i
- Probability of grid power in instant i: v

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Production function during each instant, i

$$y_{it}^{M} = A^{M} z^{1-\eta} \left[\min(k_t^{M}, e_{it}) \right]^{\eta}, \quad A^{M} = (1+\phi) A^{T}$$

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Entrepreneur's total production in period t

$$y_t^M = v y_{1t}^M + (1-v) y_{0t}^M$$

Two Ways Firms Can Get Electricity in Each Instant

1. Purchase electricity from the national electric grid, e_i^G
   - If available
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   - fuel: f_{it}

$$e_{it}^S = \min[k_t^s,\ f_{it}]$$

   - Fraction γ of modern firms have option to purchase generators

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Low grid price $\Rightarrow$ purchase grid electricity whenever possible

Optimization: Modern Firm With Generator Access

Timing

- Start of period t: choose k_t^M and k_t^S
- Each instant i: choose e_{it}^G, e_{it}^S, f_{it}

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Profits

$$\pi^M = v y_{1t}^M + (1-v) y_{0t}^M - R_t k_t^M - R_t k_t^S - (1-v) f_{0t}$$

Outages Create Idle Resources

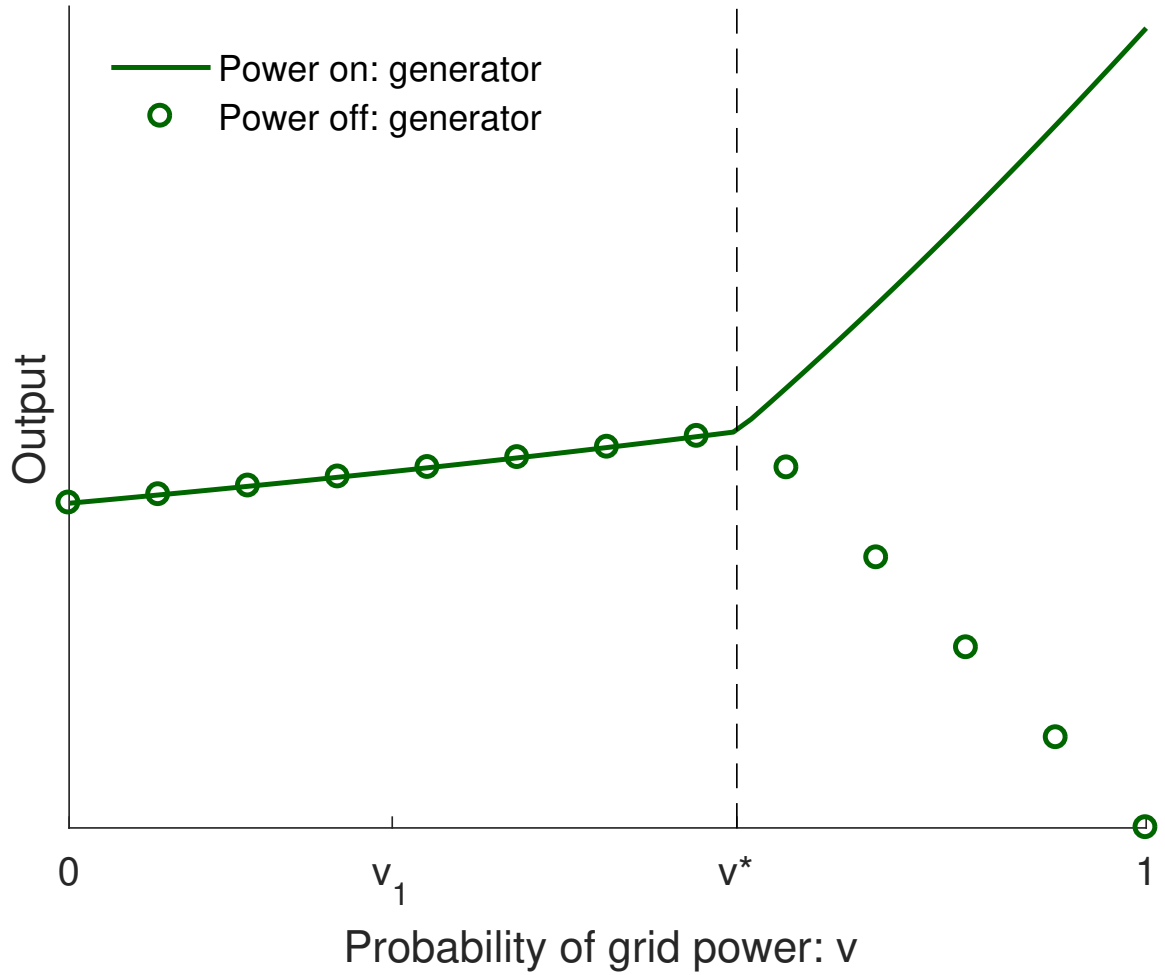
Firms without generator access

- Idle productive capital during an outage

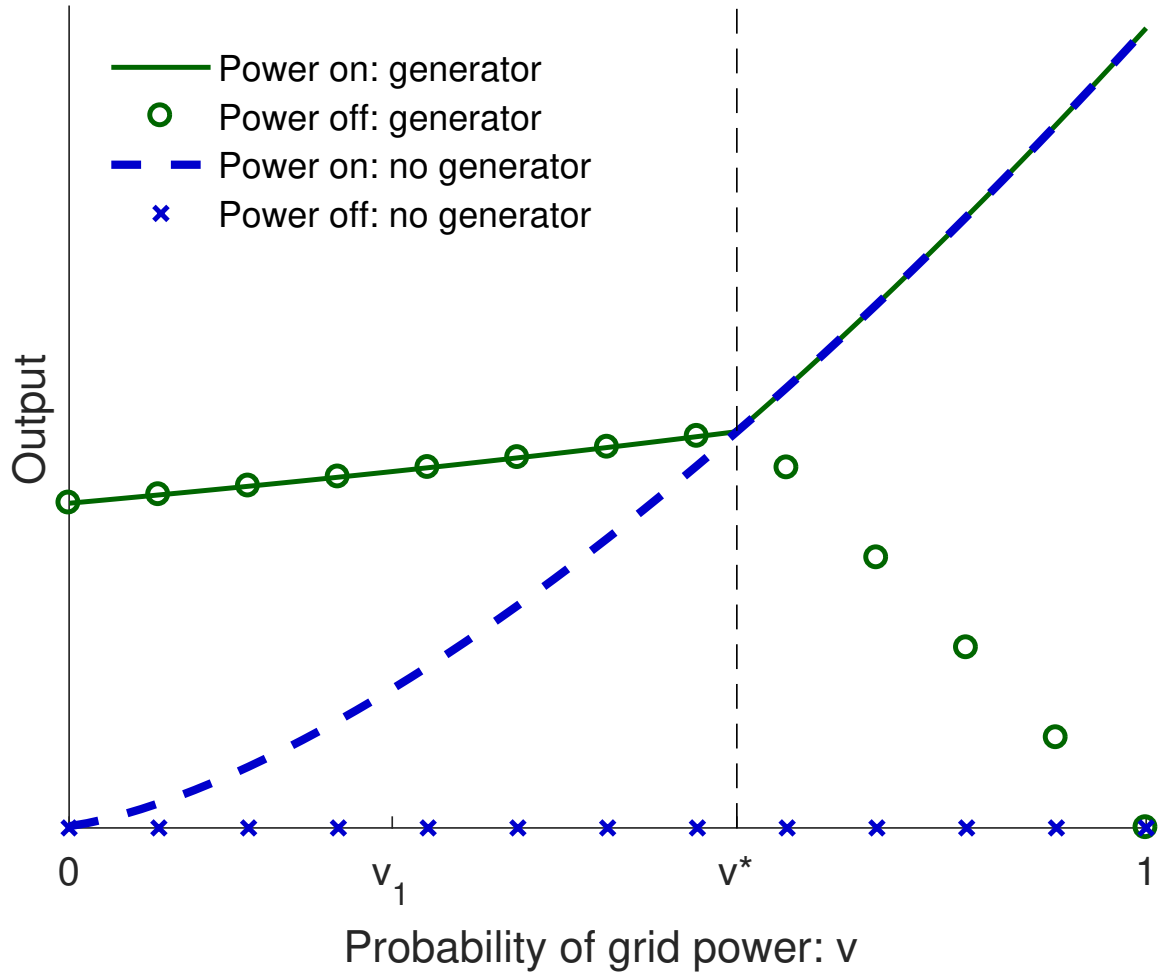
Firms with generator access: two choices

