The Aggregate Implications of Innovative Investment

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Introduction

- How much can we change the path of aggregate productivity and welfare by policy-induced increase in firms' innovative investments?

- Within a class of canonical models, characterize
  - Dynamics of Aggregate Productivity and Output
  - Welfare and Fiscal Implications

- Two key statistics
  1. Impact elasticity
  2. Intertemporal knowledge spillovers

- Measurement

$$\text{Impact elasticity} \leq \frac{\text{contribution of entrants' innovation to growth}}{\text{entrants' share of innovative investment}}$$

Wide range of intertemporal knowledge spillovers from literature

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Findings

- Permanent increase in innovation intensity of 1% of output implies
  - Consumption plus physical investment falls for 5-15 years
  - Modest impact on level of aggregate output after 20 years
  - Hard to distinguish from standard business cycle fluctuations
- Welfare Implications
  - Moderate to large *consumption equivalent* gains
  - Welfare driven by long run response of productivity
  - Hard to estimate with 20 years of data
- Fiscal Cost equals 1% of output in long run

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GHK

- Build on model of firm dynamics of Garcia-Macia, Hsieh and Klenow (2016)
- GHK decompose baseline BGP productivity growth into
  - Incumbents' Innovations on Continuing Products
  - Incumbents' Innovations in Acquiring New Products
  - Entrants' Innovations in Acquiring New Products
  - New products to firm: new to society (EV) or "stolen" from other firms (NS)
- Measurement: Contribution of entrants' innovation to growth

  See also Akcigit and Kerr 2016

Our model

- We aim to measure elasticities of aggregate productivity growth w.r.t. counterfactual, policy-induced changes in firms innovative investment.
  - Extend GHK to model innovative investment technologies
  - Nest workhorse models e.g.
    - Jones (2002)
    - NS: Grossman Helpman (1991), Aghion Howitt (1992), Klette Kortum (2004), Acemoglu and Cao (2015)
    - EV: Romer (1990), Luttmer (2007, 11), Atkeson and Burstein (2010)
  - Key property: Aggregation of types of innovative investment

$$\log Z_{t+1} - \log Z_t = G(x_{ct}, x_{mt}, x_{et})$$

Pros and Cons of Our Framework

- Pros:
  - Nest range of canonical models
  - Tractable transition dynamics and welfare
  - Simple analytical results
  - Clear guide for measurement
- Cons:
  - Does not nest models that need state variable for firm types
  - Lentz and Mortensen (2008), Luttmer (2011), Ackigit and Kerr (2016), Acemoglu, Ackigit, Bloom, and Kerr (2013) and Peters (2016)

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Why not just capitalize intangible investment?

- BEA treats intangible investment same as physical investment
    - Guess at depreciation rate
    - Guess at price deflator for intangible investment
    - Perpetual inventory intangible capital stock
    - Aggregate output CRS in capital stocks and labor
- Our model
    - No obvious intangible capital stock
    - Aggregate increasing returns
    - Spillovers
    - Business stealing

Talk Outline

- Simple Model
  - Only entrants invest
  - Two sufficient statistics for long-run, transition dynamics, welfare. Fiscal cost
  - Simple bound on impact elasticity
- Add investment by incumbent firms
  - Two extensions of analytical results
  - Conditions for bound on impact elasticity

$$\text{Impact elasticity} \leq \frac{\text{contribution of entrants' innovation to growth}}{\text{entrants' share of innovative investment}}$$

- Measurement
- Results

Simple Model

- Two final goods
  - Consumption and Physical Investment (Output)
  - Research Good (Input to Innovation)
- Output produced from differentiated intermediate goods
  - produced with physical capital and production labor
- Research good produced with research labor
- Entrants invest research good to acquire a good
  - create new intermediate goods or
  - improve upon existing goods (business stealing)

Intermediate Goods and Final Consumption Good

Intermediate Goods

$$y_t(z) = \exp(z) k_t(z)^{\alpha} l_{pt}(z)^{1-\alpha}$$

Measure of products $M_t(z)$, $\quad M_t = \sum_z M_t(z)$

Aggregate Output

$$Y_t = \left[\sum_z y_t(z)^{\frac{\rho-1}{\rho}} M_t(z) \right]^{\frac{\rho}{\rho-1}} = C_t + K_{t+1} - (1-\delta_K) K_t$$

