PhD Topics in Macroeconomics

Lecture 8: innovation and firm dynamics, part four

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This lecture

Atkeson/Kehoe (2007) model of transition to a 'new economy' following a sustained increase in pace of *embodied* technical change

1- facts on second industrial revolution, diffusion of electricity

2- model of embodied technical change and learning

3- quantitative experiments

Background

- Solow (1987 NYT *Book Review*)

  "You can see the computer age everywhere but in the productivity statistics"

- David (1990 AER)

  "Factory electrification did not...have an impact on productivity growth in manufacturing before the early 1920's. At that time only slightly more than half of factory mechanical drive capacity had been electrified.... This was four decades after the first central power station opened for business"

- Atkeson and Kehoe attempt to see if simple firm dynamics model

  (a) predicts slow transition after second industrial revolution

  (b) and also predicts slow transition after IT revolution

Transition after second industrial revolution

- Second wave of new technologies, 1860–1900
  - electricity, internal combustion engine, production of petroleum, telephones, radios, indoor plumbing
  - focus on electricity
- Three key features of transition

  (i) *productivity paradox*: lagged response of productivity growth to increased rate of technological change

  (ii) *slow diffusion of new technologies*

  (iii) *substantial ongoing investment in old technologies*

Figure 1 **A Slow Increase in Productivity Growth . . .**

Log of Output per Hour and Trend Growth in U.S. Manufacturing, 1869–1969

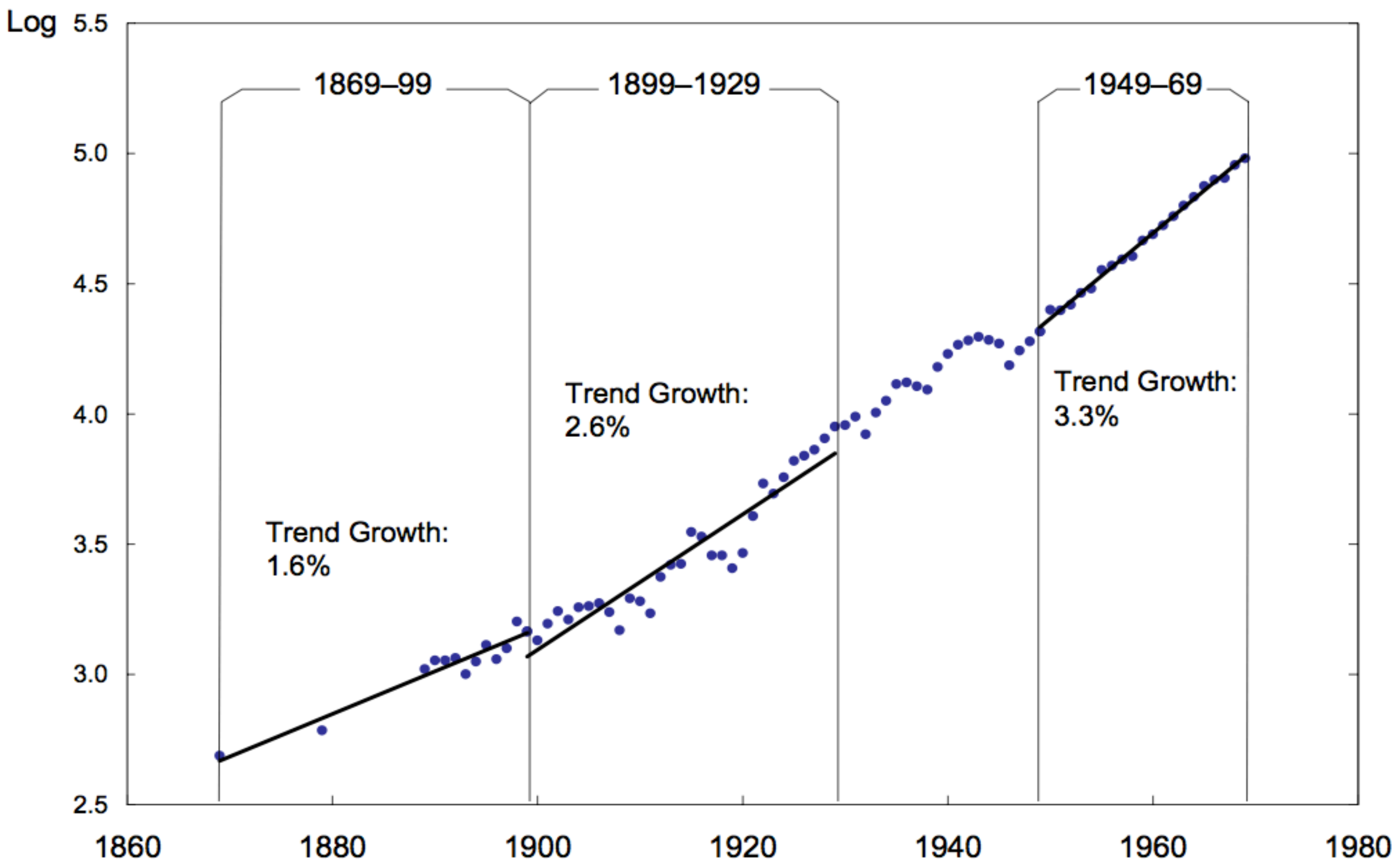
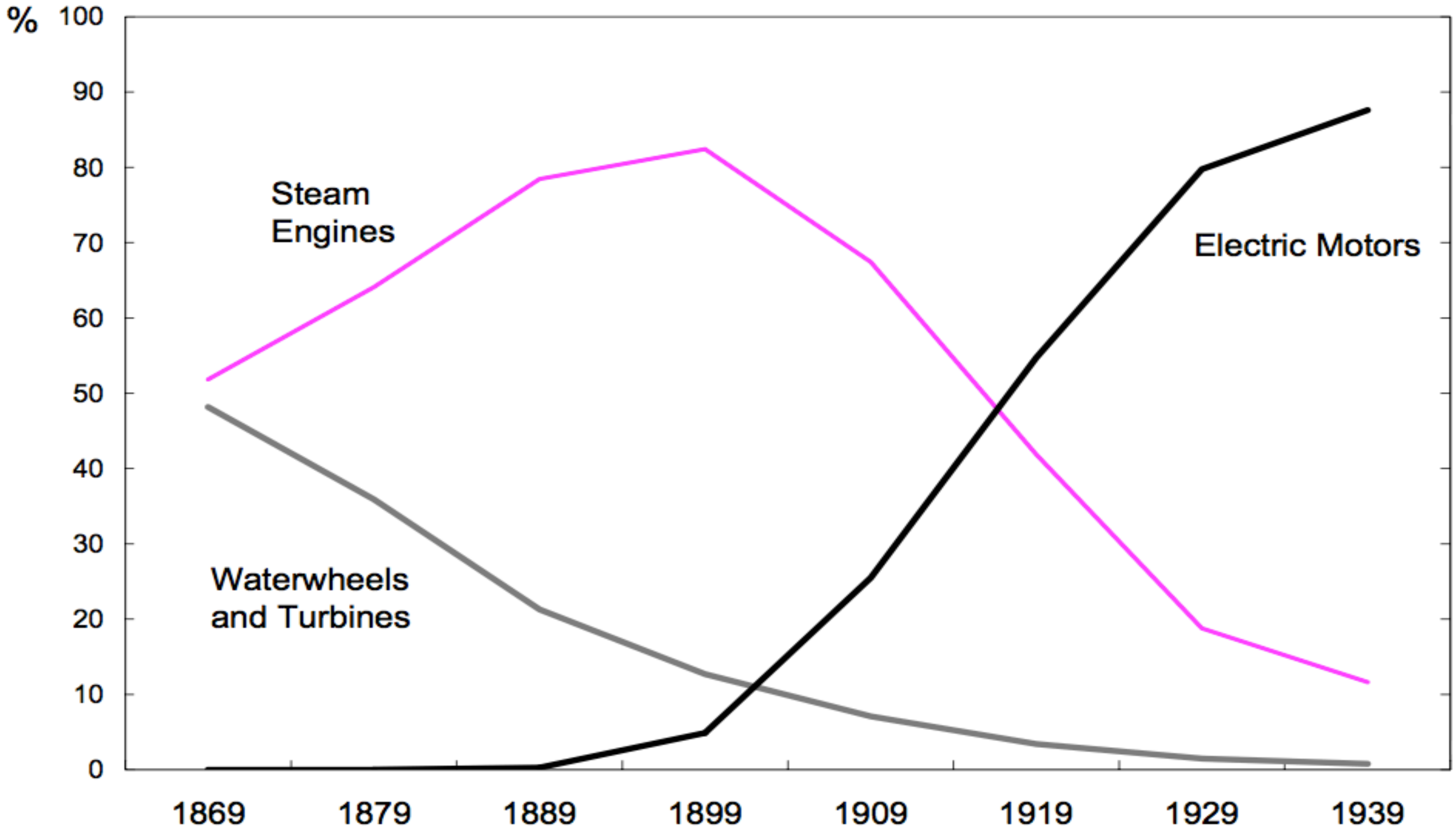