1. Idle lots of generator capital when power is on, but operate at full capacity when power is off
2. Idle less generator capital when power is on, but idle some productive capital when power is off

Solution: Modern Firm With Generator Access



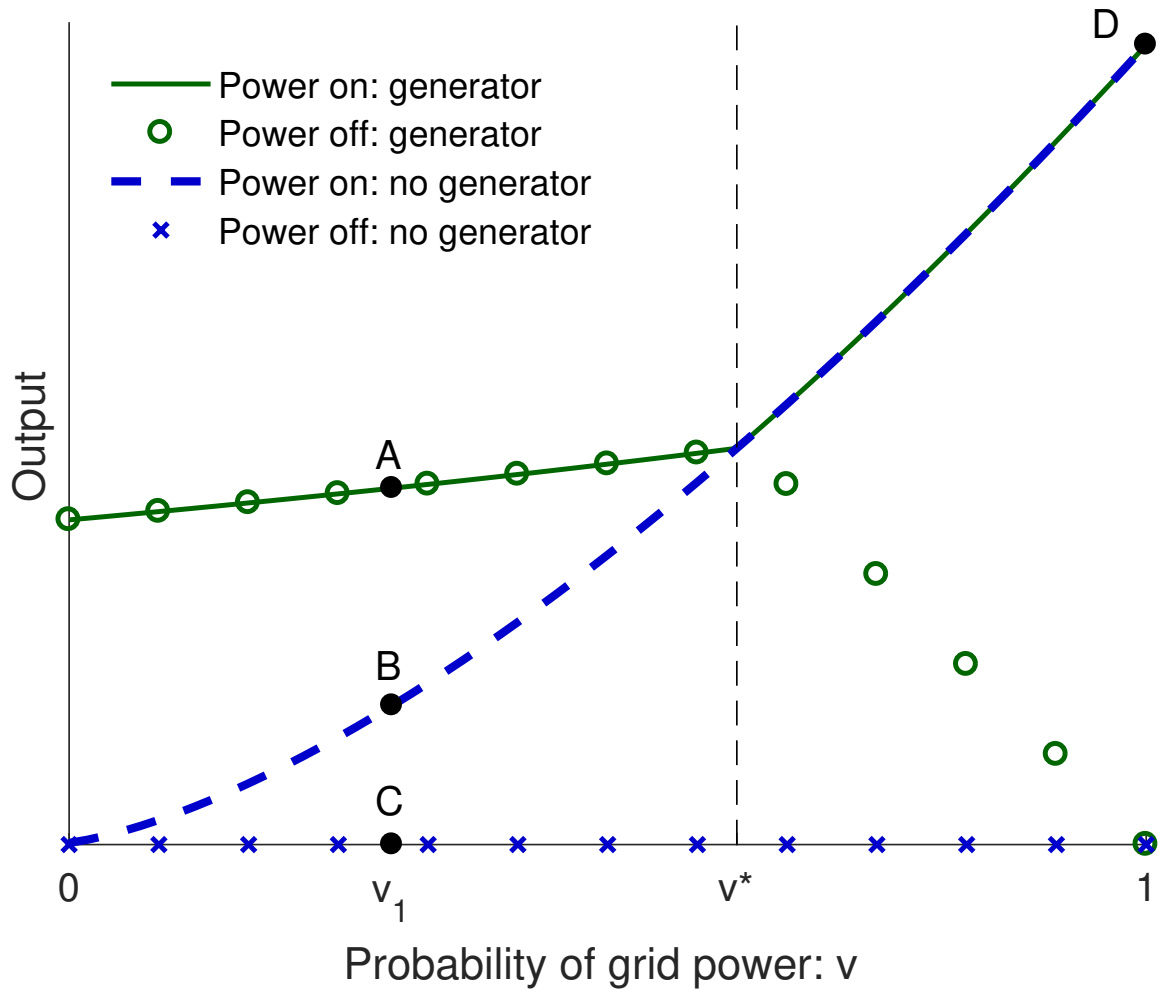
Solution: Modern Firm Without Generator Access



Short-Run Partial-Equilibrium Effect of Eliminating Outages

The increase in output when a firm learns that there will be no outages ex-post, after it has already made its long-term input decisions

