Dynamic Oligopoly and Price Stickiness

Olivier Wang
NYU Stern

Iván Werning
MIT

Imperfect Competition

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- Monopolistic competition: continuum of firms (Dixit-Stiglitz)
  - simple and tractable
  - reigns supreme: trade, macro, growth, …

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- Oligopoly: finite number of firms
  - more realistic and complicated
  - extensive IO literature
  - "rise in market power": markups, concentration, superstar firms, …
- **Q:** Oligopoly important for macro ?

This Paper

- Standard macro models…
  - representative agent, infinite horizon
  - consumption, labor and money
  - nominal rigidities a la Calvo

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  - representative agent, infinite horizon
  - consumption, labor and money
  - nominal rigidities a la Calvo
- This paper
  - oligopoly with any *n* firms
  - general demand structure
    (e.g. Kimball, not just CES)

Challenges and Methods

- Monopolistic Competition
  - best response depends on aggregates…
  - …taken as given (infinitesimal)
- Oligopoly Dynamic Game
  - off-equilibrium deviations…
  - … influence not infinitesimal

- Our paper…
  - innovation: local analysis for small shocks

Literature

- Mongey (2016)
- Rotemberg-Saloner (1986), Rotemberg-Woodford (1992)
- IO Literature (dynamic): Ericson-Pakes (1995), Bajari-Benkard-Levin (2007), …
- Passthrough Literature (static): Goldberg (1985), Atkeson-Burstein (2008), Gopinath-Itskhoki (2010), Arkolakis-Costinot-Donaldson-Rodríguez Clare (2015), Amiti-Itskhoki-Konings (2019)
- Rational Inattention: Afrouzi (2020)

Setup

- Households: consumption, labor, money
- Firms: continuum of sectors s…
  - n_s firms within sector s
  - Calvo: frequency λ_s of price change

- Markov equilibrium
- One time, unanticipated "MIT shock" to money

$$\int_0^\infty e^{-\rho t} U\left(C(t), L(t), \frac{M(t)}{P(t}\right) dt$$

$$C(t) = G(\{C_s(t)\}_s)$$
$$C_s(t) = H(c_{s,1}(t), c_{s,2}(t), \ldots, c_{s,n}(t))$$

(Golosov-Lucas)

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$$C(t) = G(\{C_s(t)\}_s) \longrightarrow C(t) = \exp \int_0^1 \log C_s(t) ds$$

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$$P(t)C(t) + \dot{B}(t) + \dot{M}(t) = W(t)L(t) + \widetilde{\Pi}(t) + T(t) + r(t)B(t)$$

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$$\mathbb{E}_0 \int_0^\infty e^{-\int_0^t r(s)ds} \widetilde{\Pi}^{i,s}(t) dt$$

$$\widetilde{\Pi}^{i,s}(t) = c_{i,s}(t)\left(p_{i,s}(t) - W(t)\right)$$

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Calvo pricing
Poisson arrival

$$\mathbb{E}_0 \int_0^\infty e^{-\int_0^t r(s)ds} \widetilde{\Pi}^{i,s}(t) dt \xrightarrow{\lambda_s}$$

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Calvo pricing
Poisson arrival
λ_s $\longrightarrow$

Reset strategy

$$p^*_{i,t} = g^{i,s}(p_{-i,s}; t)$$

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Poisson arrival
λ_s $\longrightarrow$

Reset strategy

$$p^*_{i,t} = g^{i,s}(\underbrace{p_{-i,s}}_{\{p_{j,s}\}_{j\neq i}}; t)$$

Equilibrium

$$\{C(t), L(t), M(t), P(t), W(t), r(t)\}$$

$$\{c_{i,s}(t), p_{i,s}(t)\}$$

$$\{g^{i,s}(p_{-i,s};t)\}$$

- agents: $\{P(t), W(t), r(t)\} \xrightarrow{\text{max}} \{C(t), L(t), M(t)\}$
- firms: $\left.\begin{matrix}\{C(t), P(t), W(t), r(t)\} \\ \{g^{-i,s}(\cdot;t)\}\end{matrix}\right\} \xrightarrow{\text{max}} g^{i,s}(p_{-i,s};t)$
- market clearing:

$$L(t) = \int \sum_{n_s} c_{i,s}(t) ds$$

Steady State

- Constant C, L, M, P, W, r

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  - household and market clearing

$$C = L$$

$$\frac{U_C}{P} = \frac{U_L}{W} = \frac{U_m}{rP}$$

$$r = \rho$$

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$$\rho V(p) = D^i(p)(p_i - W) + \lambda \sum_j \left[V\left(g\left(p_{-j}\right), p_{-j}\right) - V(p)\right]$$

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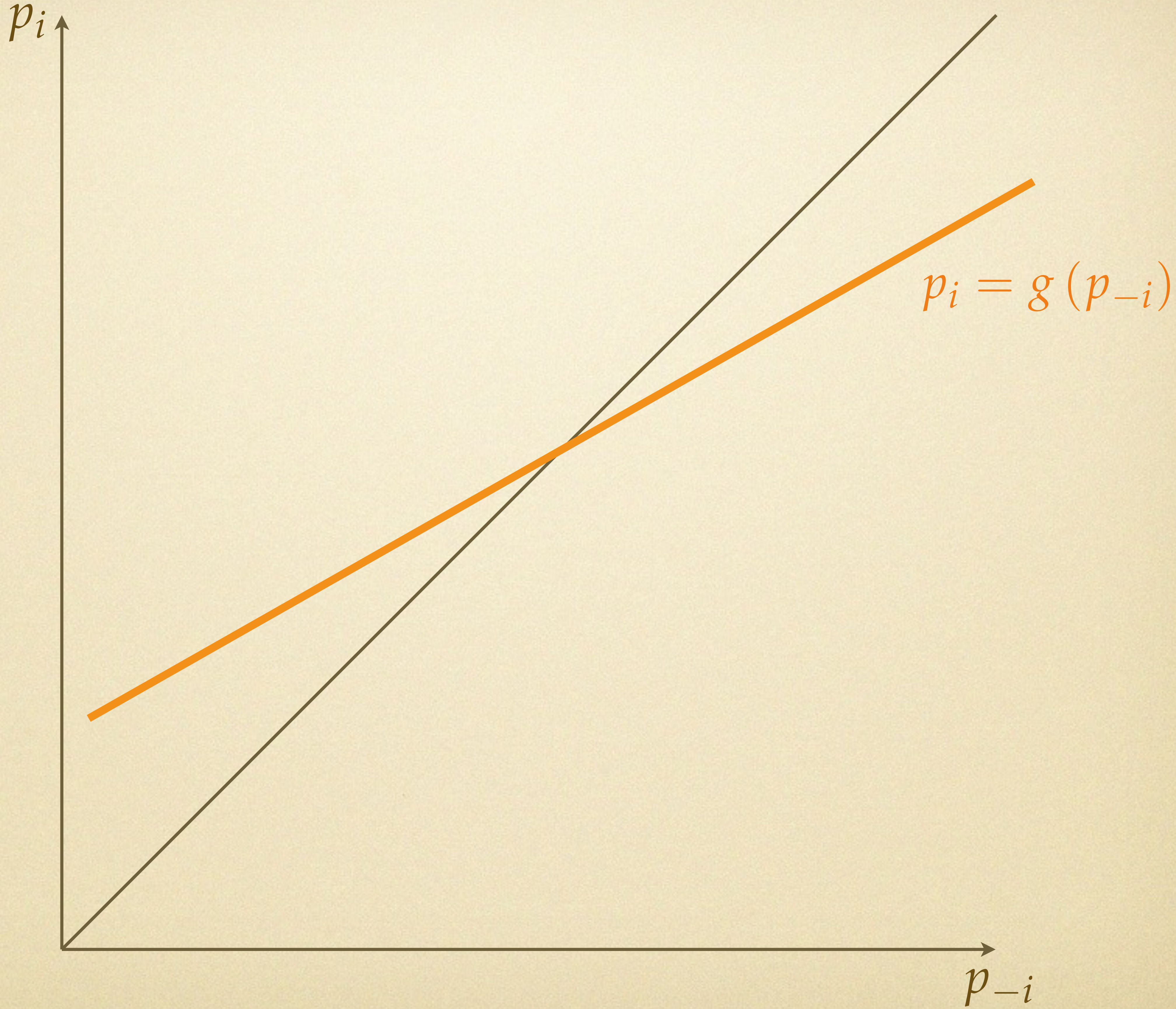
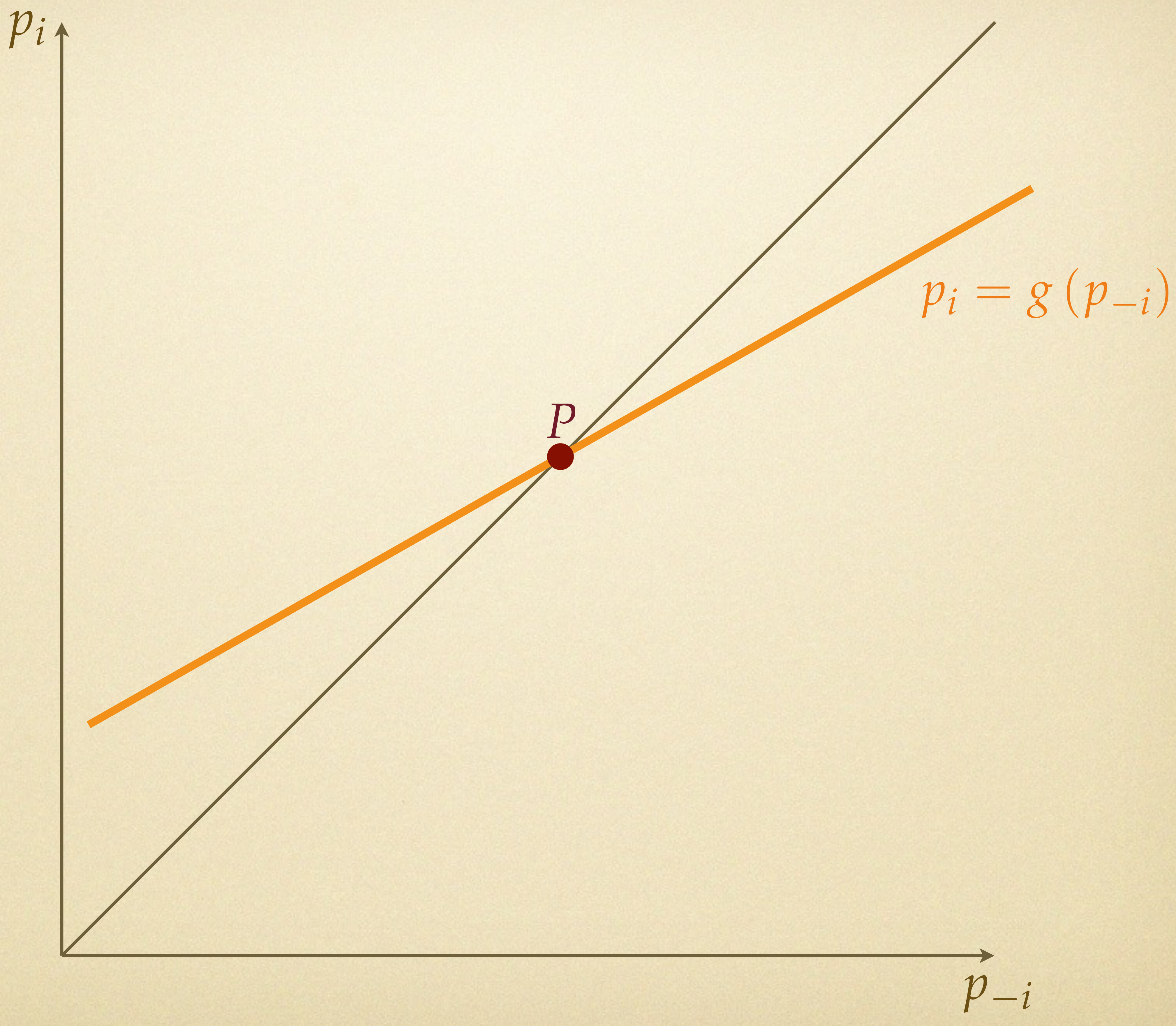
  - steady state price vector $P = g\left(P, P, \ldots, P\right)$