Figure 2 . . . . **And Slow Diffusion of Electric Power**

Percentage of Total Horsepower from Three Sources of Mechanical Drive in U.S. Manufacturing, 1869–1939



Model: key assumptions

- *New plants embody new technologies*: manufacturing plants need to be completely redesigned to make efficient use of new technologies (e.g., electricity vs. steam and water)

- *Improvements in technology for new plants ongoing*: persistent increase in rate of improvement of frontier technology

- *New plants improve their technology through learning*

Model

- Discrete time $t = 0, 1, \ldots$

- Representative household

$$U = \sum_{t=0}^{\infty} \beta^t \log c_t, \qquad 0 < \beta < 1$$

  consists of a *worker* and a *manager*, each inelastically supplies one unit of labor for wages w_t and $w_{m,t}$ respectively

- Intertemporal budget constraint

$$\sum_{t=0}^{\infty} p_t c_t \leq \sum_{t=0}^{\infty} p_t (w_t + w_{m,t}) + k_0 + a_0$$

  where p_t is price of date-t consumption, k_0 is initial capital and a_0 initial value of *plants*

- Gross real interest rate p_t/p_{t+1}. No aggregate uncertainty

Plants

- Monopolistically competitive intermediate goods

- Produced at *plants*, require 1 manager plus capital and labor

$$y = zA^{(1-\gamma\theta)/\theta}F(k,l)^{\gamma}, \qquad 0 < \gamma, \theta < 1$$

  where γ is the manager's *span of control* and θ determines elasticity of substitution between plants

- Economy-wide productivity z grows at exogenous rate

- Plants characterized by *specific productivity* A and *age* s

Final good

- Homogenous final good with CES technology

$$Y_t = \Big(\sum_s \int_A y_t(A)^\theta d\lambda_t(A,s) \Big)^{1/\theta}, \qquad 0 < \theta < 1$$

where $\lambda_t(A,s)$ is distribution of plants over (A,s)

- Let $p_t(A)$ denote the price of a plant of productivity A, then residual demand from final good producer

$$y_t(A) = p_t(A)^{-1/(1-\theta)} Y_t$$

where final good is numeraire ($P_t = 1$)

Static problem

- Static problem for a plant

$$\pi_t(A) := \max_{p,y,k,l} \Big[py - r_t k - w_t l\Big]$$

subject to production technology

$$y = z_t A^{(1-\gamma\theta)/\theta} F(k,l)^\gamma$$

and residual demand curve

$$y = p^{-1/(1-\theta)} Y_t$$

- Let $p_t(A), y_t(A), k_t(A), l_t(A)$ denote solution to this static problem

- Note these are independent of age

Timing

- At beginning of period, plant has state (A, s)
- Owner decides to operate or not, if not get outside option $(= 0)$
- If operate, implement plan $p_t(A), y_t(A), k_t(A), l_t(A)$
- Then draw shock $\varepsilon \sim G_{s+1}(\varepsilon)$ from *age-dependent distribution* (stochastically decreasing in age s)
- Enter next period with state $(A\varepsilon, s+1)$. Shocks are *permanent*

Dynamic problem

- Let $V_t(A, s)$ denote value of plant with (A, s) at beginning of t

- This value function satisfies the Bellman equation

$$V_t(A,s) = \max\left[0\,,\ \pi_t(A) - w_{m,t} + \frac{p_{t+1}}{p_t}\int V_{t+1}(A\varepsilon, s+1)\, dG_{s+1}(\varepsilon)\right]$$

(taking sequence $\{p_t, z_t, w_t, w_{m,t}, r_t\}_{t=0}^{\infty}$ as given)

- *Age-dependent cutoff rule*, only plants $A \geq A_t^*(s)$ continue

Blueprints

- Before new plant can operate at t, manager must spend period $t-1$ preparing new plant *blueprint*

- Economy-wide *frontier blueprint* τ_t, exogenous growth g_τ

- New plants *embody* this frontier blueprint

- New plant starts period t with state $(A, s) = (\tau_t, 0)$

Entry decision

- Let V_t^0 denote value of entry at beginning of t
- Satisfies the Bellman equation

$$V_t^0 = -w_{m,t} + \frac{p_{t+1}}{p_t} V_{t+1}(\tau_{t+1}, 0)$$

- Let η_t denote mass of entrants. Free-entry condition

$$V_t^0 \eta_t = 0, \qquad \text{so that } V_t^0 = 0 \text{ whenever } \eta_t > 0$$