S.R. P.E. Effect of Eliminating Outages in Our Model



Modern Sector Entry

An entrepreneur enters the modern sector if

$$E(\pi_t^M(z)) - \Omega \geq \pi_t^T(z)$$

Productivity cutoff: $z^\star$

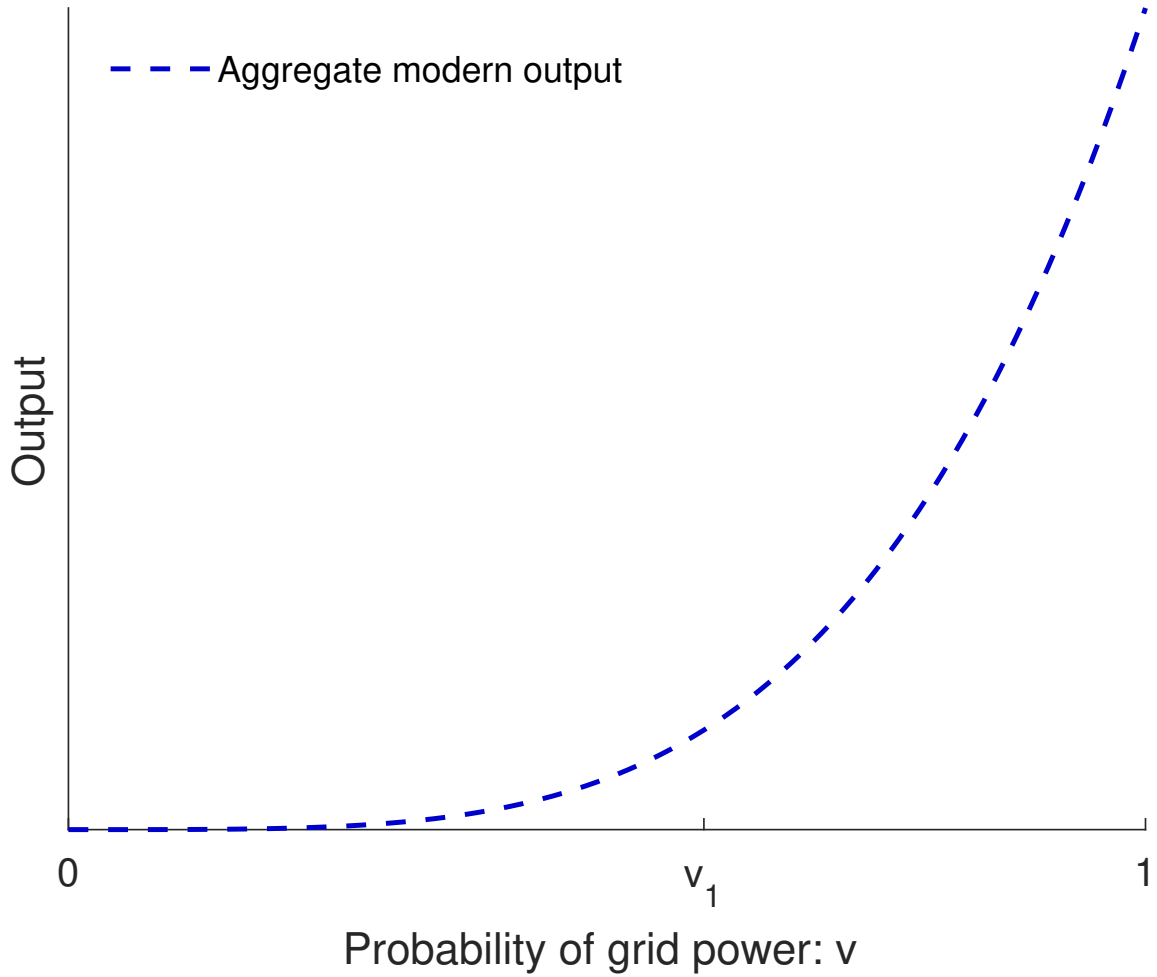
$$E(\pi_t^M(z^\star)) - \Omega = \pi_t^T(z^\star)$$

Power Outages Reduce SS Number of Modern Firms

Intuition

- Traditional profits are independent of outages
  - Depend only on R, pinned down by SS HH Euler equation
- Outages decrease modern profits
  - Increase average cost of electricity
  - Create idle resources

Long Run G.E. Effect > Short Run P.E. Effect



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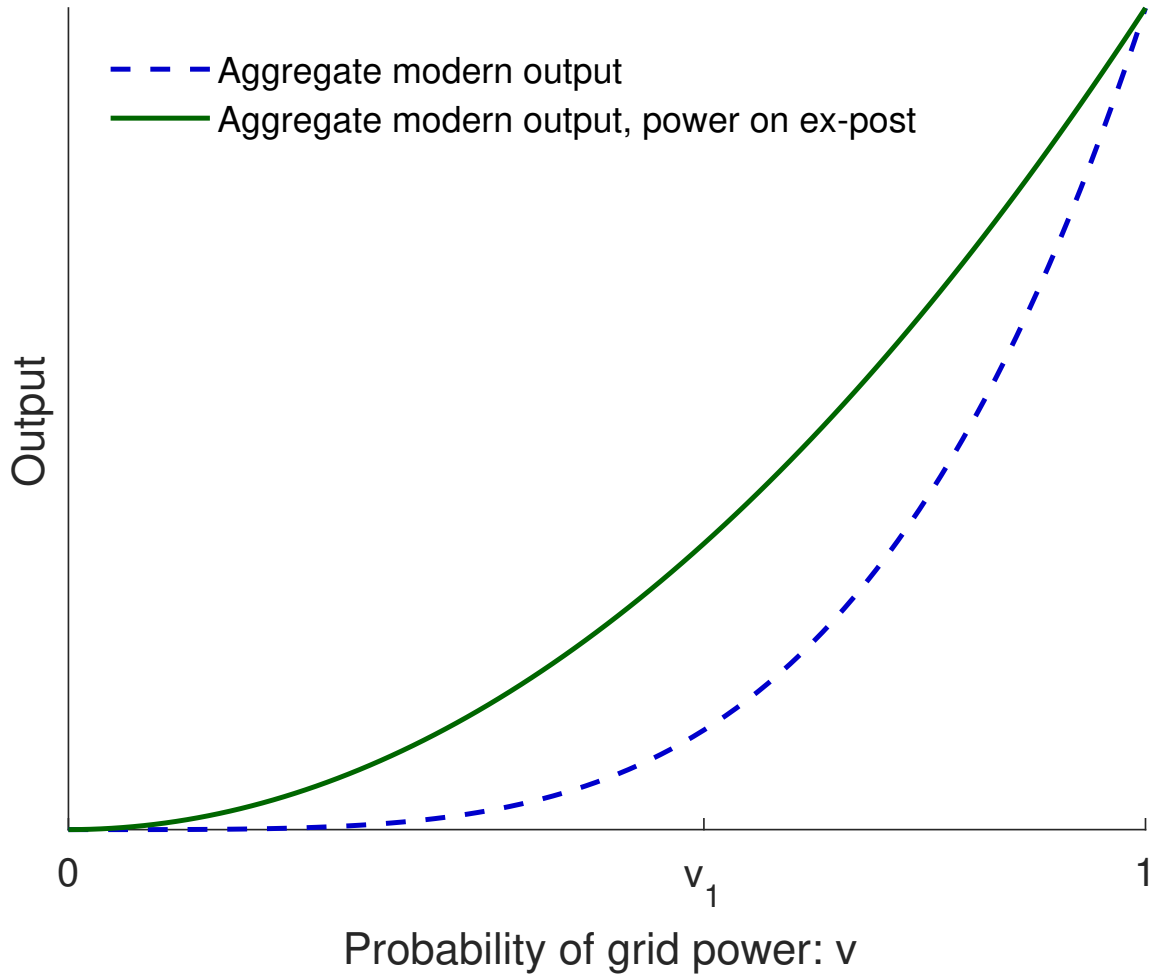