p_i
$p_i = g(p_{-i})$
p_{-i}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P
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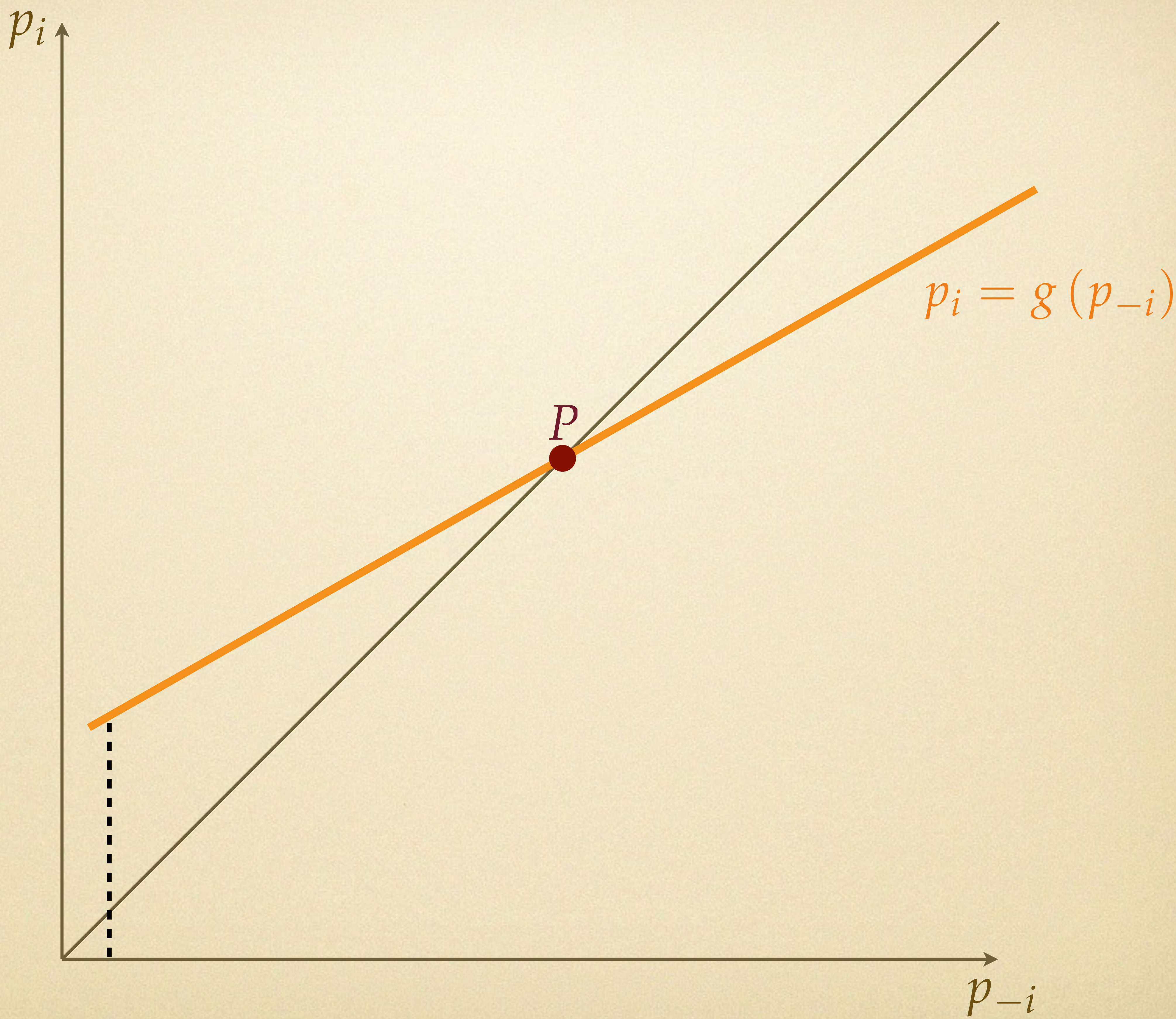

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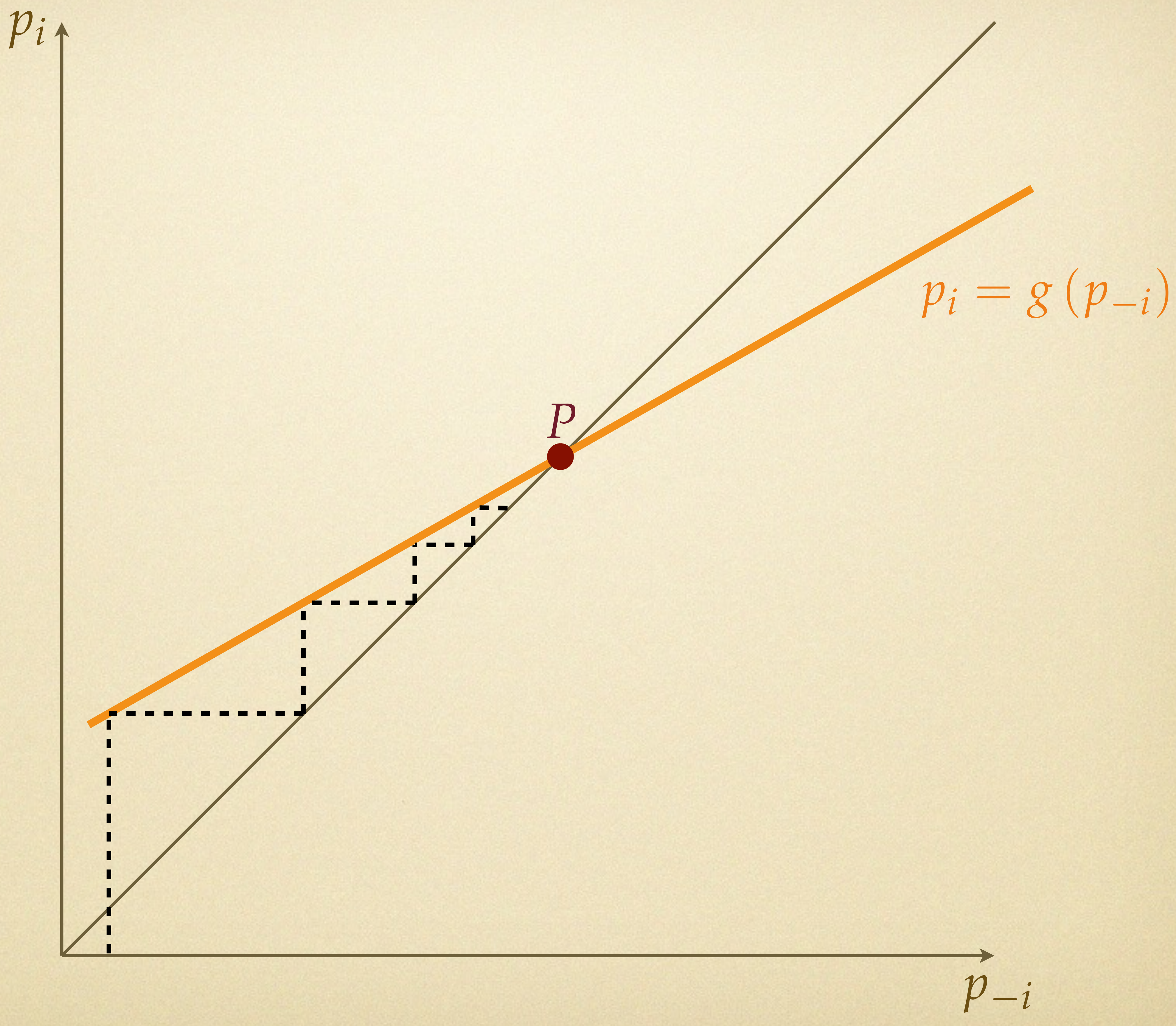