Assuming constant markups $\mu > 1$ and common factor prices

$$Y_t = Z_t K_t^{\alpha} L_{pt}^{1-\alpha} \qquad K_t = \sum_z k_t(z) M_t(z) \qquad L_{pt} = \sum_z l_{pt}(z) M_t(z)$$

Aggregate productivity

$$Z_t = \left[\sum_z \exp(z)^{\rho-1} M_t(z) \right]^{1/(\rho-1)}$$

Inputs into Innovative Investment

Research good

$$Y_{rt} = A_{rt} Z_t^{\phi - 1} L_{rt}$$

Research labor $L_{rt} = L_t - L_{pt}$. Ratios $l_{rt} = L_{rt}/L_t$ and $l_{pt} = L_{pt}/L_t$.

Intertemporal knowledge spillovers $\phi \leq 1$

Research TFP $= A_{rt} Z_t^{\phi - 1}$ Jones (2002) and Bloom et. al. (2017)

Exogenous Scientific Progress A_{rt} grows at $\bar{g}_{Ar}$, labor L_t grows at $\bar{g}_L$

$\phi < 1$ ideas get “harder to find"

Balanced growth path — Y_{rt} constant

$$\bar{g}_Z = \frac{\bar{g}_L + \bar{g}_{A_r}}{1 - \phi}$$

Investments and Aggregate Productivity Growth

innovation technologies imply tractable equilibrium aggregation:

$$\log Z_{t+1} - \log Z_t = G(x_{et})$$

subject to

$$x_{et} = Y_{rt}$$

- Each entrant spends $1/M_t$ units of the research good at t
- New products for entrants, $x_{et}M_t$,
- fraction δ_e stolen, $1 - \delta_e$ new to society
- Externalities in productivity — $\mathbb{E}\exp(z')^{\rho-1} = \eta_e \frac{Z_t^{\rho-1}}{M_t}$

Evolution of aggregate productivity

$$\log Z_{t+1} - \log Z_t = \frac{1}{\rho - 1} \log\left[(1 - \delta_{ct}) + \eta_e x_{et}\right]$$

Product exit $\delta_{ct} = \delta_0 + \delta_e x_{et}$

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Innovation Policy Experiment

Subsidize expenditure on research good τ'_{et}

Raise research intensity of economy

$$i_{rt} = \frac{P_{rt} Y_{rt}}{Y_t}$$

Reallocate labor to research

$$L_{rt} = \frac{i_{rt}}{i_{rt} + W L_p / Y}$$

What are the dynamics of aggregate productivity and output?

Simple Model Dynamics

$$\log Z_{t+1} - \log Z_t = G(Y_{rt})$$

Impact Elasticity

$$\log Z_{t+1} - \log Z_t - \bar{g}_Z \approx \Theta \left(\log Y_{rt} - \log \bar{Y}_r\right)$$

$$\Theta \equiv G'(\bar{Y}_r)\bar{Y}_r$$

From production function for research good

$$\log Y_{rt} - \log \bar{Y}_r = (\phi - 1)\left(\log Z_t - \log \bar{Z}_t\right) + \left(\log l_{rt} - \log \bar{l}_r\right)$$

Two key statistics Θ and ϕ

Long Run Impact on Productivity

Permanent innovation subsidy and reallocation of labor

$\phi < 1$ implies Y_{rt} constant across BGP's

$$\log \bar{Z}_t' - \log \bar{Z}_t = \frac{1}{1-\phi} \left(\log \bar{l}_{rt}' - \log \bar{l}_r \right)$$

$\phi = 1$ change in BGP growth rate

$$\bar{g}_Z' - \bar{g}_Z = \Theta \left(\log \bar{l}_{rt}' - \log \bar{l}_r \right)$$