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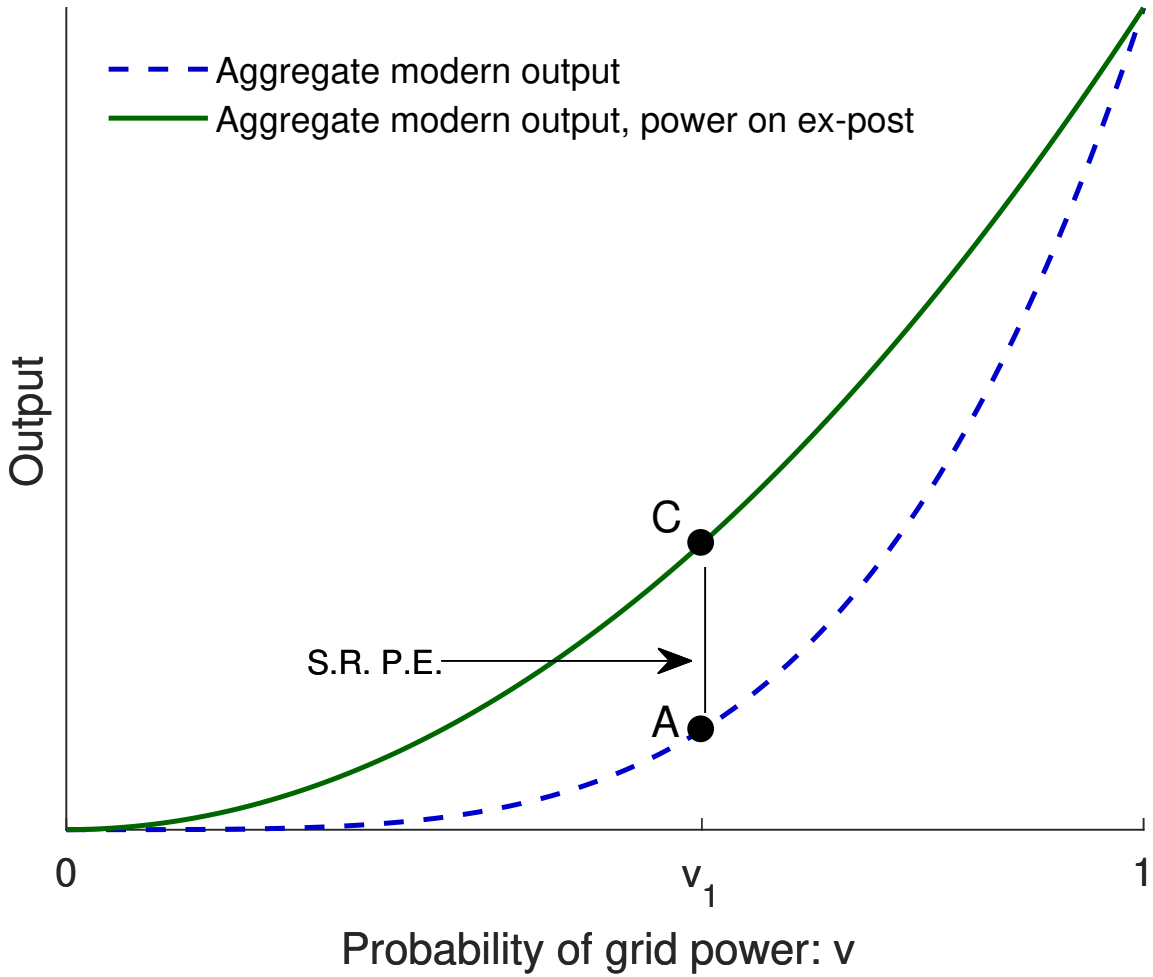

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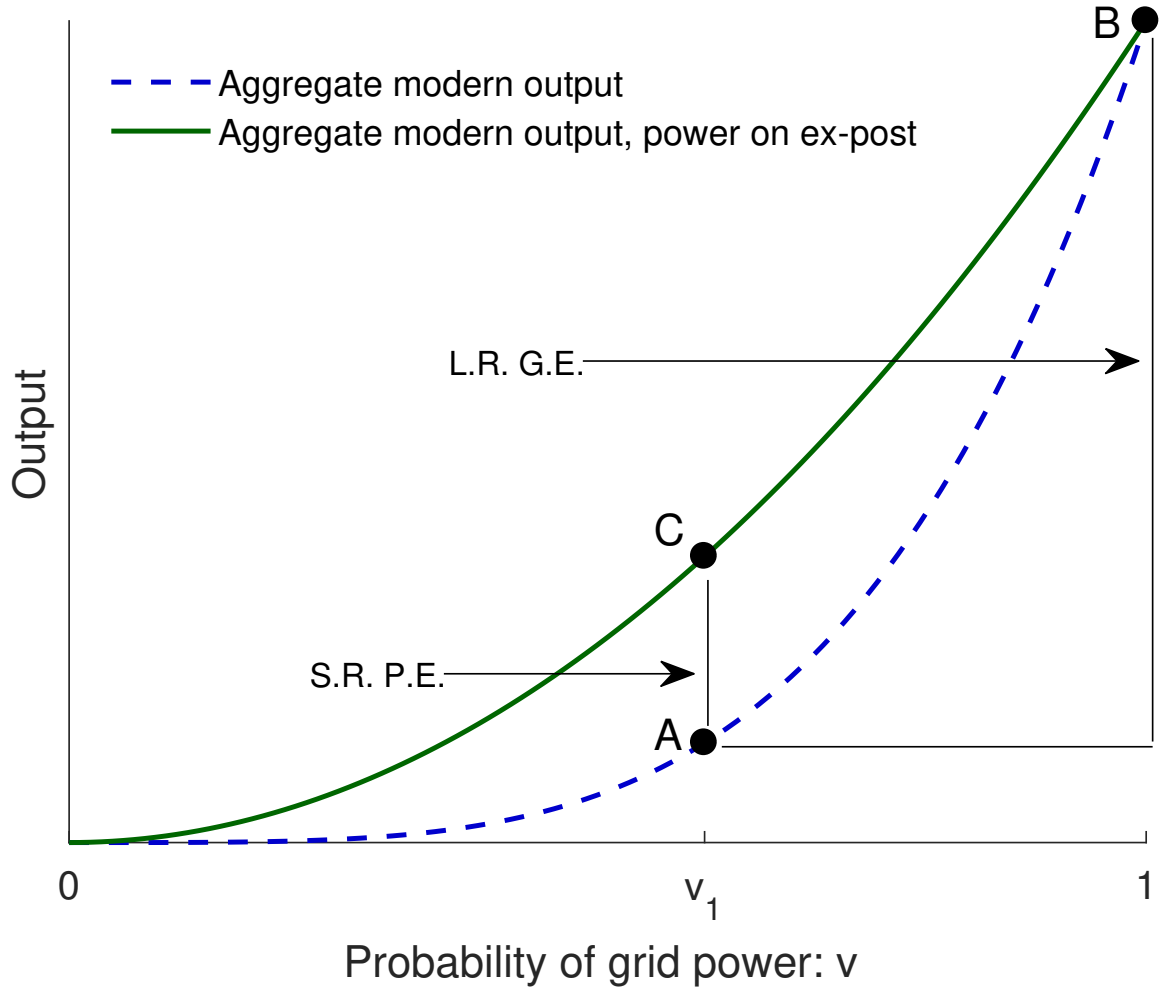

Quantitative Model: Endogenize Outages

- Perfectly competitive firms produce electricity
- Price is regulated below the market clearing level
- Rationing determined so that supply equals rationed demand