Market clearing and aggregates

- Market clearing for physical capital, workers, and managers

$$K_t = \sum_s \int_A k_t(A)\, d\lambda_t(A, s)$$

$$L_t = \sum_s \int_A l_t(A)\, d\lambda_t(A, s) = 1$$

and

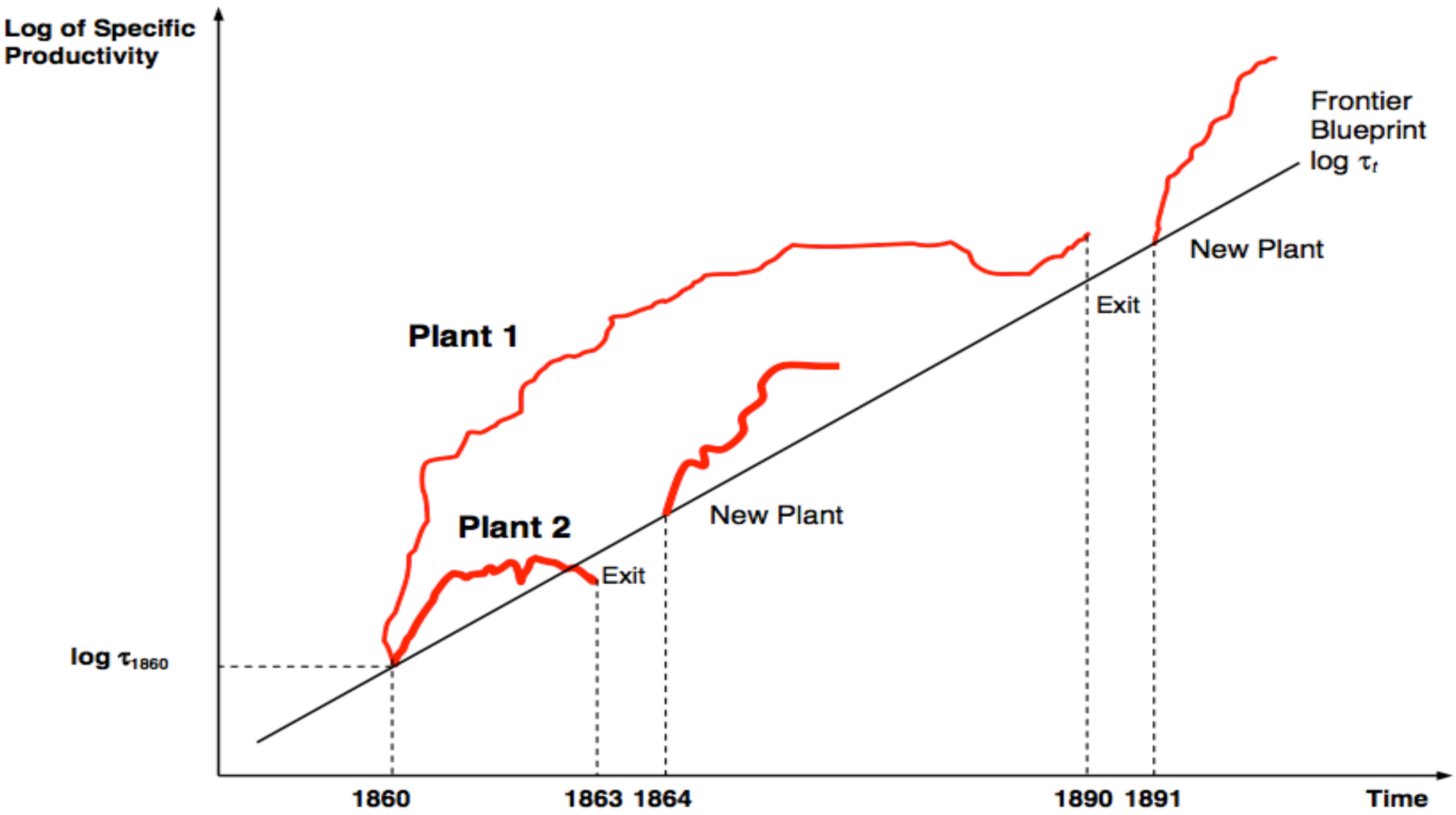
$$\sum_s \int_A d\lambda_t(A, s) + \eta_t = 1$$

- Resource constraint for final output

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

Figure 3 **The Life Cycle of Plants in the Model**

Productivity of Two Plants vs. That of Frontier Blueprint Over Time



Productivity and size

- Let $\bar{A}_{t,s}$ denote specific productivity for cohort s

$$\bar{A}_{t,s} = \int_A A \, d\lambda_t(A, s)$$

- Let $\bar{A}_t$ denote economy-wide specific productivity

$$\bar{A}_t := \sum_s \int_A A \, d\lambda_t(A, s)$$

- Let $n_t(A)$ denote the effective *size* of plant (A, s) in period t

$$n_t(A) := \frac{A}{\bar{A}_t} \qquad \Leftrightarrow \qquad \frac{\bar{A}_{t,s}}{\bar{A}_t} = \int_A n_t(A) \, d\lambda_t(A, s)$$

- Equilibrium allocations $k_t(A) = n_t(A)k_t$, $l_t(A) = n_t(A)l_t$, etc

Inferring learning from size

- Let $l_{t,s}$ denote share of employment at plants of cohort s

$$l_{t,s} := \int_A \frac{l_t(A)}{l_t} \, d\lambda_t(A, s)$$

$$= \int_A n_t(A) \, d\lambda_t(A, s) = \frac{\bar{A}_{t,s}}{\bar{A}_t}$$

- Growth in employment shares by cohort used to infer growth in specific productivity
  - in data: employment shares of plants rise for at least first 20 years of plant life
  - inference: aggregate of specific productivities $\bar{A}_{t,s}$ grows faster that $\bar{A}_t$ for at least 20 years

Contrast with traditional learning estimation

- Standard to look at coefficient on age s_{it} in regression of form

$$\log y_{it} = b_{1,t} + b_2 \log l_{it} + b_3 s_{it}$$

- But model predicts labor productivity y_{it}/l_{it} is same for all plants (i.e., $b_2 = 1$ and $b_3 = 0$)

- Intuition

  – individuals who learn increase their labor productivity

  – but organizations that learn respond by *adding variable inputs*, so labor productivity equated across firms

Parameterization

- Cobb-Douglas production $F(k,l) = k^{\alpha} l^{1-\alpha}$, implies capital income share is $\alpha\gamma\theta$ etc. Otherwise fairly standard macro parameters

- Lognormal age-dependent shock distributions $G_s(\varepsilon)$

$$\log \varepsilon \sim N(m_s \, , \, \sigma_s^2)$$

with means

$$m_s = \kappa_1 + \kappa_2 \left(\frac{s_{\max} - s}{s_{\max}} \right)^2, \qquad s = 0, 1, \ldots, s_{\max}$$

and standard deviations

$$\sigma_s = \kappa_3 + \kappa_4 \left(\frac{s_{\max} - s}{s_{\max}} \right)^2, \qquad s = 0, 1, \ldots, s_{\max}$$