Transition Dynamics of Productivity and Output

Aggregate Productivity

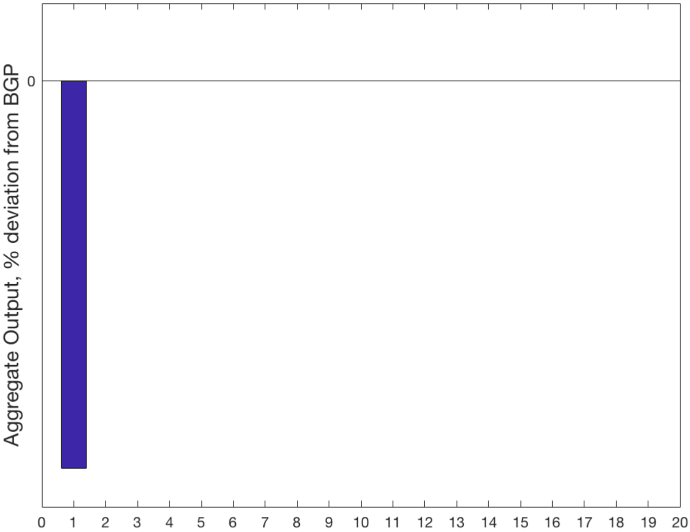
$$\log Z'_{t+1} - \log \bar{Z}_{t+1} = \sum_{k=0}^{t} \Gamma_k \left(\log I_{rt} - \log \bar{I}_r\right)$$

$$\Gamma_0 = \Theta, \qquad \Gamma_{k+1} = [1 - \Theta(1-\phi)]\, \Gamma_k$$

Aggregate Output

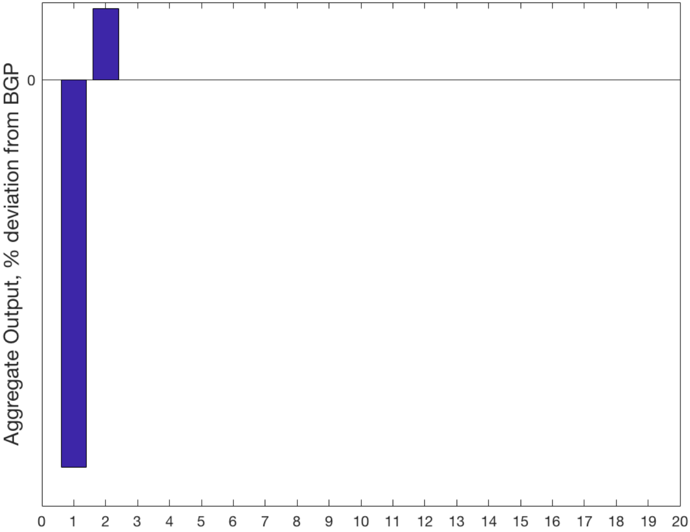
$$\log Y'_t - \log \bar{Y}_t = \frac{1}{1-\alpha}\left(\log Z'_t - \log \bar{Z}_t\right) + \left(\log I'_{pt} - \log \bar{I}_p\right) - \frac{\alpha}{1-\alpha}\left(\log R'_{kt} - \log \bar{R}_k\right)$$