Simple Model of Electricity Production

Decreasing returns to scale production function for electricity

$$e^G = A^G (k^G)^{\psi}$$

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Supply of electricity is increasing in electricity price, P^G

$$e^G = (A^G)^{\frac{1}{1-\psi}} \left(\frac{\psi P^G}{R} \right)^{\frac{\psi}{1-\psi}}$$

Quantitative Exercise

Simulate the long-run, G.E. effects of eliminating outages

- Compare to the short-run, partial-equilibrium effects
- Quantify role of firm-expansion and firm-entry channels

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Calibrate to five major Sub-Saharan African economies

- Ethiopia, Ghana, Nigeria, Tanzania, and Uganda

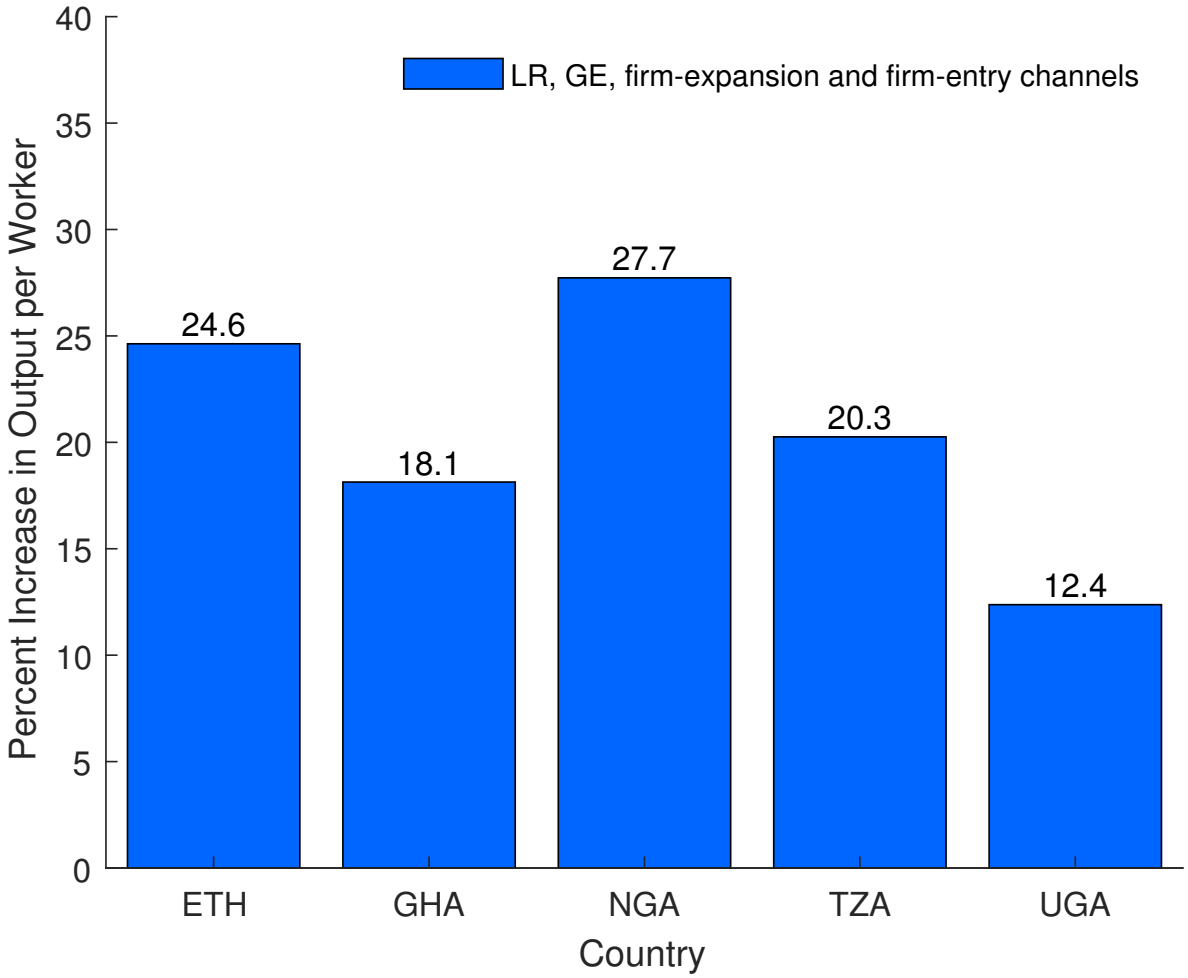
Experiment: Compare Two Steady States

1. Baseline calibrated steady state
2. Counterfactual "no-outages" steady state
   - De-regulate electricity market
   - Electricity price adjusts so that supply = demand

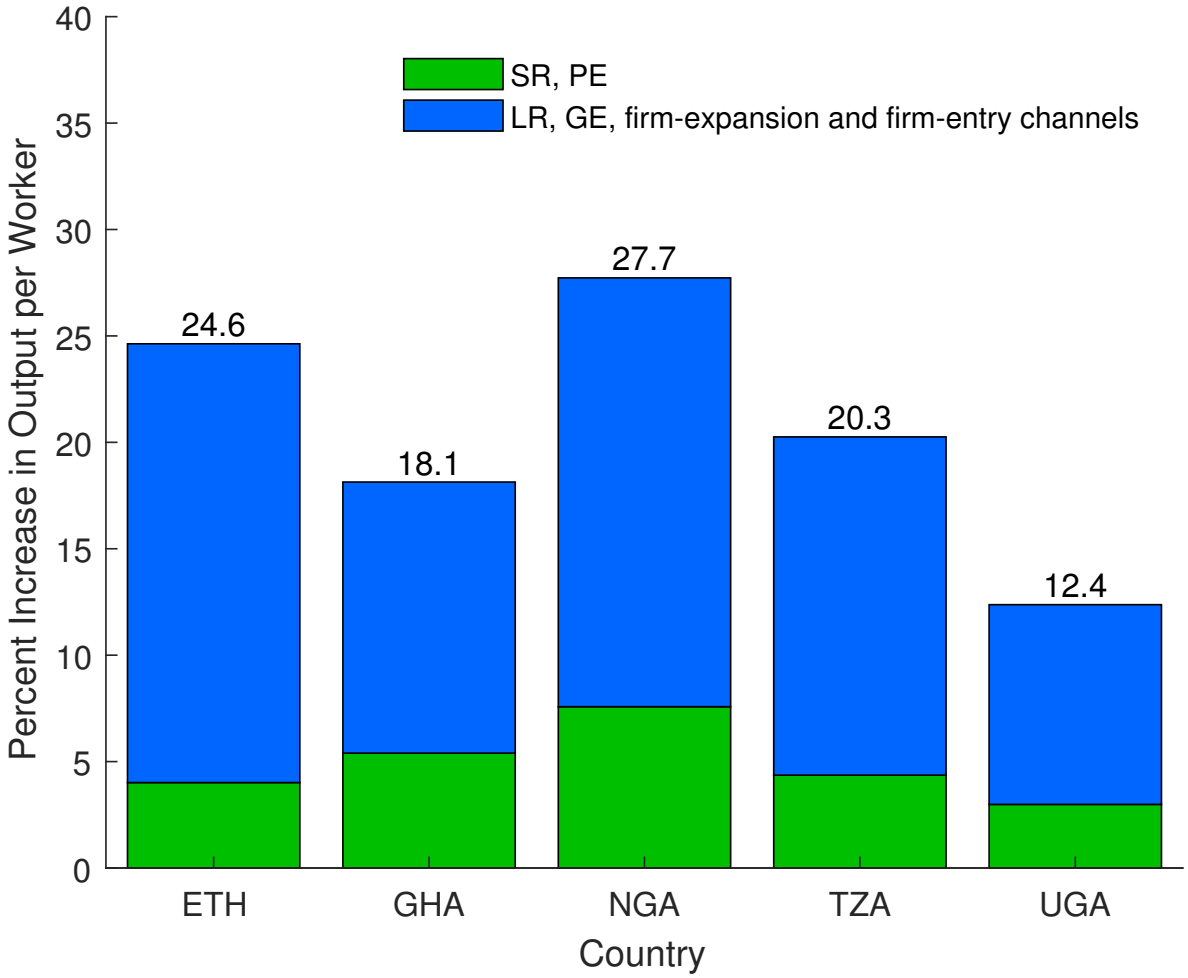
Increases in Electricity Price and Supply In No-Outages SS