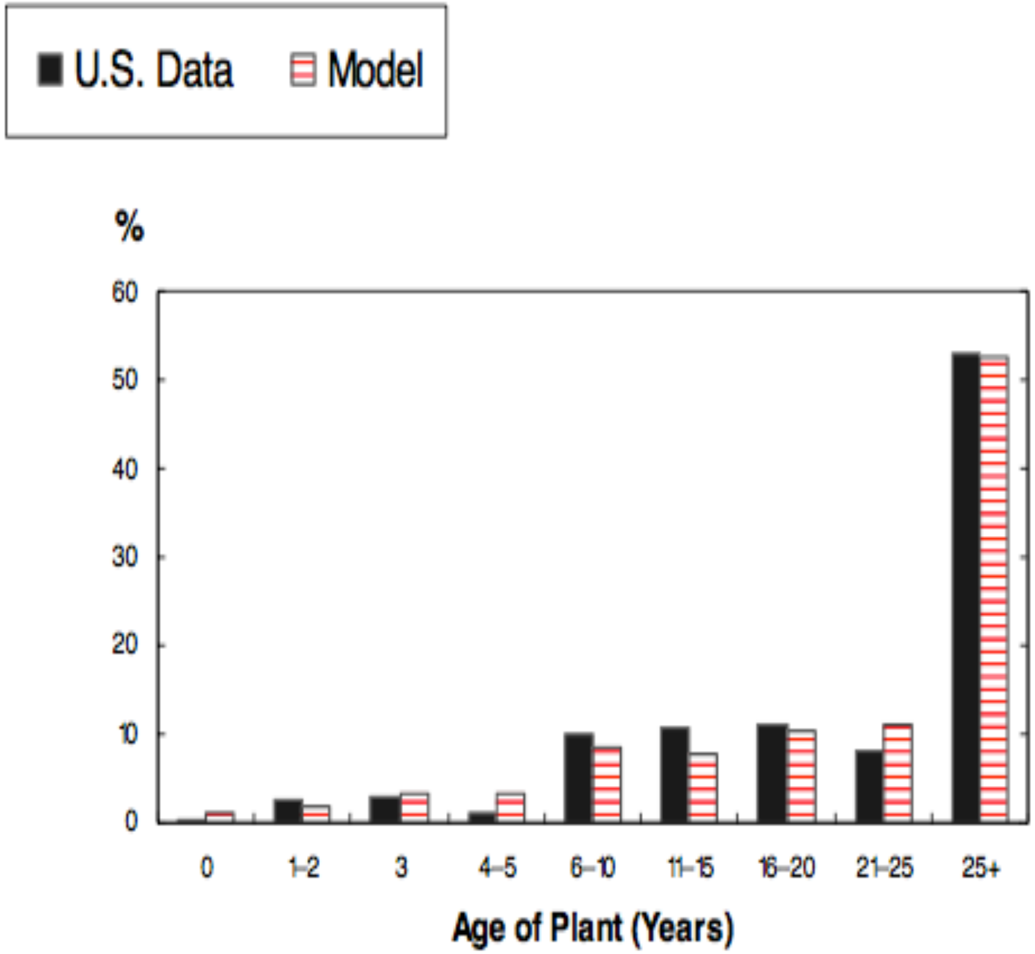
- Five parameters to calibrate, $\kappa_1, \kappa_2, \kappa_3, \kappa_4$ and $s_{\max}$

- Targets: employment, job creation and job destruction moments for each of 9 age categories

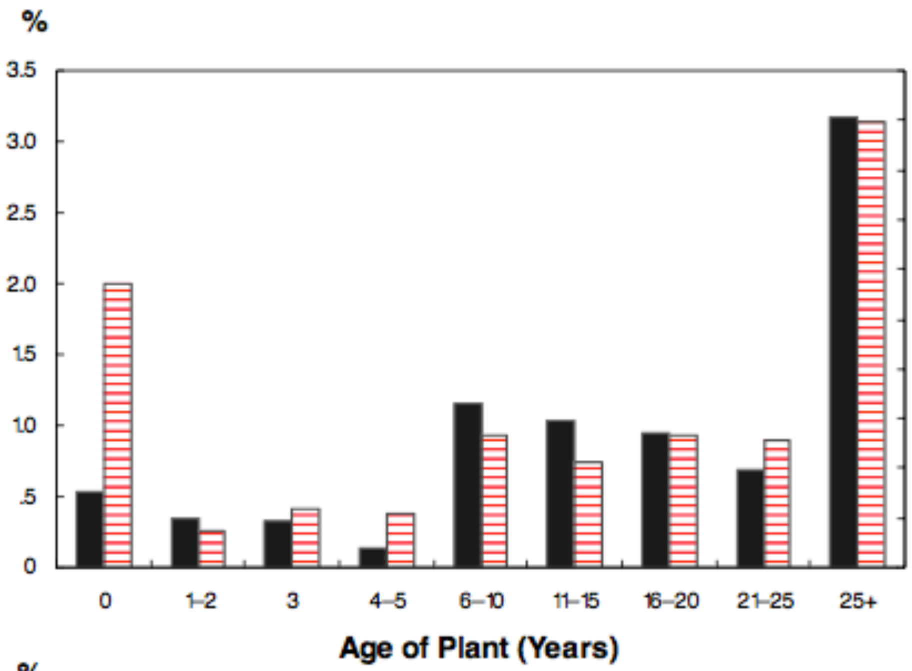
Figure 4 **The Model's Reproduction of U.S. Data on Employment, Job Creation, and Job Destruction**

Each Statistic as a Percentage of Total U.S. 1988 Employment
for Manufacturing Plants of Various Ages