One-period reallocation of labor towards research



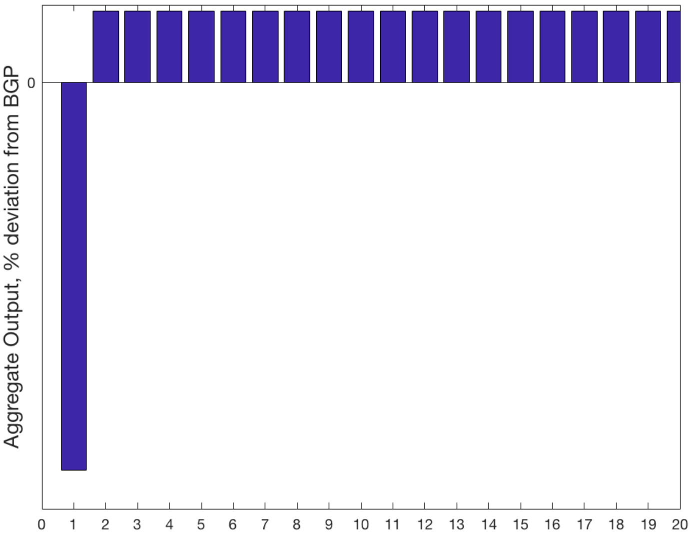
Impact Elasticity

Increase in aggregate productivity above trend



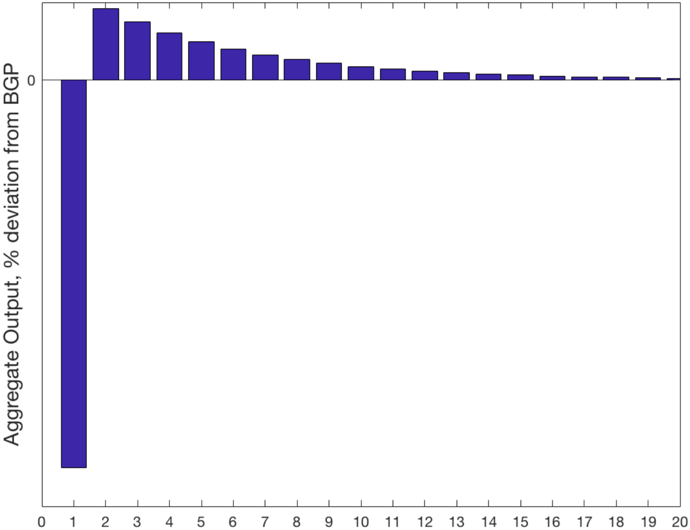
Dynamics: Full Intertemporal Knowledge Spillovers

Permanent increase in aggregate productivity above trend



Limited Intertemporal Knowledge Spillovers

Aggregate productivity reverts back to its initial path



Welfare

Consumption Equivalent Welfare

$$\log \xi \approx (1-\tilde{\beta}) \sum_{t=0}^{\infty} \tilde{\beta}^t \frac{\bar{Y}}{\bar{C}} \left[\left(\log Z_t' - \log \bar{Z}_t \right) + (1-\alpha) \left(\log l_{pt}' - \log \bar{l}_p \right) \right]$$

$$\tilde{\beta} = \frac{\exp(g_Y)}{1+R}$$

Socially Optimal Research Intensity

$$i_r^* = \frac{\tilde{\beta}\Theta}{1-\tilde{\beta}\left[1-(1-\phi)\Theta\right]}$$

Fiscal Implications

What subsidy rate is required to change the innovation intensity of the economy

$$\log \bar{i}_r' - \log \bar{i}_r = \log(1 - \bar{\tau}_e) - \log(1 - \bar{\tau}_e')$$

and what fiscal cost is required?

$$\frac{\bar{E}'}{\bar{Y}'} - \frac{\bar{E}}{\bar{Y}} = \bar{i}_r' - \bar{i}_r$$

Bounding the Impact Elasticity Θ

$$\Theta = \frac{1}{\rho - 1} \frac{\exp(\bar{g}_Z)^{\rho-1} - \exp(G(0))^{\rho-1}}{\exp(\bar{g}_Z)^{\rho-1}} \leq \bar{g}_z - G(0)$$

or more generally

$$\Theta \equiv G'\left(\bar{Y}_r\right)\bar{Y}_r \leq G(\bar{Y}_r) - G(0) = \bar{g}_z - G(0)$$

Interpreted as

$$\text{Impact elasticity} \leq \frac{\text{contribution of entrants' innovation to growth}}{\text{entrants' share of innovative investment}} = \frac{\bar{g}_Z - G(0)}{1}$$

Firm Dynamics Data

$$\frac{\exp(\bar{g}_Z)^{\rho-1} - \exp(G(0))^{\rho-1}}{\exp(\bar{g}_Z)^{\rho-1}} \leq \text{employment share of entrants}$$

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Investments and Aggregate Productivity Growth