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1. Sufficient Statistics

Money Shock

- Starting at steady state…

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- …unanticipated permanent shock to money…

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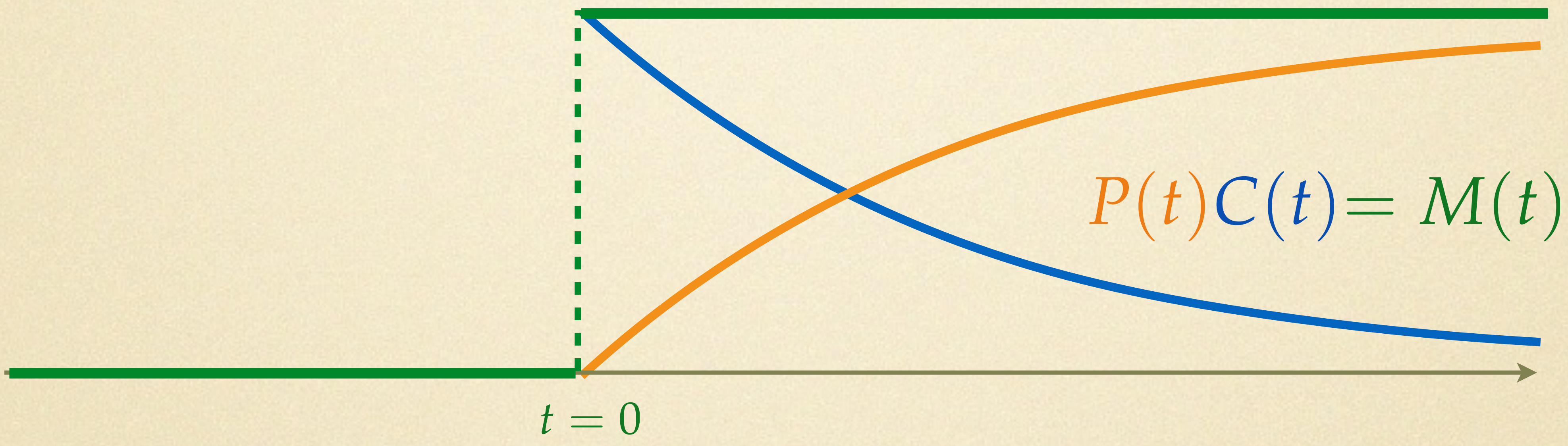

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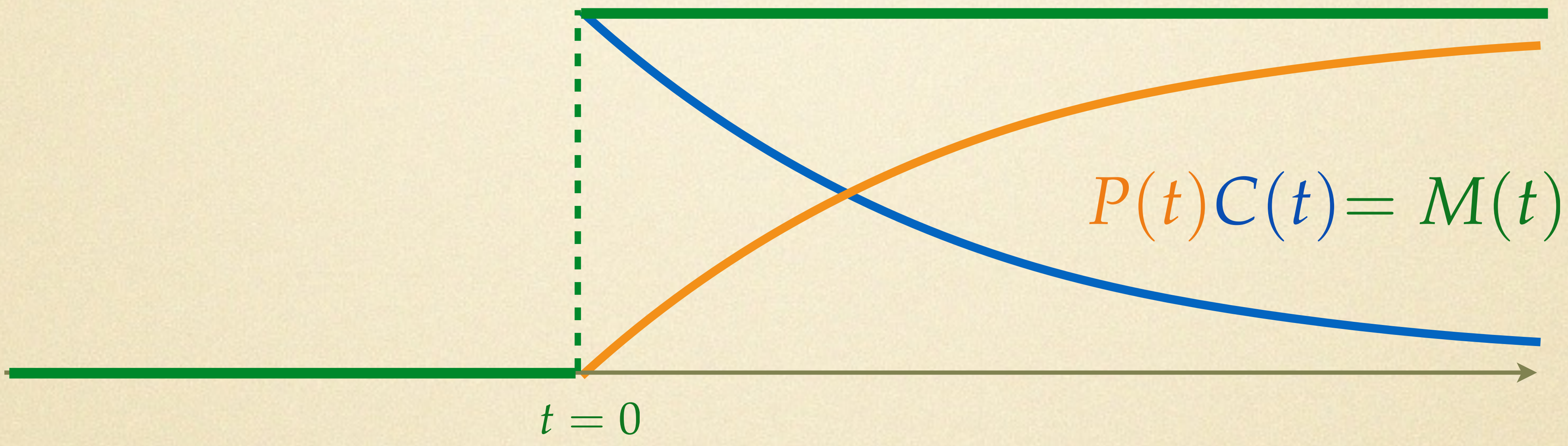

- Nominal interest rate unchanged…

Money Shock

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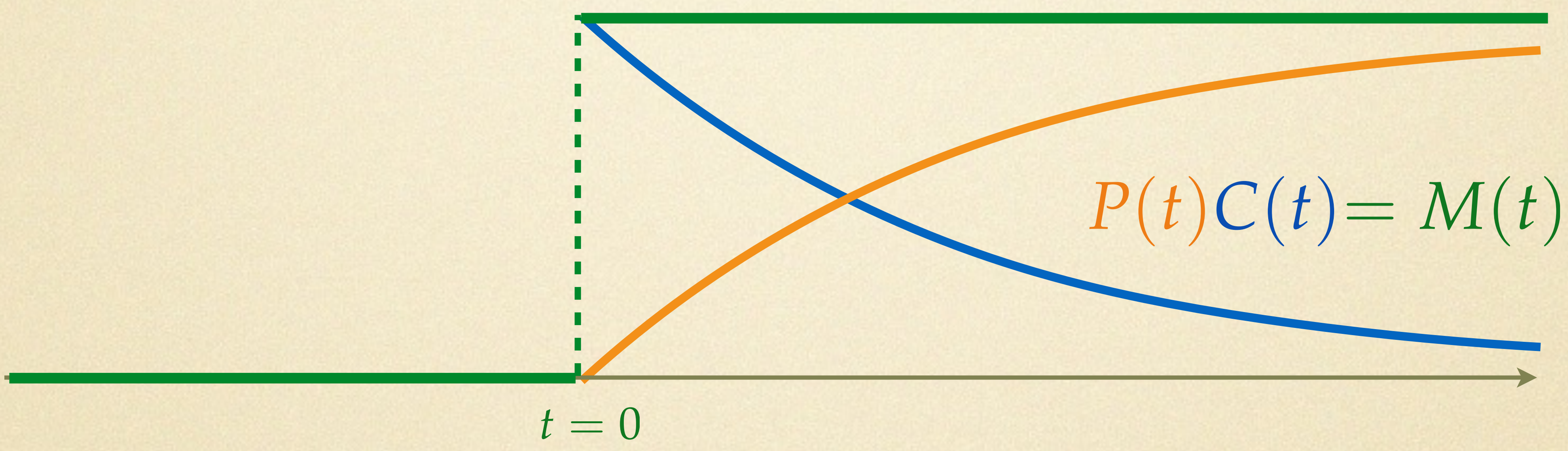