A. Employment

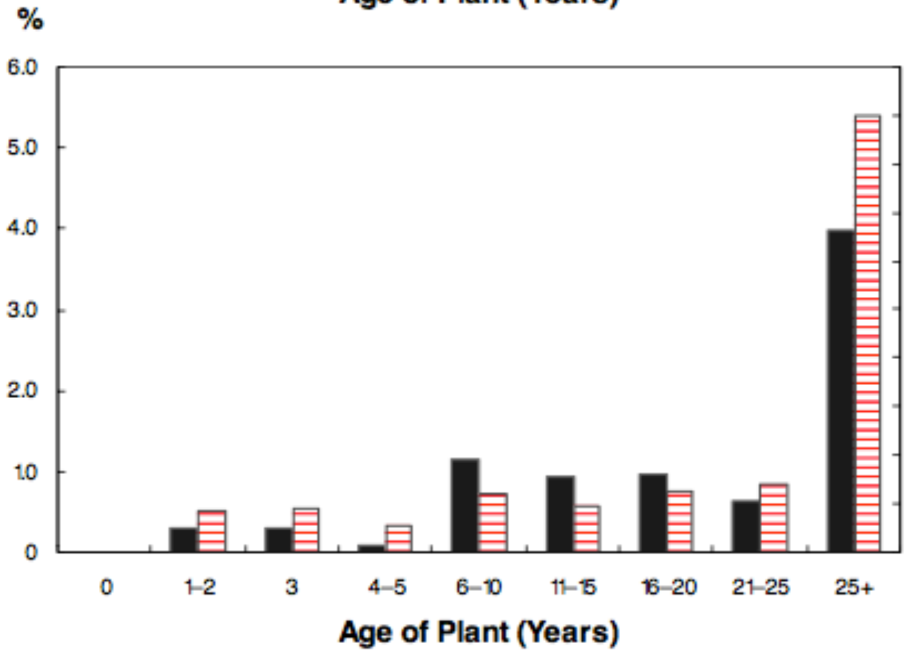


B. Job Creation



All Plants 1988	
Model	9.7%
Data	8.3%
S.D. 1972–93	2.0% pts

C. Job Destruction



All Plants 1988	
Model	9.7%
Data	8.4%
S.D. 1972–93	2.7% pts

Main transition experiment

- Can model reproduce transition after second industrial revolution?

- Shock: unexpected, permanent increase in pace of embodied technical change. In particular

  – start with g_τ^{old} for 1.6% growth path (corresponding to 1869–1899)

  – learn that g_τ^{new} for 3.3% growth path (corresponding to 1949–1969)

  – shock arrives in period $t = 1869$, compute transition between old and new growth paths

- Initial conditions

  – initial capital/output ratio and distribution of (A, s) as per steady-state of *old* economy

  – amounts to assuming process of learning does not depend on g_τ

Figure 5 **A Slow Increase in Productivity Growth . . .**

Log of Output per Hour and Trend Growth in Manufacturing, 1869–1969, in the Data and the Model

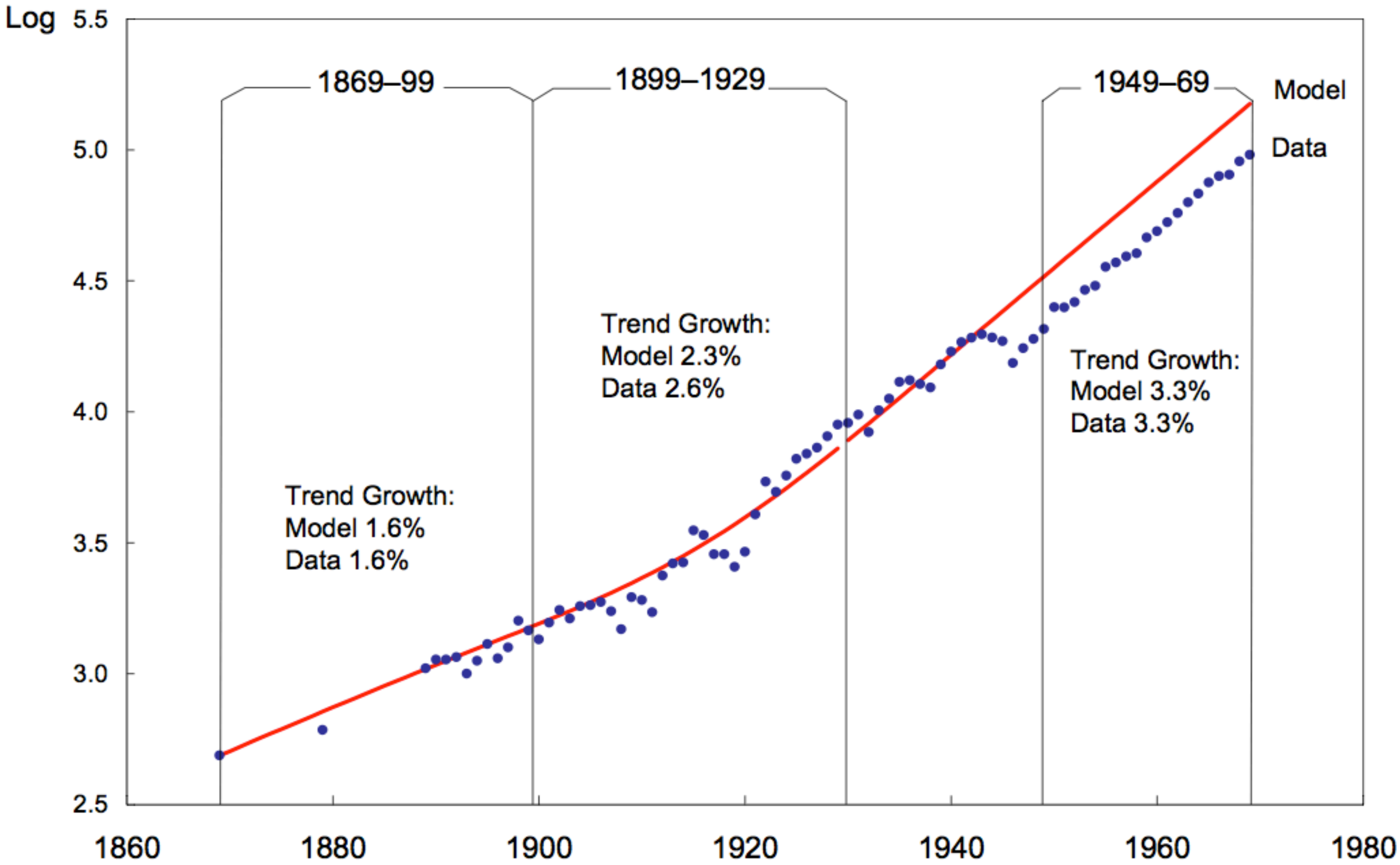


Figure 6 **. . . A Slow Diffusion of New Technology . . .**

Model's Predicted % of Output Produced in Plants with New Blueprints (1869 or later)
vs. Actual % of Horsepower Provided by Electric Motors in U.S. Manufacturing Plants, 1869–1939