Product-level innovation technologies imply tractable equilibrium aggregation:

$$\log Z_{t+1} - \log Z_t = G(x_{ct}, x_{mt}, x_{et})$$

subject to

$$x_{ct} + x_{mt} + x_{et} = Y_{rt}$$

1. New products by entrants, $x_{et} M_t$, fraction δ_e stolen, $\mathbb{E} \exp(z')^{\rho-1} = \eta_e \frac{Z_t^{\rho-1}}{M_t}$
2. New products by incumbent firms, $h(x_{mt}) M_t$, δ_m stolen, $\mathbb{E} \exp(z')^{\rho-1} = \eta_m \frac{Z_t^{\rho-1}}{M_t}$
3. Improvements of incumbents' products, if continue, $\mathbb{E} \exp(z')^{\rho-1} = \zeta(x_{ct}) \frac{Z_t^{\rho-1}}{M_t}$

Evolution of aggregate productivity

$$Z_{t+1}^{\rho-1} = \left[(1 - \delta_{ct}) \zeta(x_{ct}) + \eta_m h(x_{mt}) + \eta_e x_{et}\right] \frac{Z_t^{\rho-1}}{M_t} M_t$$

Product exit

$$\delta_{ct} = \delta_0 + \delta_m h(x_{mt}) + \delta_e x_{et}$$

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Product exit

$$\delta_{ct} = \delta_0 + \delta_m h(x_{mt}) + \delta_e x_{et}$$

Impact Elasticities

Start from

$$\log Z_{t+1} - \log Z_t = G(x_{ct}, x_{mt}, x_{et}) \quad \text{where} \quad x_{ct} + x_{mt} + x_{et} = Y_{rt}$$

Differentiating

$$\log Z_{t+1} - \log Z_t - \bar{g}_Z \approx \Theta \left(\log Y_{rt} - \log \bar{Y}_r\right)$$

$$\Theta = \frac{dx_c}{dY_r}\Theta_c + \frac{dx_m}{dY_r}\Theta_m + \frac{dx_e}{dY_r}\Theta_e$$

where $\Theta_i = G_i(\bar{x}_c, \bar{x}_m, \bar{x}_e)\bar{Y}_r$ and $\frac{dx_c}{dY_r} + \frac{dx_m}{dY_r} + \frac{dx_e}{dY_r} = 1$

Now no single measure of Θ

Plan for measurement in full model

- Two scenarios under which

$$\Theta \leq \Theta_e$$

  - Conditional Efficiency
  - Proportional Policy Change

Concavity of G in x_e implies

$$\Theta_e \leq (\bar{g}_Z - G(\bar{x}_c, \bar{x}_m, 0)) \frac{\bar{Y}_r}{\bar{x}_e}$$

- Contribution of entrants' to growth $\bar{g}_Z - G(\bar{x}_c, \bar{x}_m, 0)$
- Entrant's share of innovative investment $\bar{x}_e / \bar{Y}_r$

Conditional Efficiency

$$Y_r^* = \min x_c + x_m + x_e$$

$$G(x_c, x_m, x_e) = \bar{g}_Z$$

If $\bar{Y}_r = Y_r^*$

$$\Theta = \Theta_c = \Theta_m = \Theta_e$$

$$\Theta = \frac{dx_c}{dY_r}\Theta_c + \frac{dx_m}{dY_r}\Theta_m + \frac{dx_e}{dY_r}\Theta_e$$

Allocation of investment doesn't matter. Dynamics from simple model go through

General Mapping from Y_r to g_Z

Equilibrium first order conditions at any date t when $x_{et} > 0$

$$Y_{rt} = x_{ct} + x_{mt} + x_{et}$$

$$\frac{(1-\tau'_{mt})}{(1-\tau'_{et})}\eta_e = \eta_m h'(x_{mt})$$

$$\frac{(1-\tau'_{ct})}{(1-\tau'_{et})}\eta_e = (1-\delta_{ct})\,\zeta'(x_{ct})$$

$$\log Z_{t+1} - \log Z_t = G(x_{ct}, x_{mt}, x_{et})$$

Policy ratios constant over time implies a time-invariant mapping Y_{rt} to g_{Zt}

$$\frac{1-\tau'_{ct}}{1-\tau'_{et}} = \frac{1-\bar{\tau}'_c}{1-\bar{\tau}'_e} \quad \textit{and} \quad \frac{1-\tau'_{mt}}{1-\tau'_{et}} = \frac{1-\bar{\tau}'_m}{1-\bar{\tau}'_e}$$