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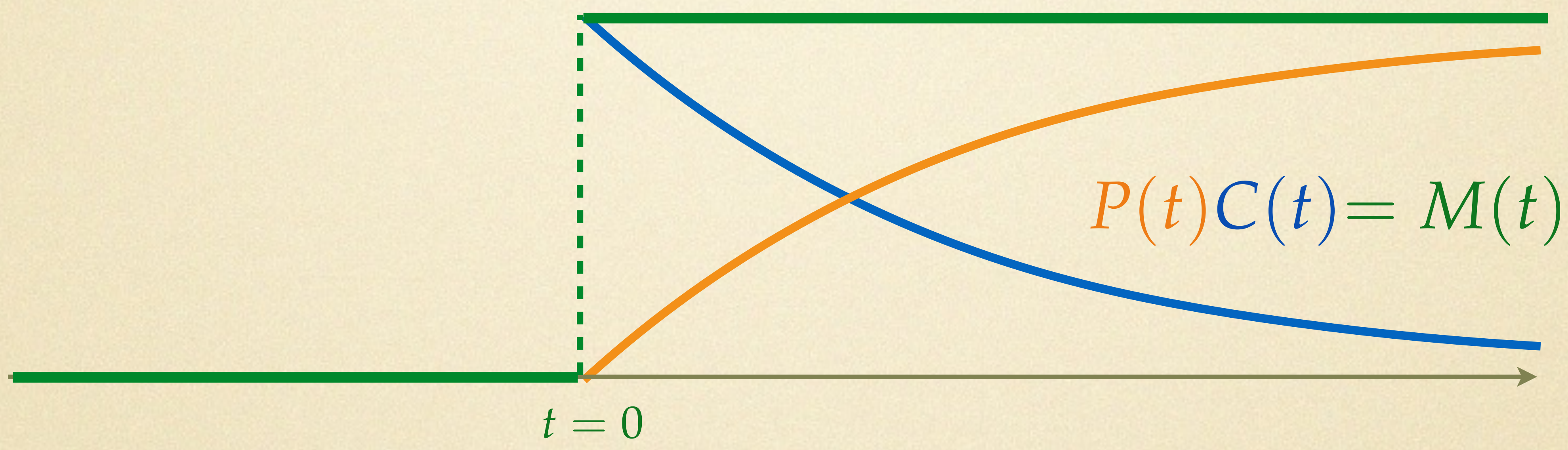

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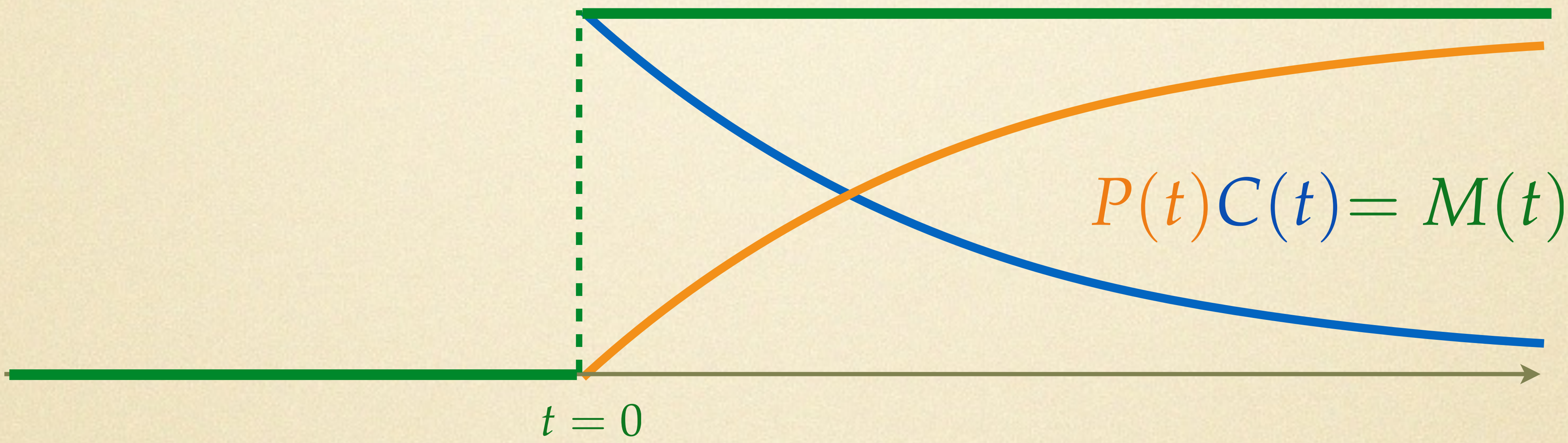

- Nominal interest rate unchanged…

$$r(t) = \rho$$

- Wage jumps to new level: $W = (1 + \delta)W\_$

Money Shock

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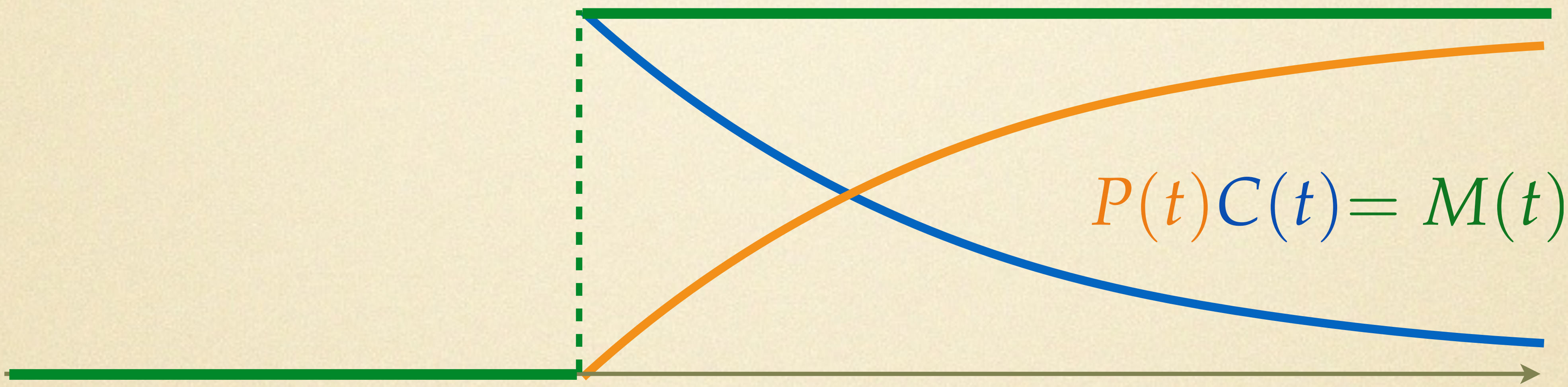
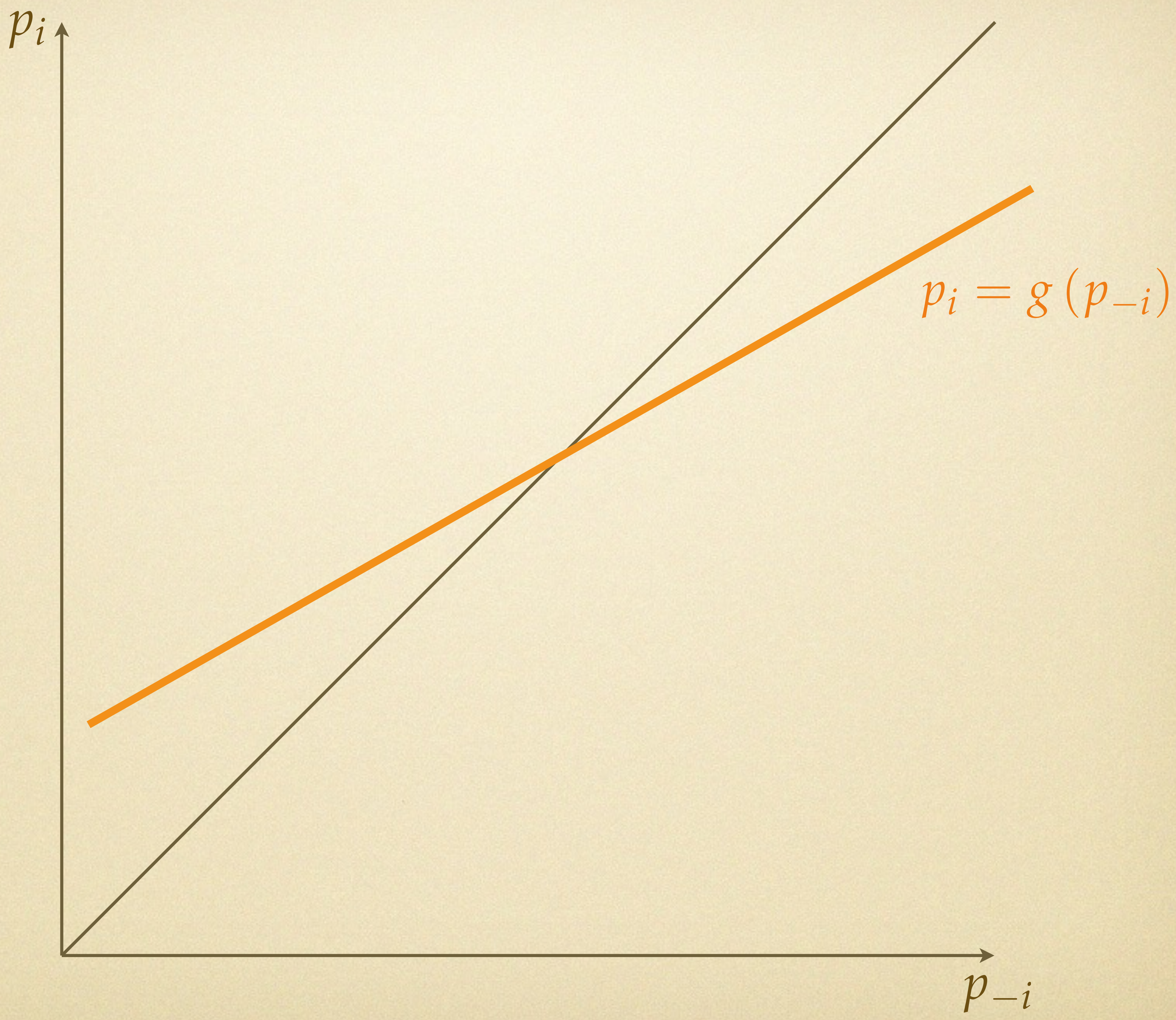


Result #1.