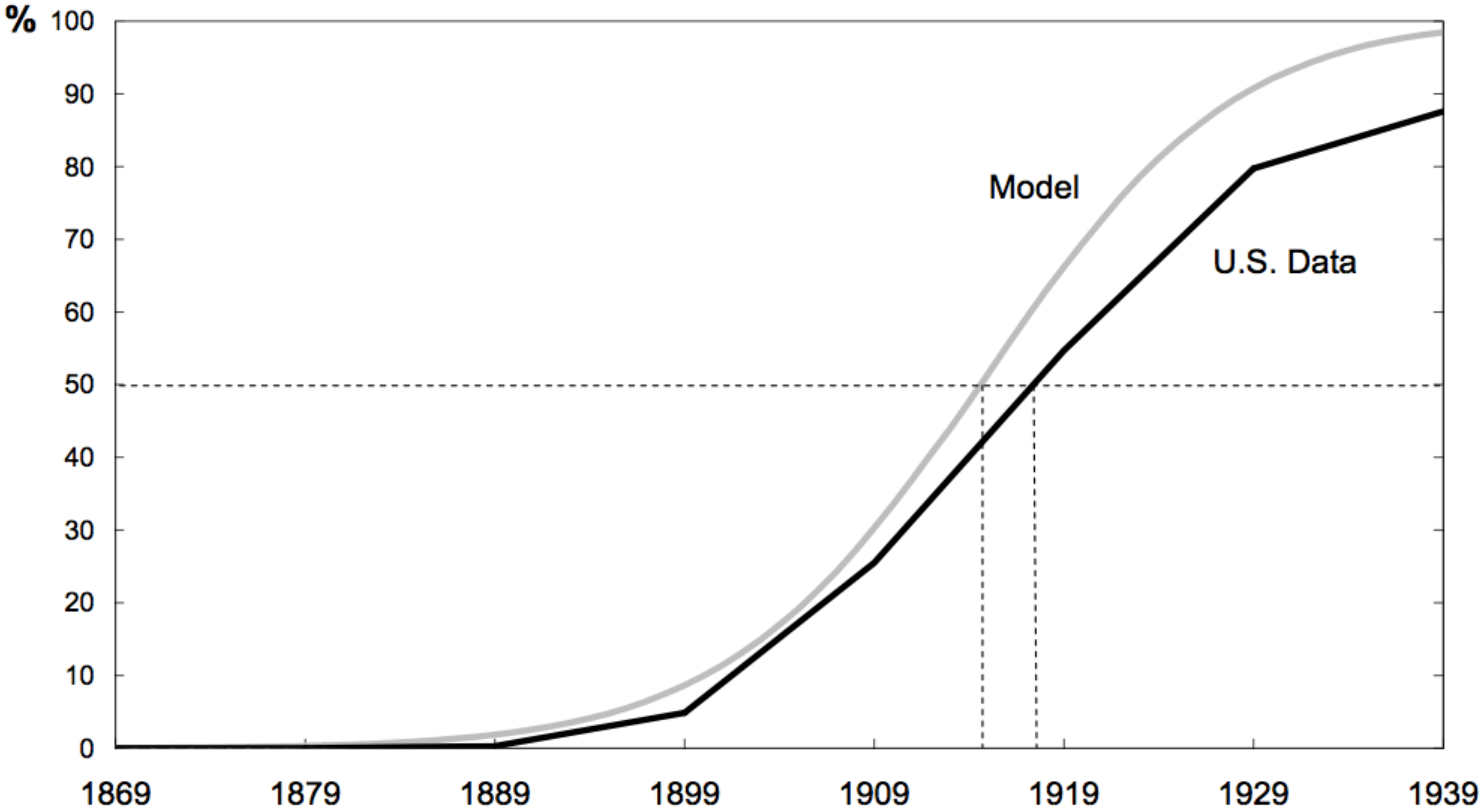
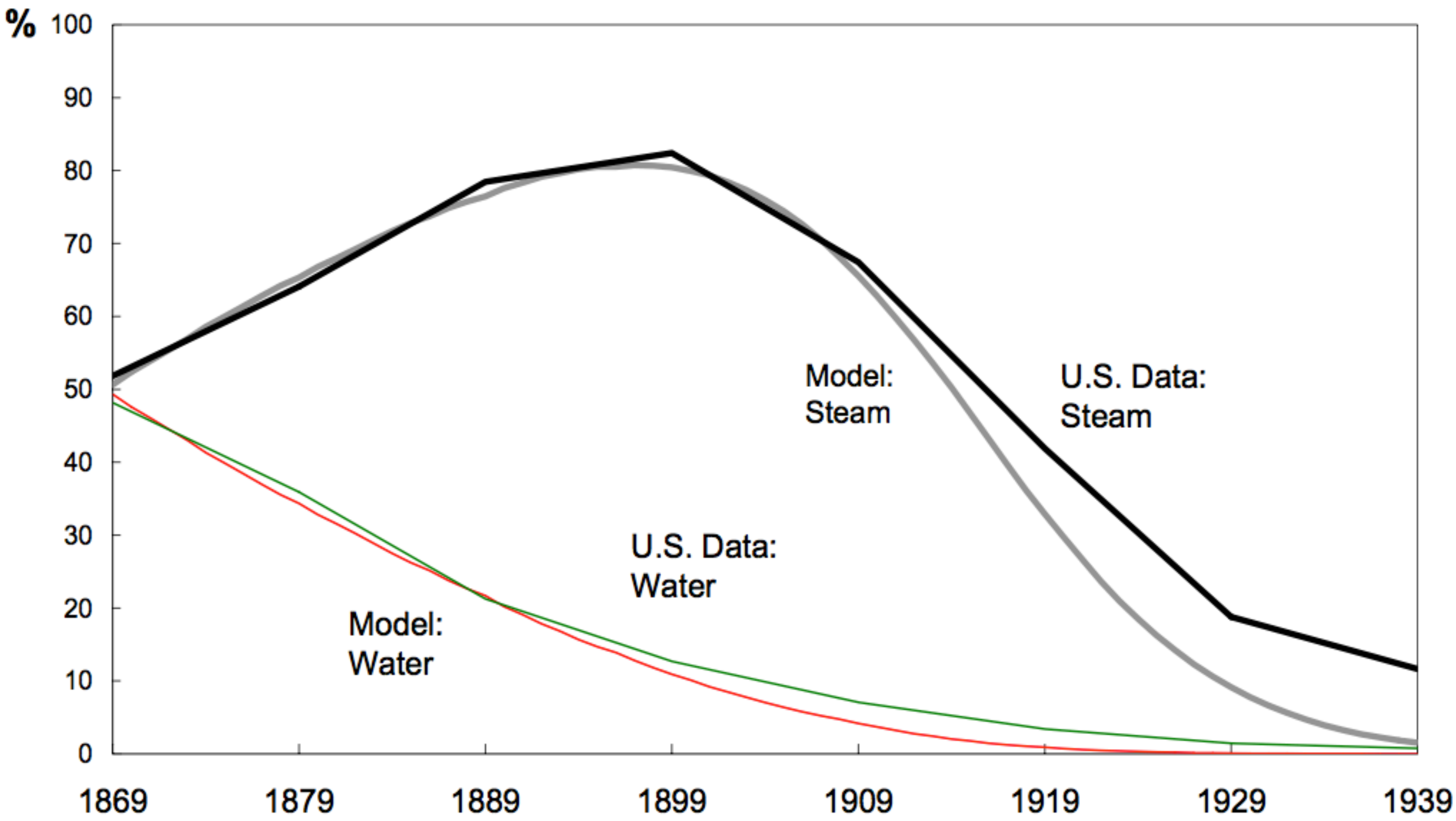