General Policy Changes

$$\Theta = \frac{dx_c}{dY_r}\Theta_c + \frac{dx_m}{dY_r}\Theta_m + \frac{dx_e}{dY_r}\Theta_e$$

Policy ratios constant over time implies imply

$$\frac{dx_c}{dY_r}, \quad \frac{dx_m}{dY_r}, \quad \frac{dx_e}{dY_r} \qquad \text{constant over time}$$

Transition Dynamics around new BGP allocation of investment

$$\log Z'_{t+1} - \log \bar{Z}_{t+1} \approx \sum_{k=0}^{t} \Gamma'_k \left[\log I'_{rt-k} - \log \bar{I}_r - \left(\log \bar{Y}'_r - \log \bar{Y}_r\right)\right]$$

$\Gamma'_0 = \Theta'$ and $\Gamma'_{k+1} = [1 - (1-\phi)\Theta']\,\Gamma'_k$

Efficiency gain from reallocation of investment: $\log \bar{Y}'_r - \log \bar{Y}_r$

But need to know old and new BGP allocation of investment

Proportional Policy Changes

$$\frac{1-\bar{\tau}_c'}{1-\bar{\tau}_c} = \frac{1-\bar{\tau}_m'}{1-\bar{\tau}_m} = \frac{1-\bar{\tau}_e'}{1-\bar{\tau}_e}$$

With proportional policy changes, allocation of innovative investment is the same on the old and new BGP.

$$\Theta' = \Theta \qquad \bar{Y}_r' = \bar{Y}_r$$

Implies results from simple model apply

With regularity conditions $\Theta_e \leq \Theta_c$

Proportional increase in innovation subsidies $\uparrow x_e$ and $\downarrow x_c \implies \Theta <= \Theta_e$

Measurement

Need to measure ϕ and $\Theta \leq \Theta_e \leq (\bar{g}_Z - G(\bar{x}_c, \bar{x}_m, 0))\frac{\bar{Y}_r}{\bar{x}_e}$

1. Intertemporal Knowledge Spillovers ϕ
   - $\phi = 0.96$ — $\approx$ endogenous growth
   - $\phi = -1.6$ — Fernald and Jones (2014)
2. Contribution of Entrants to Growth
   - with no business stealing $= \frac{1}{\rho - 1}$ *employment share of entering firms*
   - estimates of $\bar{g}_Z - G(\bar{x}_c, \bar{x}_m, 0)$ from GHK and Akcigit and Kerr (2016)
3. Share of entrants' innovation expenditure in total innovation expenditure
   - NIPA measures of innovation expenditures of incumbent firms
   - impute investment in entry equal to value of entering firms

Measurement

Three quantities to be measured

1. Intertemporal Knowledge Spillovers ϕ
   - $\phi = 0.96$ — $\approx$ endogenous growth
   - $\phi = -1.6$ — Fernald and Jones (2014)
2. Contribution of Entrants to Growth
   - $\frac{1}{\rho - 1}$ *employment share of entering firms* $= \frac{0.027}{3} = 0.009$
   - AK 2016 $\frac{\bar{g}_Z - G(\bar{x}_c, \bar{x}_m, 0)}{\bar{g}_Z} = 0.257 \implies \bar{g}_Z - G(\bar{x}_c, \bar{x}_m, 0) = 0.0037$
3. Share of entrants' innovation expenditure in total innovation expenditure
   - incumbent firms invest 6.1% of output in innovation
   - imputed innovative investment of entering firms 3.1% of output

Measurement

Implied parameter values

1. Intertemporal Knowledge Spillovers ϕ
   - $\phi = 0.96$ — $\approx$ endogenous growth
   - $\phi = -1.6$ — Fernald and Jones (2014)
2. Impact Elasticity
   - $\Theta = \Theta_e = 0.026$ — no business stealing
   - $\Theta \leq \Theta_e = 0.01$ — AK 2016
3. Ratio of growth rate to interest rate and physical capital share
   - $\tilde{\beta} = 0.986$
   - $\alpha = 0.25$

A Policy Experiment

Uniform subsidy to innovative investment to permanently raise research labor $\log l_r - \log \bar{l}_r$ by 0.10