Equilibrium transition after shock δ satisfies steady-state policies…

$$\hat{p}_{i,s} = g\left(\hat{p}_{-i,s}\right)$$

with $\hat{p}_{i,s} = p_{i,s}/(1+\delta)$



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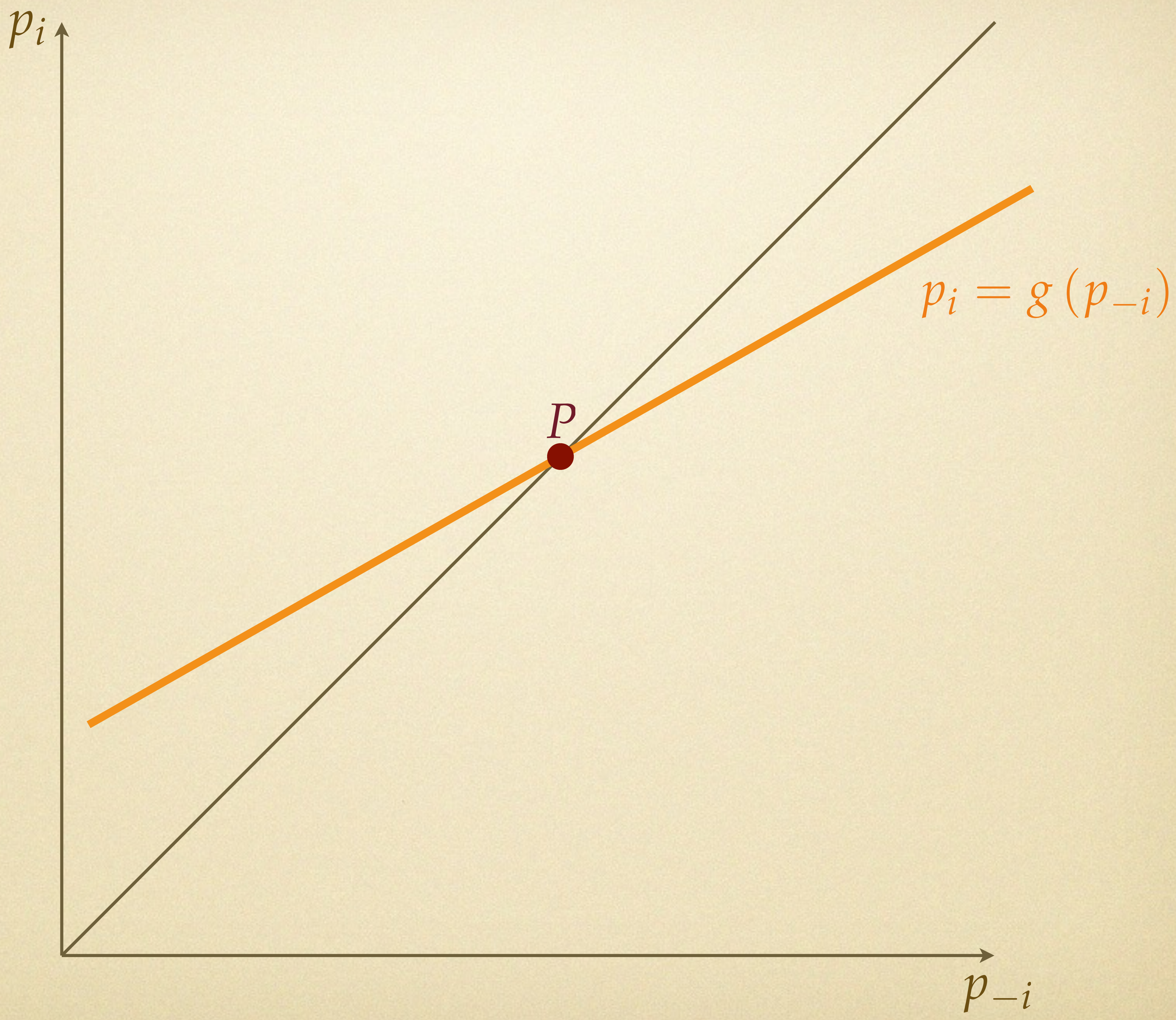
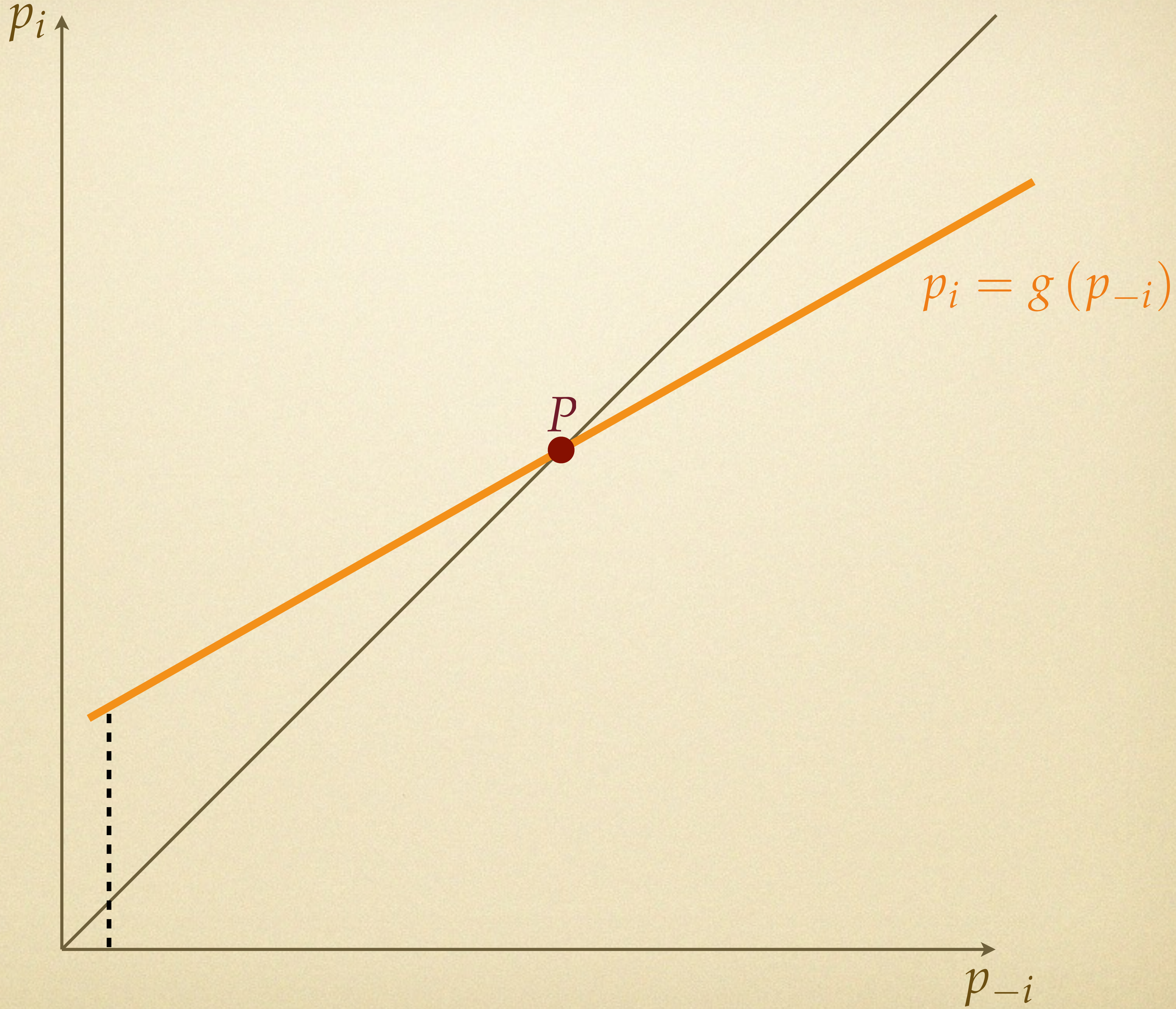
p_{-i}