	Percent change from the initial steady state	
	Grid price: P^G	Grid electricity: E^G
Ethiopia	77	281
Ghana	22	60
Nigeria	81	299
Tanzania	41	122
Uganda	24	65

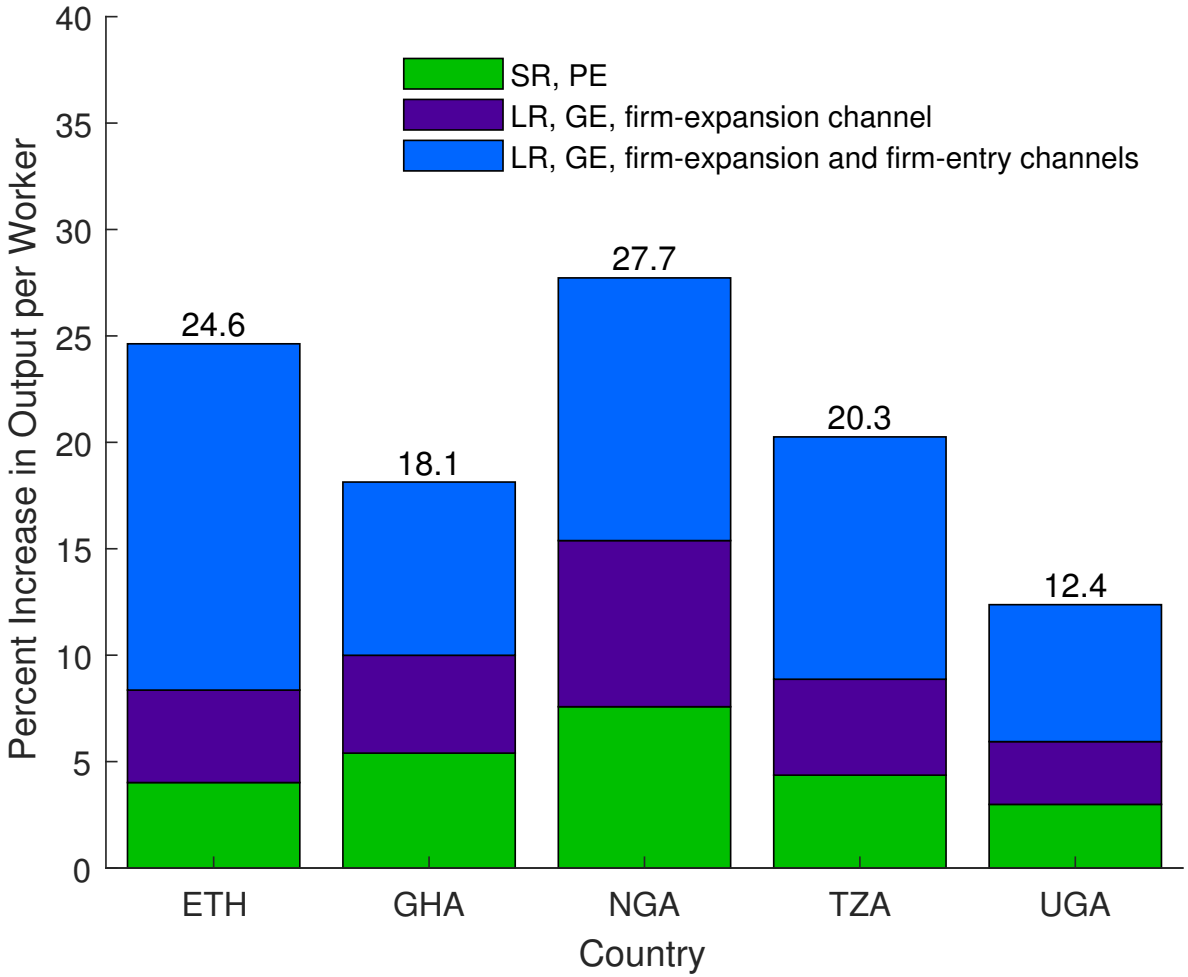
Long-Run G.E. Effect of Eliminating Outages



L.R. G.E. Effects ≈ 4 times Larger than S.R. P.E. Effect



Firm Entry and Firm Expansion Are Both Important



Supporting Evidence: Surveys of Business Owners

- Survey Ghanaian and Nigerian business owners
- What would happen at your business if outages were eliminated?
- Responses consistent with firm-expansion and firm-entry channels

Conclusion

Long run general equilibrium effects of eliminating outages are big

- Increases in aggregate capital per worker (firms expand)
- Increases in TFP (fewer idle resources, more modern firms)

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More to be do to understand the long-run effects of electrification

- Empirical evidence
- Households

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Thank you!