Figure 7 . . . **And Ongoing Investment in Old Technologies**

Model's Predicted % of Output Produced in Plants with Blueprints Dated 1802–1869 (Steam) and Before 1802 (Water) vs. Actual % of Horsepower Provided by Steam and Water Power in U.S. Manufacturing Plants, 1869–1939



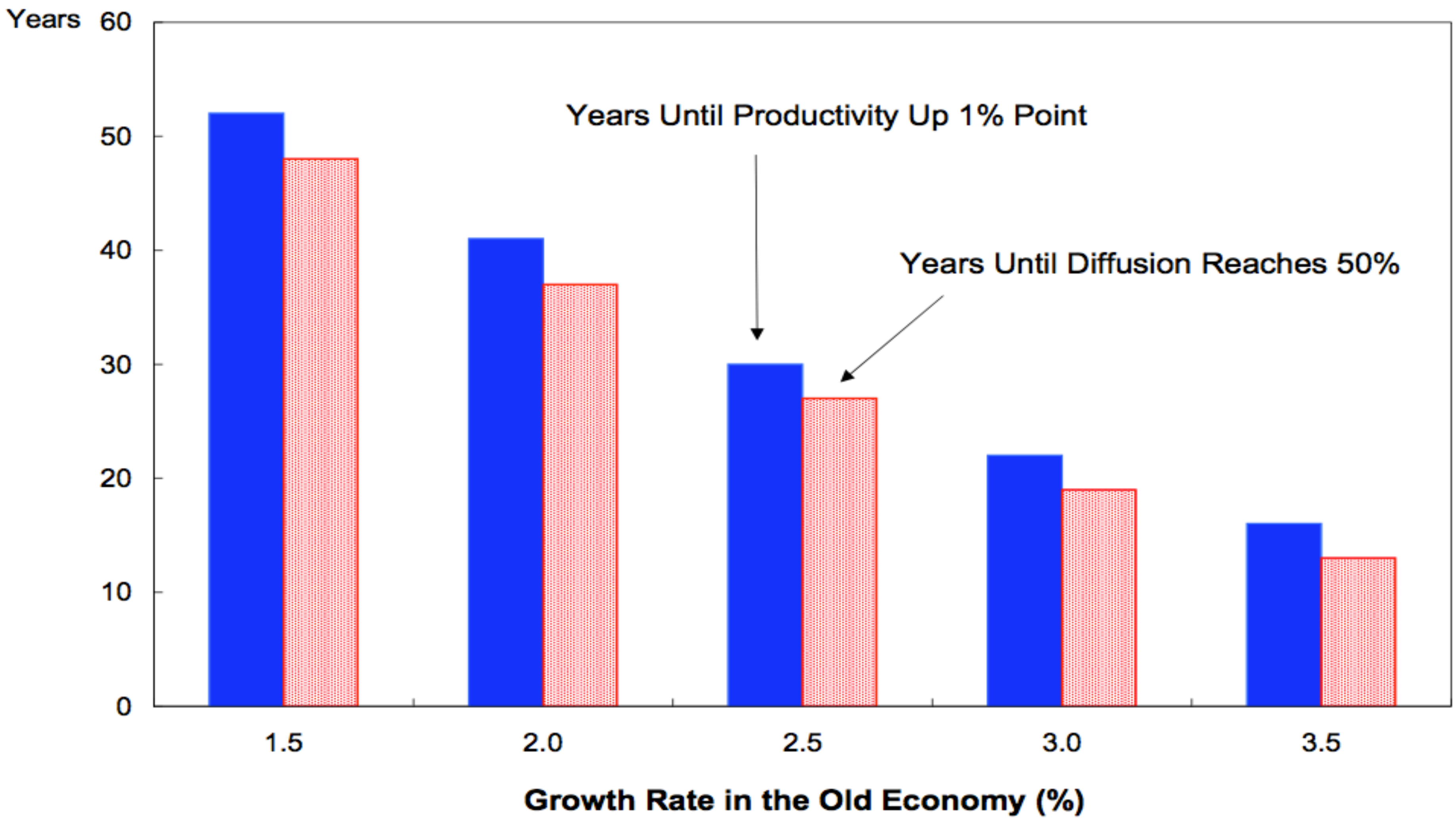
Lessons for other technological revolutions?

- Model gives slow transition after second industrial revolution
- Will it also give slow transition after IT revolution?
- Perhaps not. Model predicts slow transition only if there is large stock of *built-up knowledge* about old technologies
  - large stock of built-up knowledge of water and steam before electricity revolution
  - is there are similar built-up stock of knowledge about pre-IT organizational practices?

Figure 8 **Initial Growth Rates Matter for . . .**

A. . . . The Speed of Transition . . .

Model's Predictions, with Various Initial Steady-State Growth Rates, for the Time
Until Productivity Growth Increases 1% Point and the Time Until Diffusion Reaches 50%



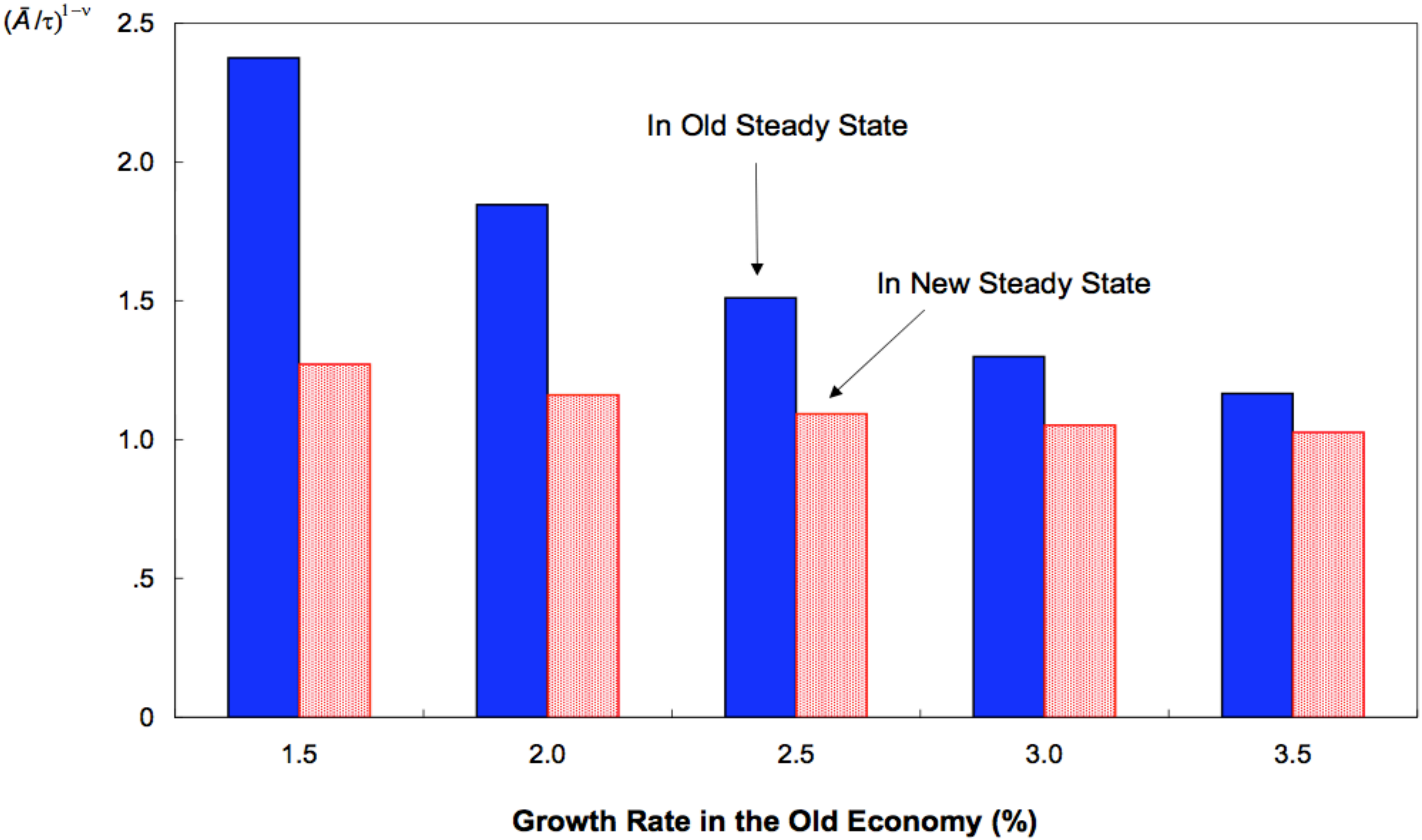
- Why does *old-economy* growth rate matter so much for speed of transition and diffusion?