p_i
$p_i = g(p_{-i})$
P
p_{-i}



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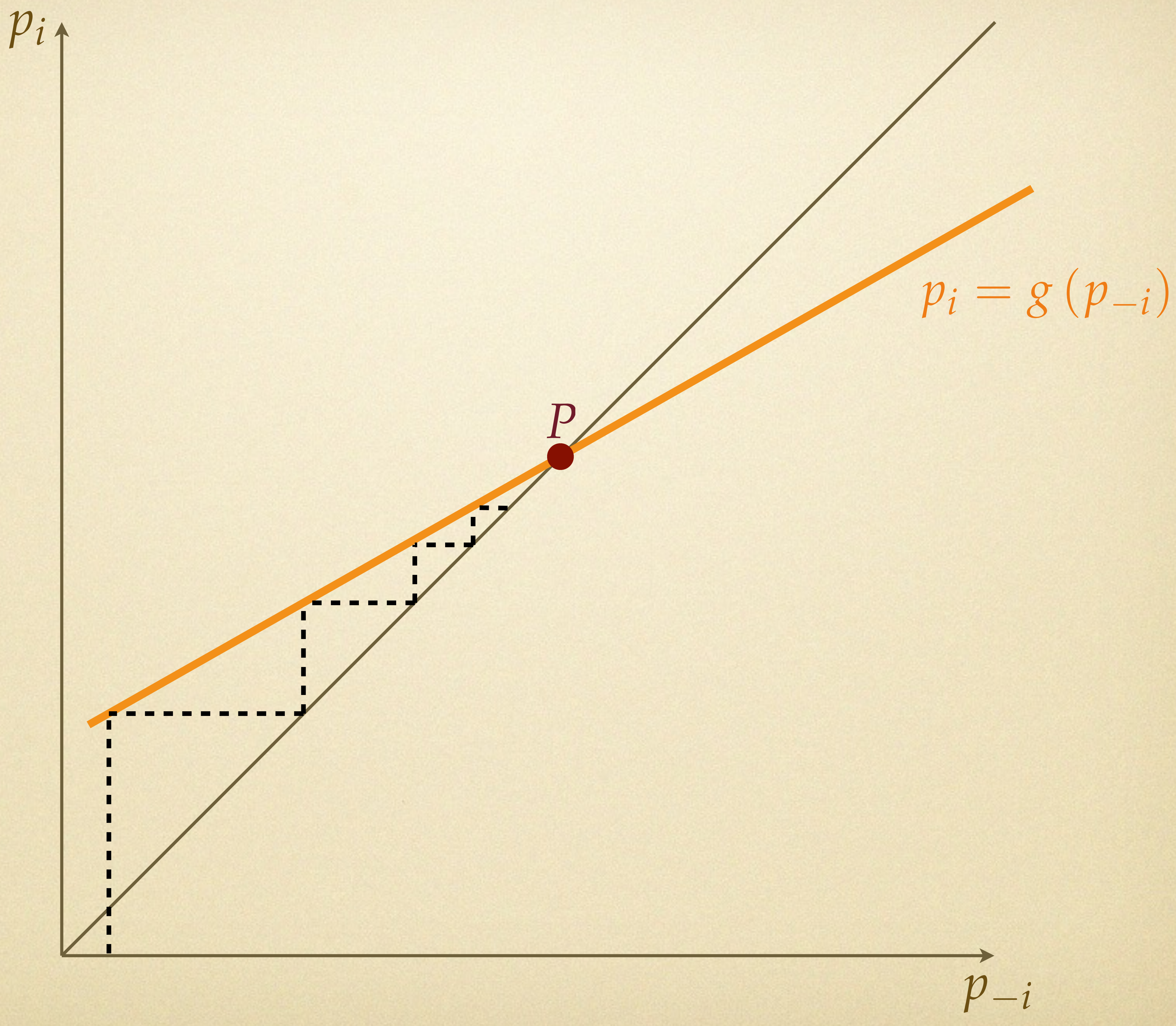

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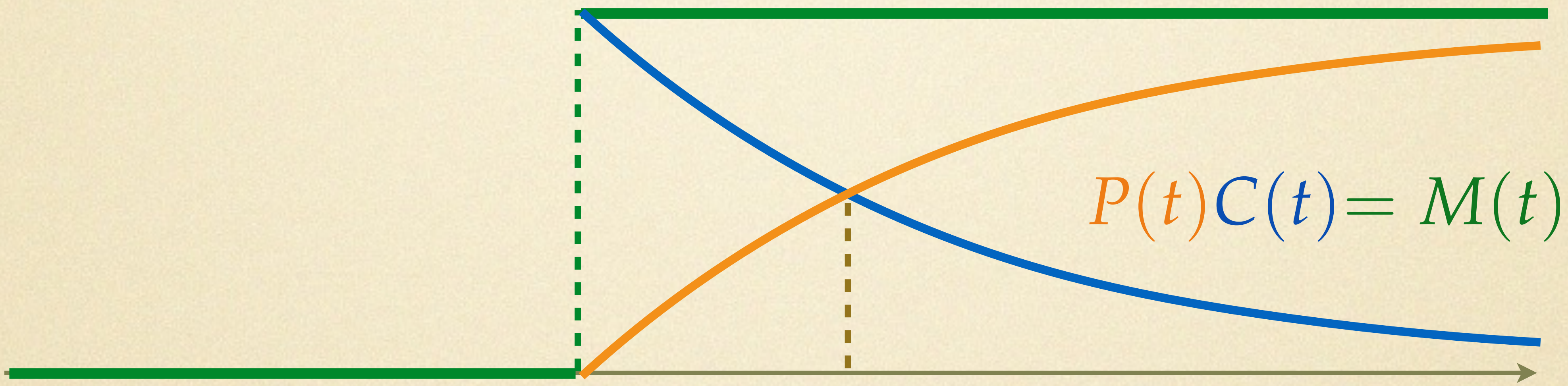
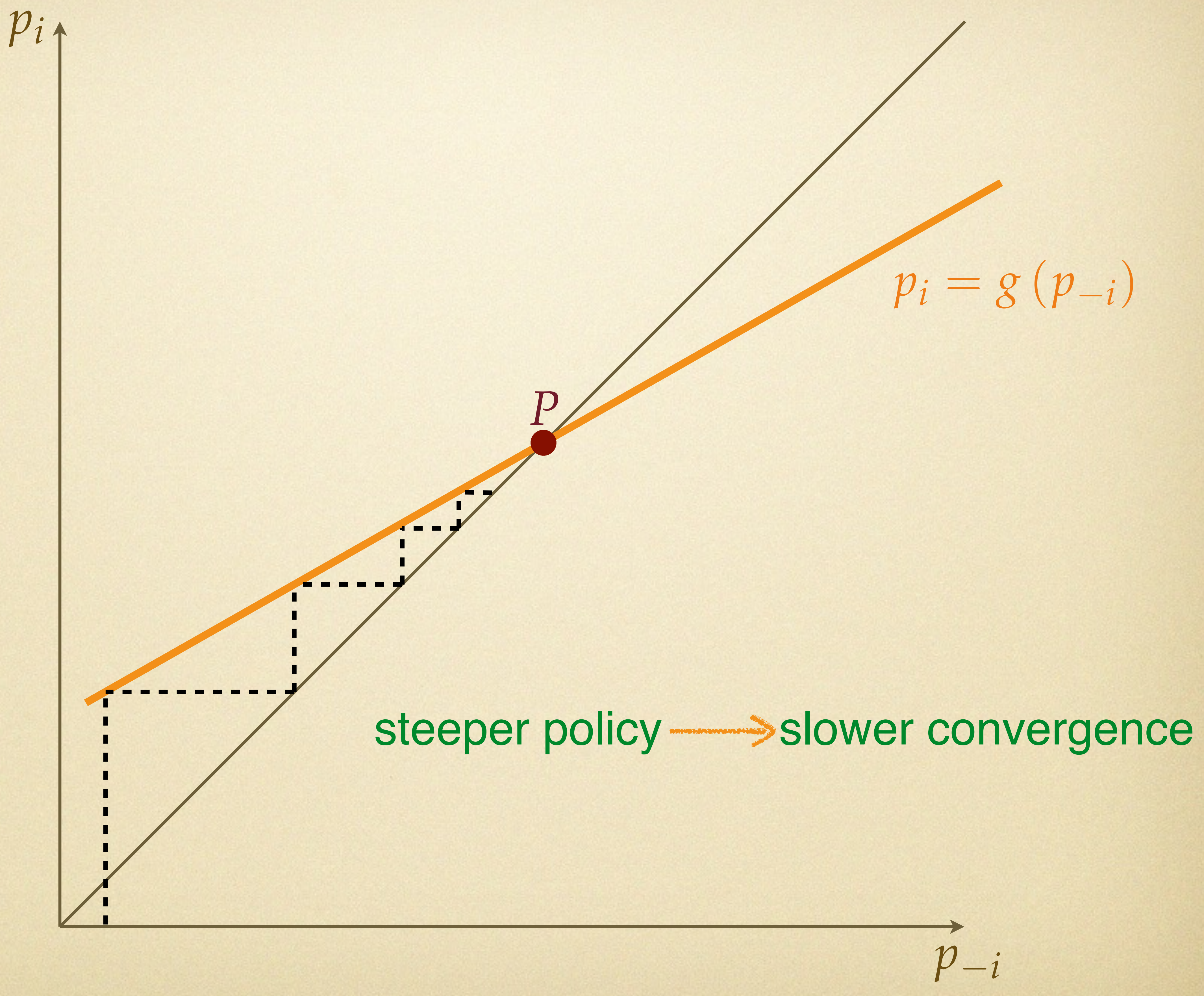


Result # 2.