Labor Is Used in Both Sectors

Traditional production

$$y_t^T = A^T z^{1-\eta}[(k_t^T)^{\alpha}(n_t^T)^{1-\alpha}]^{\eta}$$

Modern production

$$y_{it}^M = A^M z^{1-\eta}\left[\min((k_t^M)^{\alpha}(n_t^M)^{1-\alpha}, \mu e_{it})\right]^{\eta}, \quad A^M = (1+\phi)A^T$$

$$e_{it}^S = A^S \min[k_t^s, \chi f_{it}]$$

Calibration Approach

- Baseline calibration for the Nigerian economy
- Re-calibrate electricity-related parameters and productivity for each country
- Take some parameters directly from data and literature
- Choose other parameters to match a set of moments

Direct Calibration: Main Parameter Values

Parameter	Value
Span of control: η	0.85
Capital share: α	0.33
Traditional productivity: A^T	1
Grid-electricity productivity: A^G	1
Modern productivity boost: ϕ	0.4
Fraction of modern firms with generator access: γ	0.91
Grid capital share: ψ	0.7

Method of Moments

Parameter	Value	Target
Leontief parameter: χ	2.14	(variable cost self)$/p^G = 4.33$
Generator productivity: A^S	1.3	(average cost self)$/p^G = 5.51$
Grid electricity price: P^G	0.08	$E^S/(E^S + E^G) = 0.59$
Leontief parameter: μ	1.59	Modern electricity share $= 0.074$
Pareto parameter: λ	3.16	Frac modern labor$= 0.63$
Entry cost: Ω	0.32	Frac modern firms$= 0.30$

Country-Specific Calibration

1. Fraction of modern firms with generator access: γ
   - Measure directly from World Bank (2016)
2. Self-generation Leontief parameter: χ
   - Cost of self-generation relative to grid electricity
3. Grid-electricity price: P^G
   - Match frequency of power outages, relative to Nigeria
4. Grid electricity productivity: A^G
   - Match in cost per kwh, relative to Nigeria
5. Traditional productivity: A^T
   - Match output per worker, relative to Nigeria

Survey Ghanaian and Nigerian Business Owners

- Google Surveys
- Random sample of internet news readers
- Screening question: Do you own or operate a business?
- If yes, then 3-6 follow up questions
  - Effects of power outages on their business
  - Effects of a placebo (airport going solar) on their business

Screening Question

Matthew Dodd from the January 16, 2013 issue

Jurgen Habermas R&D Android cops beat The Weekender mathewi Tim Carmody attracting young readers tweets, collaboration tags the medium is the message blog plagiarism horse-race coverage advertising the other longer Book Review....

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Please complete the following survey to access this premium content.

Question 1 of 5 or fewer:

Do you own and operate your own business?

- Yes
- No
- Don't Know

OR

- Show me a different question
- Skip survey

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Sample Follow Up Question

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Please complete the following survey to access this premium content.

Question 3 of 5 or fewer:

How often have you experienced power outages / dumsor at your business in the last year?

- ○ Never
- ○ 1 to 2 times
- ○ 3 to 5 times
- ○ 6 to 10 times
- ○ More than 10 times
- ○ I don't know