- In slow-growing economies, large stock of built-up knowledge (so owners of plants reluctant to abandon them)

- In fast-growing economies, small stock of built-up knowledge (so employment also relatively more concentrated at *young* plants)

B. . . . And the Stock of Built-Up Knowledge

Model's Predictions, with Various Initial Steady-State Growth Rates, for the Amount of Built-Up Knowledge, $(\bar{A}/\tau)^{1-\nu}$, in the Old and New Steady States



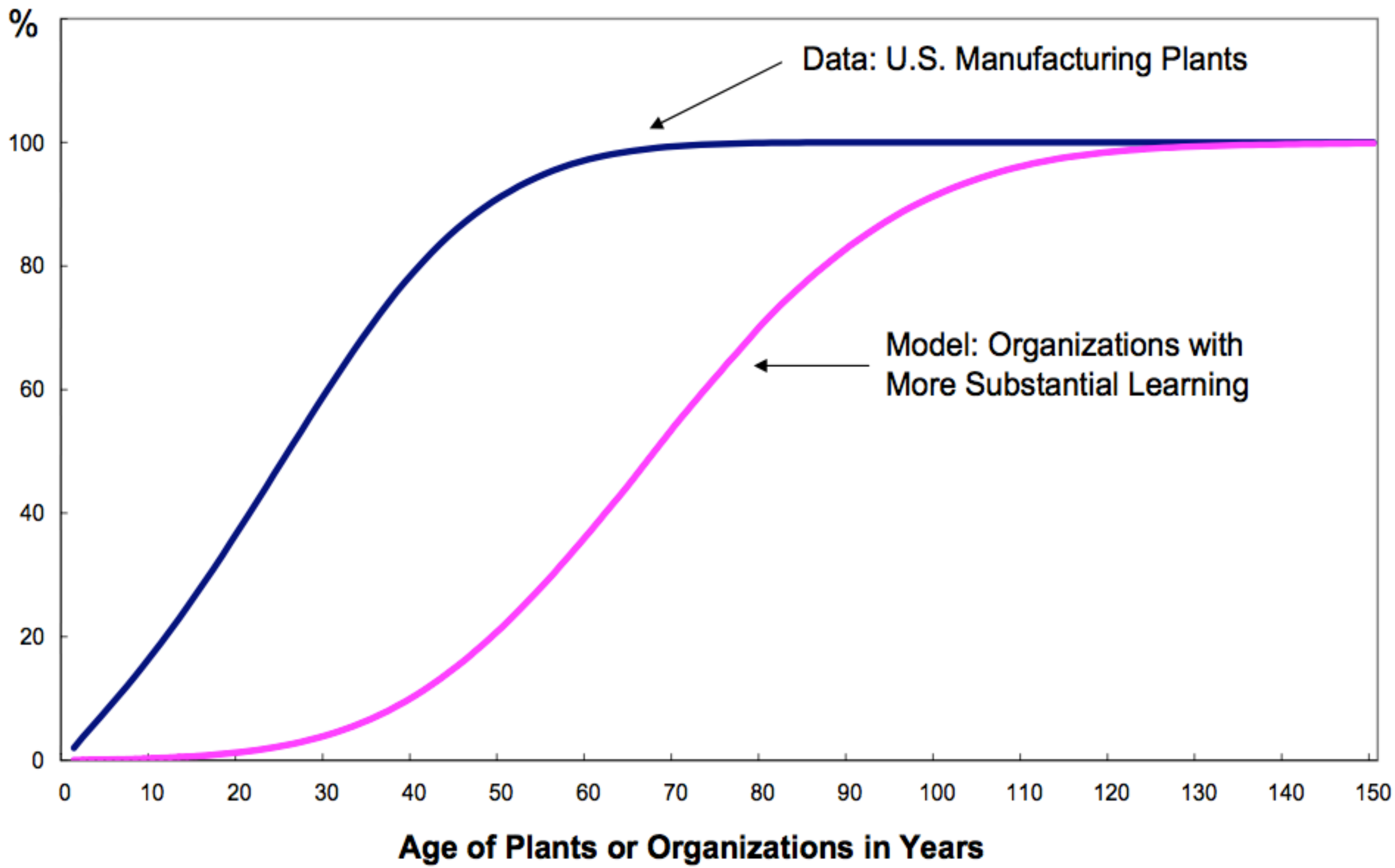
- Suppose economy starts on 3.3% growth path, then increases to 5% growth path

- Transition is now slow, similar to transition after second industrial revolution

- What does the age profile of organizations look like in this alternate model with substantially more learning?

Figure 9 **The Distribution of Employment With More Substantial Learning**

Cumulative Distribution of Employment by Age of Plants or Organizations



Next

- Misallocation, part one

- Productivity and welfare consequences of idiosyncratic distortions

  ◇ Restuccia and Rogerson (2008): Policy distortions and aggregate productivity with heterogeneous establishments, *Review of Economic Dynamics*.

  ◇ Hsieh and Klenow (2009): Misallocation and manufacturing TFP in China and India, *Quarterly Journal of Economics*.