$$\log P(t) - \log \bar{P} = -\delta \; e^{-\lambda(1-B)t}$$

$$B = (n-1)\,\frac{\partial g^i}{\partial p_j}(\bar{p})$$


p_i
$p_i = g(p_{-i})$
P
steeper policy → slower convergence
p_{-i}

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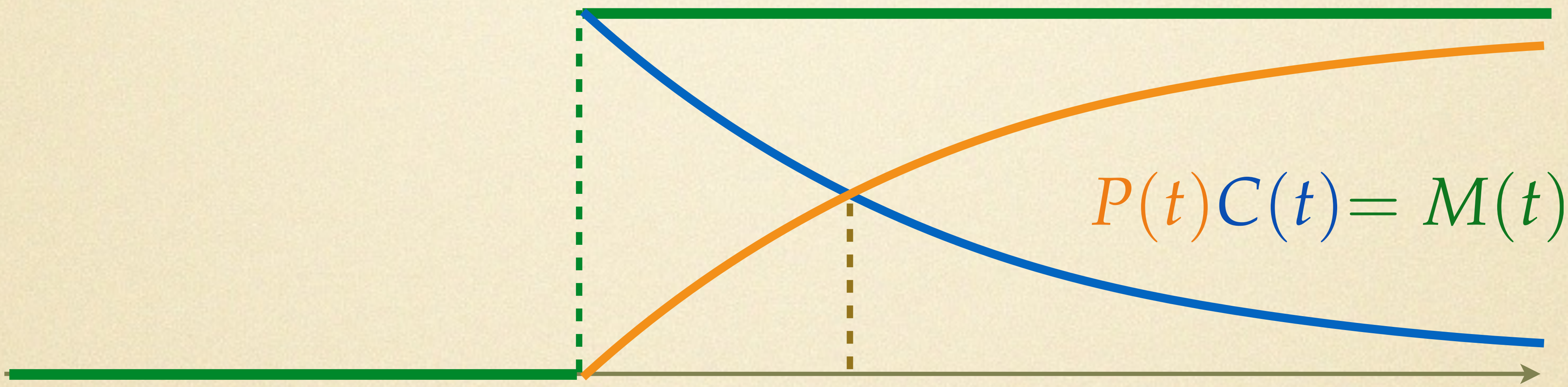

Result # 2.

$$\log P(t) - \log \bar{P} = -\delta \int_s \zeta_s e^{-\lambda_s (1-B_s) t} ds$$

$$B_s = (n-1) \frac{\partial g_s^i}{\partial p_j} (\bar{p}_s)$$

Adding Heterogeneity!

Metrics for Stickiness

- Cumulative Output

$$\int_0^\infty e^{-rt} \log\left(\frac{C(t)}{\bar{C}}\right) dt = \delta \int_s \frac{\zeta_s ds}{r + \lambda_s (1 - B_s)}$$

- Half Life: $\log(2) \cdot h$

$$h = \frac{1}{\lambda(1 - B)}$$

- Phillips Curve?

$$\dot{\pi}(t) = \rho\pi(t) - \kappa\, mc(t)$$

$$\pi(t) = \kappa \int e^{-\rho s} mc(t + s) ds$$

Metrics for Stickiness

Result #3

After M shock

→ $$\dot{\pi}(t) = \rho\pi(t) - \kappa\, mc(t)$$

- Phillips Curve?

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Metrics for Stickiness

Result #3

After M shock

$$\rightarrow \quad \dot{\pi}(t) = \rho\pi(t) - \kappa\, mc(t)$$

$$\kappa = \hat{\lambda}(\rho + \hat{\lambda}) \qquad \hat{\lambda} = \lambda(1 - B)$$

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Metrics for Stickiness

Result #3

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$$\kappa = \hat{\lambda}(\rho + \hat{\lambda}) \qquad \hat{\lambda} = \lambda(1 - B)$$

$$\kappa \approx \frac{1}{h^2}$$

- Phillips Curve?

$$\dot{\pi}(t) = \rho\pi(t) - \kappa\, mc(t)$$

$$\pi(t) = \kappa \int e^{-\rho s} mc(t+s)ds$$

Sufficient Statistic

Result #4

$$B = \frac{1 + \frac{\rho}{\lambda}}{1 + \frac{1}{(n-1)[(\epsilon-1)(\mu-1)-1]}}$$

$$\mu = \frac{P}{W}$$

$$\epsilon = \frac{-\partial \log D^i}{\partial \log p_i}$$

Sufficient Statistic

Result #4

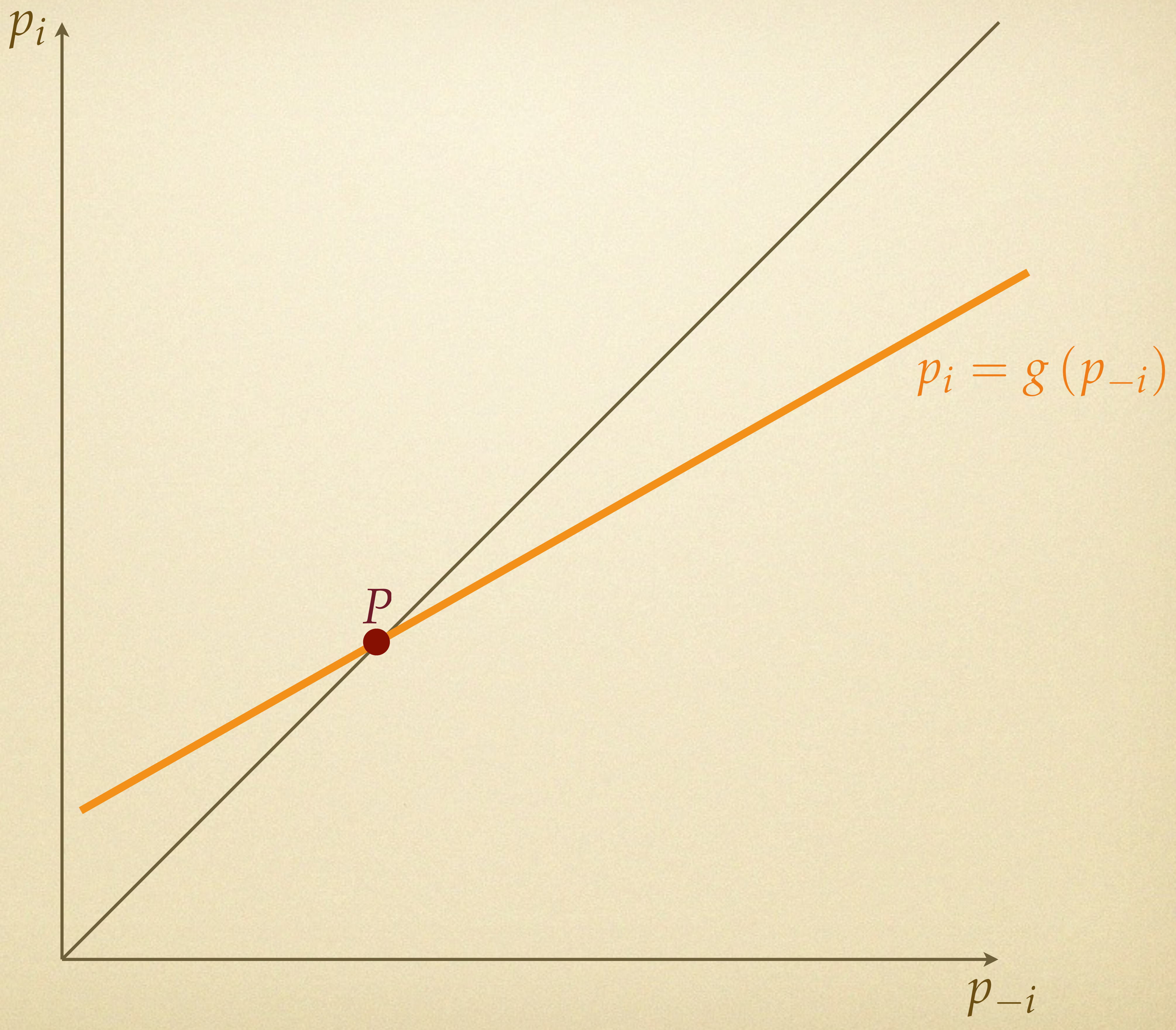
$$B = \frac{1+\frac{\rho}{\lambda}}{1+\frac{1}{(n-1)[(\epsilon-1)(\mu-1)-1]}}$$

$$\mu = \frac{P}{W}$$

$$\epsilon = \frac{-\partial \log D^i}{\partial \log p_i}$$

- Intuition… (reverse causality)
  - Nash markup $\Longleftrightarrow$ $B = 0$
  - higher markup $\Longleftrightarrow$ rivals mimic my price (high B)