OR

Show me a different question

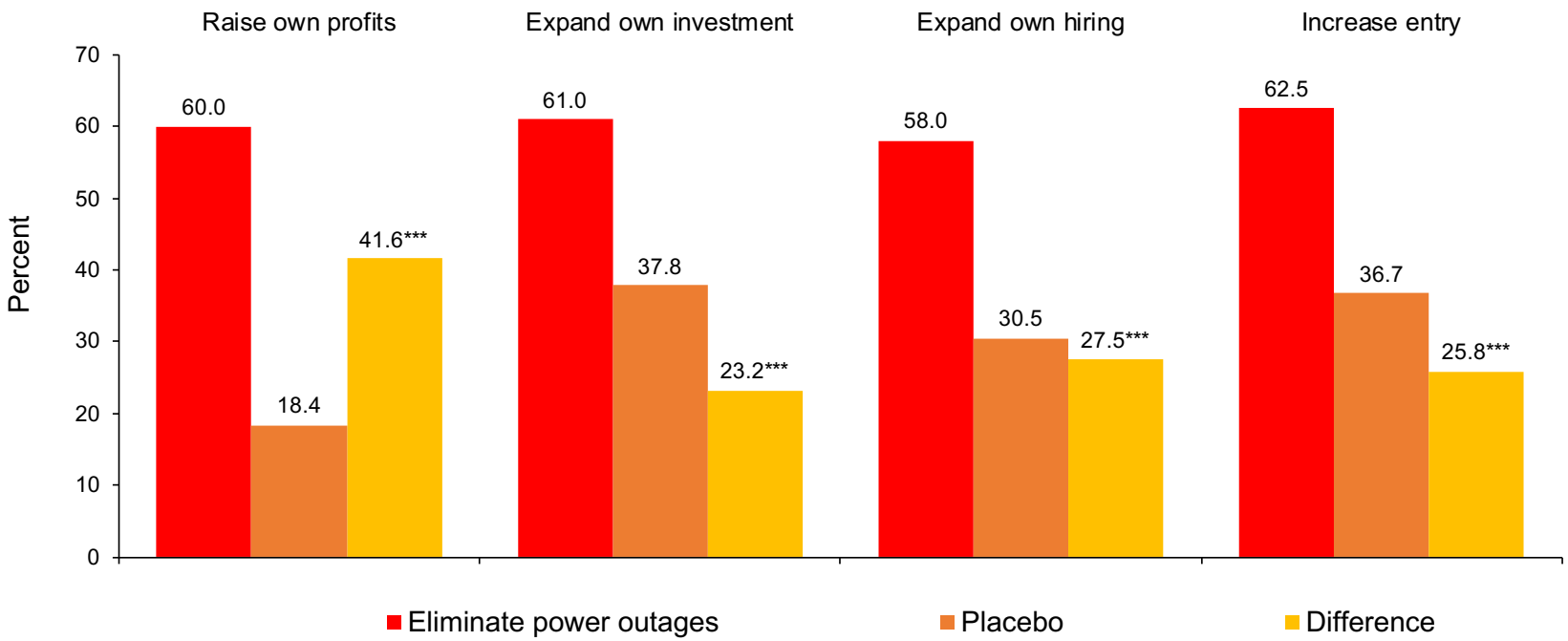
Skip survey

Google INFO PRIVACY

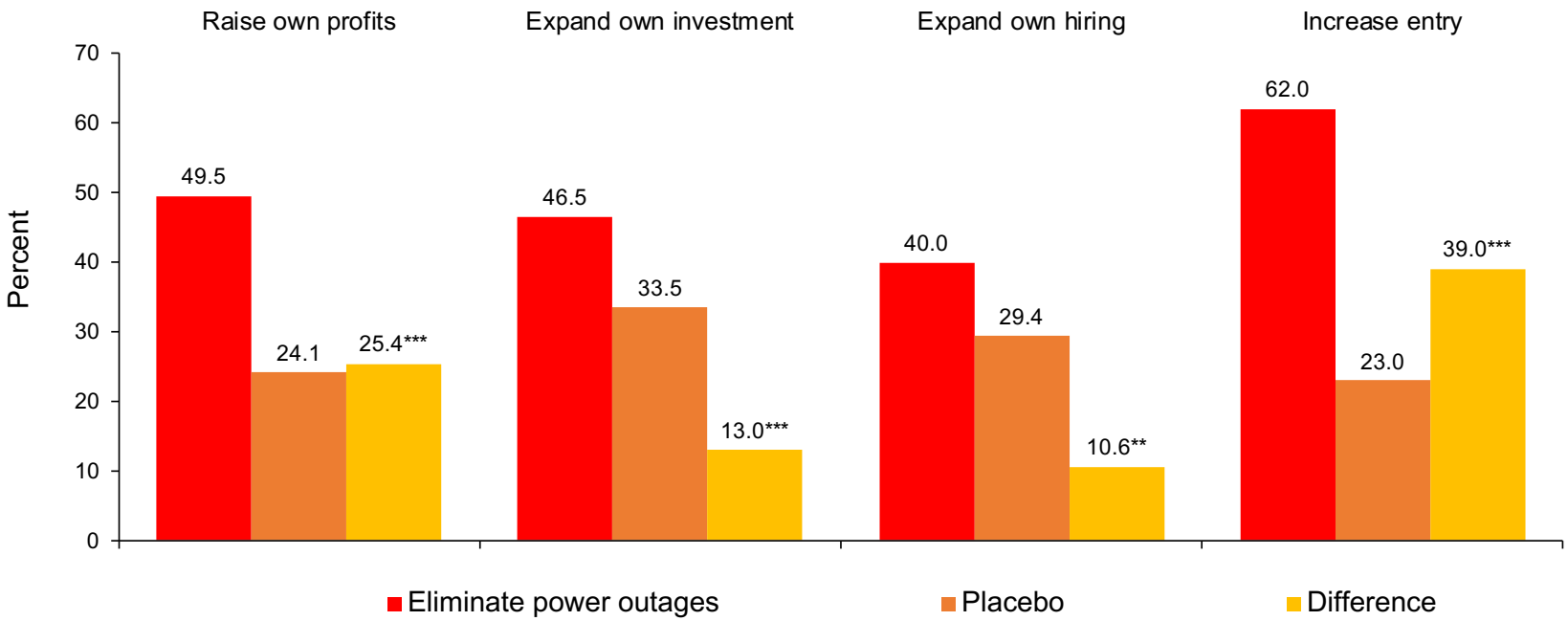
Surveyed Population

- Covered 3,425 firms
  - 1,913 from Ghana and 1,512 from Nigeria
- More educated and more urban than average population
  - Perhaps not a bad approximation of model: modern entrepreneurs have higher productivity
- Younger and more male than average population

Effects of Eliminating Power Outages: Nigeria



Effects of Eliminating Power Outages: Ghana

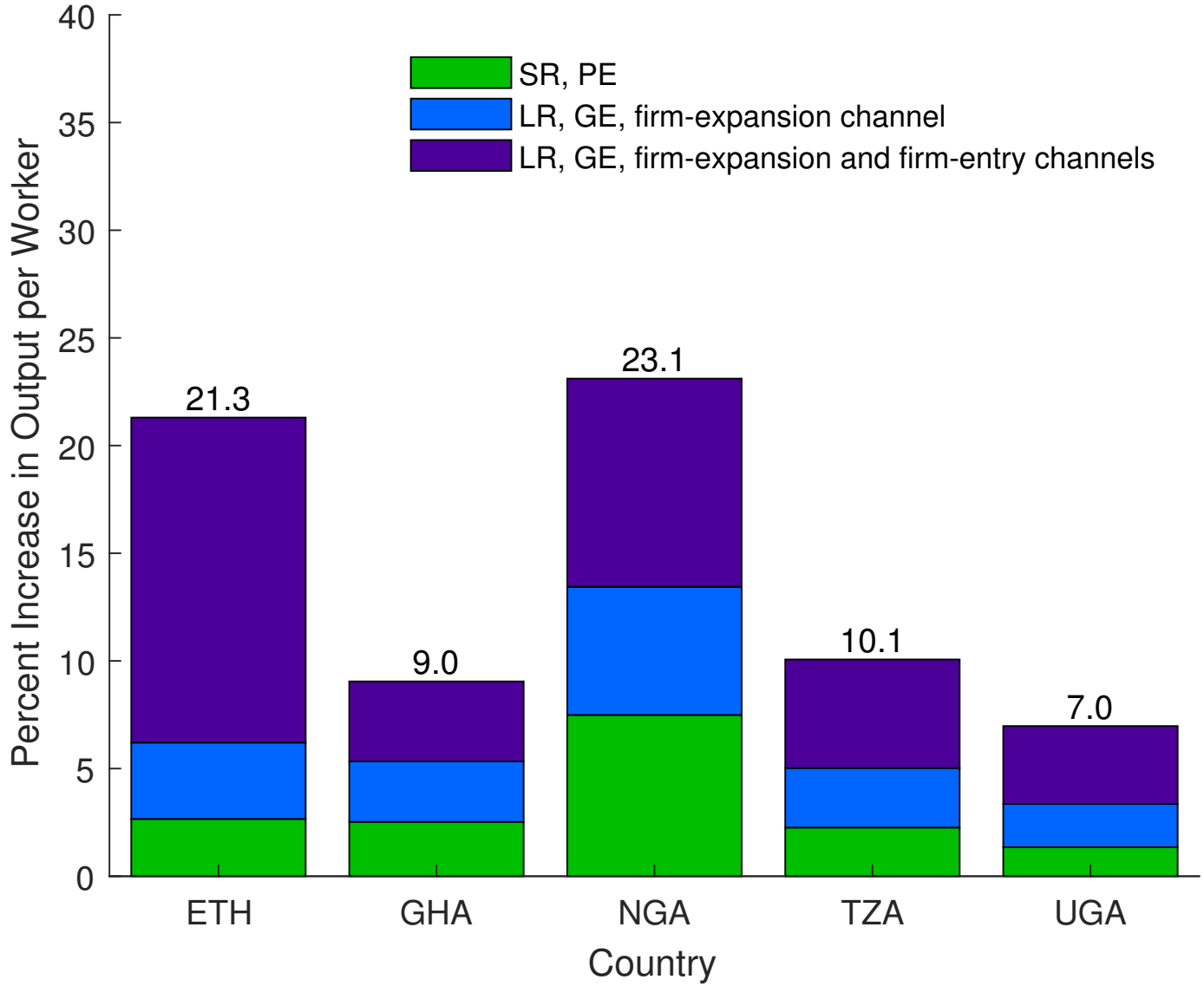


Effects of Eliminating Outages on Aggregates

Table: Effects of Eliminating Outages on Macro Aggregates
(percent change from the initial steady state)

	Ethiopia	Ghana	Nigeria	Tanzani
Modern entrepreneurs: Q^M	448	85	141	172
Modern labor: N^M	212	29	53	79
Wage rate: W	13	17	25	14
Modern productive capital: K^M	254	51	91	103
Traditional capital: K^T	-61	-73	-85	-61
Aggregate capital stock: K	36	17	30	26
Measured TFP: $Y/(\tilde{K}^{\alpha}N^{1-\alpha})$	11	12	17	11
Consumption: C	15	14	21	13

Sensitivity: $\gamma = 1$



Sensitivity

	Percent increase in output	
	Long run, G.E.	Short run, P.E.
Capital share in grid-electricity production: ψ		
$\psi = 0.6$	21	6
$\psi = 0.7$	28	8
$\psi = 0.8$	34	9
Modern productivity boost: ϕ		
$\phi = 0.3$	26	7
$\phi = 0.4$	28	8
$\phi = 0.5$	31	8
Electricity share of modern output		
Share $= 0.05$	22	5
Share $= 0.074$	28	8
Share $= 0.1$	35	11
Self-generation costs		
50 percent decrease in costs	20	5
Baseline costs	28	8
50 percent increase in costs	39	12