Innovation intensity of the economy up by 1.1 percentage point

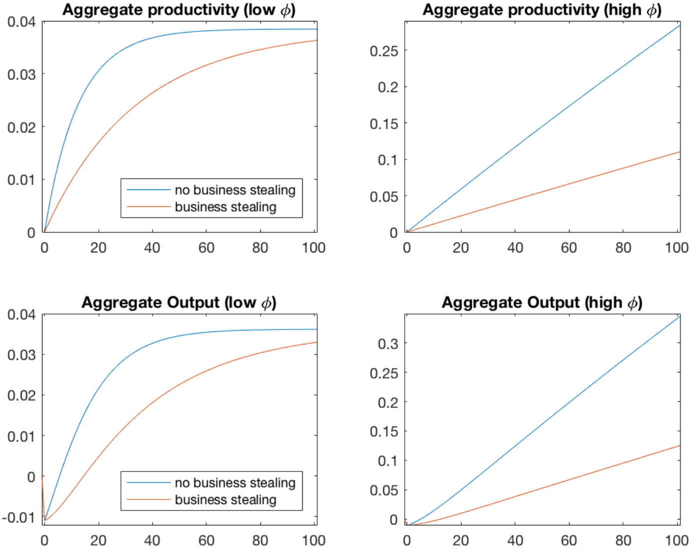
Long run fiscal cost of 1.1 percentage point of output

Path of Productivity and Output over 100 years

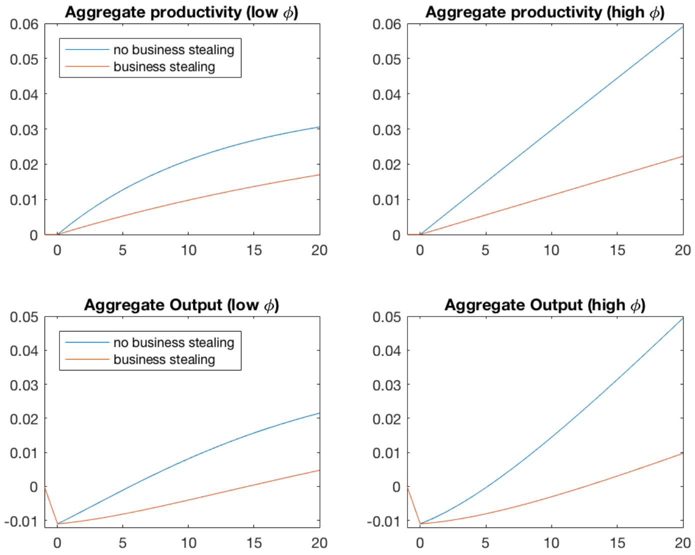
Path of Productivity and Output over 20 years

Welfare Impact

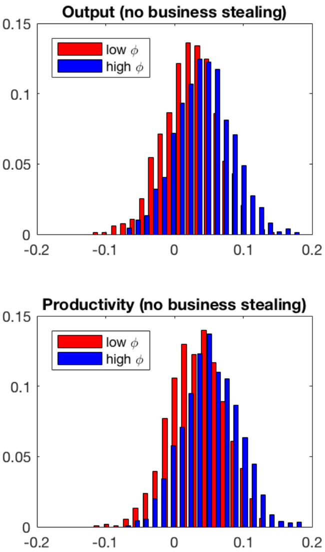
Productivity and Output over 100 years



Productivity and Output over 20 years



Hard to distinguish from business cycles



Welfare implications

Welfare (equivalent variation)	$\phi = -1.6$	$\phi = 0.96$
No Bus. stealing $\Theta = 0.026$	0.026	0.21
AK $\Theta = 0.01$	0.017	0.073

Optimal Inn. Intensity	$\phi = -1.6$	$\phi = 0.96$
No Bus. stealing $\Theta = 0.026$	0.32	1.70
AK $\Theta = 0.01$	0.24	0.66

Conclusion

- A tractable model
- Guide for measurement
- Results consistent with time series evidence
- Long term gains from innovation policy possibly large
- Near-term gains from innovation policy must likely come from reallocation