$$\frac{\mu - 1}{\mu^{\text{Nash}} - 1} = 1 + \frac{1}{n-1} \cdot \frac{B}{1-B}$$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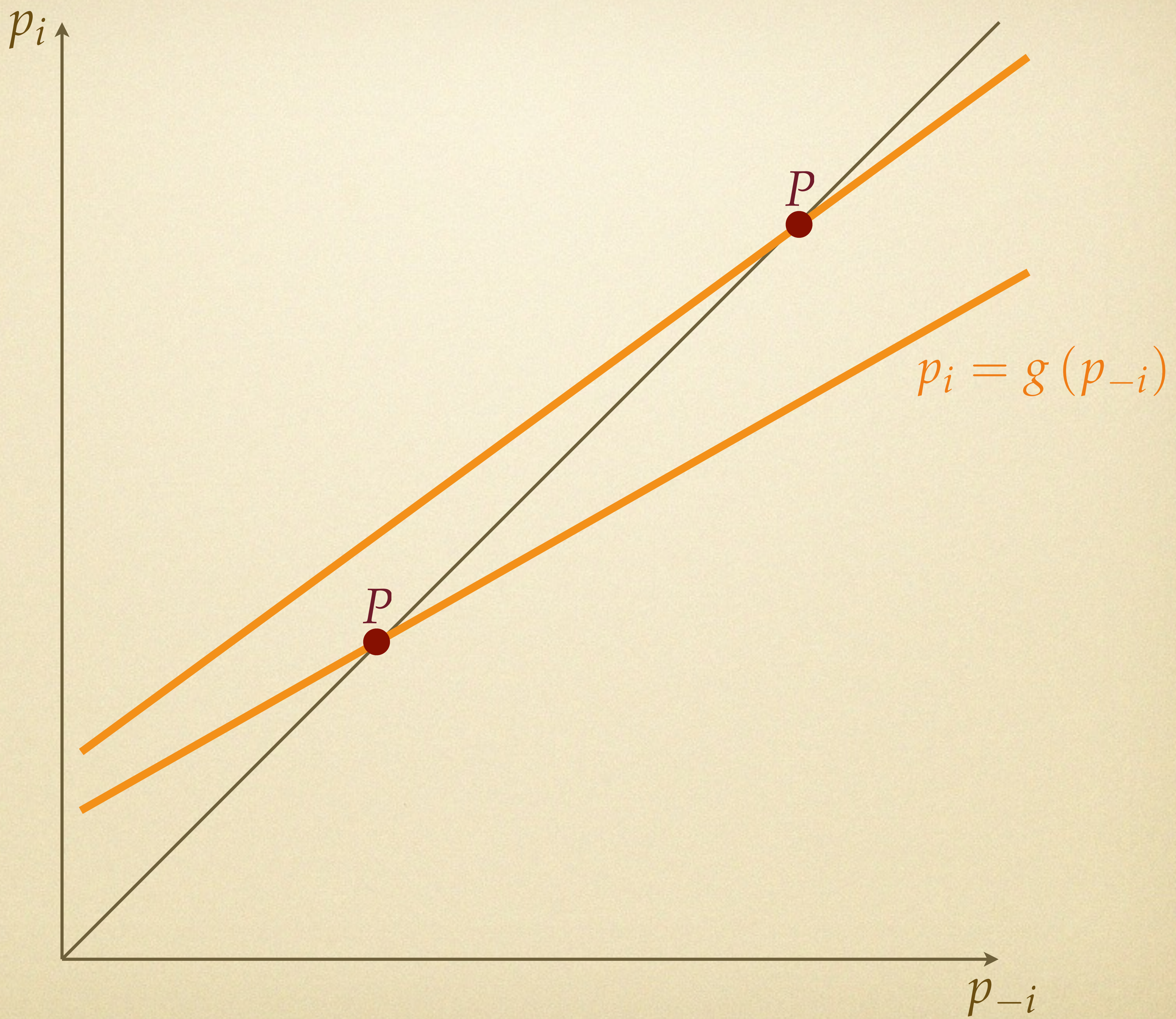
P
p_{-i}

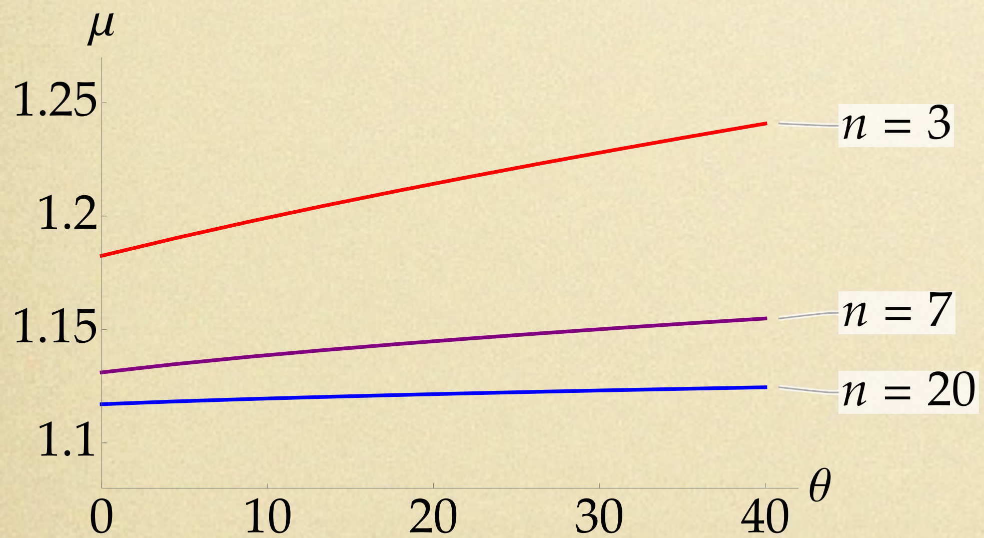


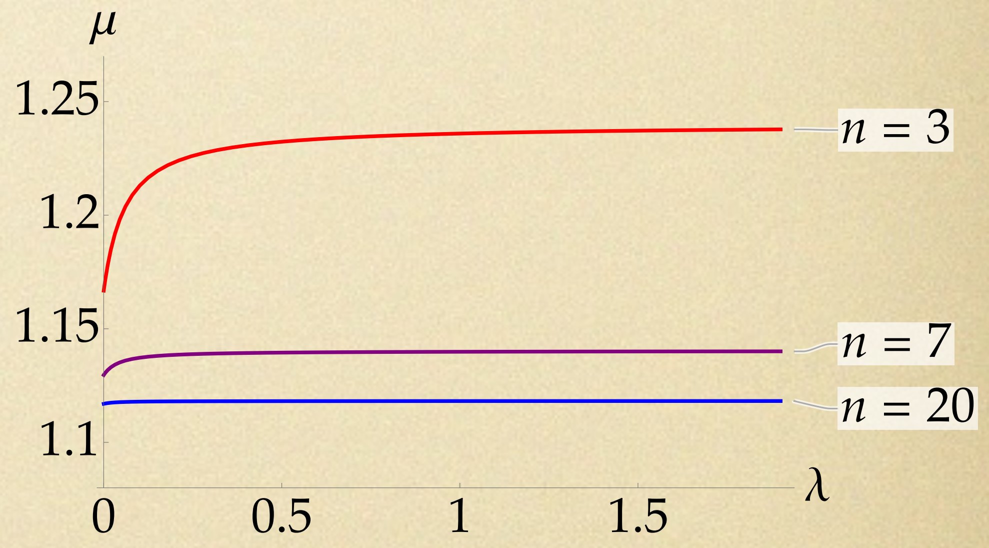
p_i
P
$p_i = g\left(p_{-i}\right)$
P
p_{-i}

Markups

- Monopolistic competition + Static oligopoly: markup only depends on local elasticity

- Dynamic oligopoly: conditional on elasticity, markup depends on $n, \theta, \lambda\ldots$





2. Counterfactuals

Solving MPE

Solving MPE

- Previous: stickiness from observed steady-state markup

Solving MPE

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- Now: Comparative statics…
  - counterfactuals: do not know steady state
  - must solve MPE
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  - solve exact approximate model i.e. demand system
  - benefit: tractable and flexible
  - check approximation with other methods

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- Our Method…
  - solve exact approximate model i.e. demand system
  - benefit: tractable and flexible
  - check approximation with other methods
- IO literature: other approximations (“oblivious” equilibria)

Kimball Demand

$$d^{i,s}(p_{i,s}(t)) \longleftrightarrow \frac{1}{n}\sum \Psi(\frac{c_i}{C}) = 1$$

$$\epsilon = -\frac{\partial \log d^i}{\partial \log p_i} \quad \Sigma = \frac{\partial \log \epsilon}{\partial \log p_i} \qquad \eta = -\frac{\Psi'(x)}{x\Psi''(x)} \quad \theta = -\frac{\partial \eta}{\partial x}$$

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$$\epsilon = \left(1 - \frac{1}{n}\right)\eta + \frac{1}{n}\omega$$

$$\Sigma = \frac{n-1}{n} \cdot \frac{(n-2)\theta\eta + \eta^2 - (1+\omega)\,\eta + \omega}{(n-1)\,\eta + \omega}$$

Kimball Demand

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$$\epsilon = \eta$$

$$\Sigma = \theta$$

$$n \to \infty$$

Method

- 2 equations in 2 unknowns…
  - Sufficient statistic formula…

$$B = B(\mu, \epsilon, n, \lambda/\rho)$$

  - One extra equation…

$$\mu = \mu(B, \epsilon, \Sigma, n, \lambda/\rho)$$

- Verified: good approximation!
- More general: k-order derivatives of demand (see paper)

Changing n

Changing n

Changing n

- What to hold fixed?

1. Preferences (η, θ)

3. Calibrate: evidence on pass-through

5. Local elasticities of demand (ϵ, Σ)

Changing n

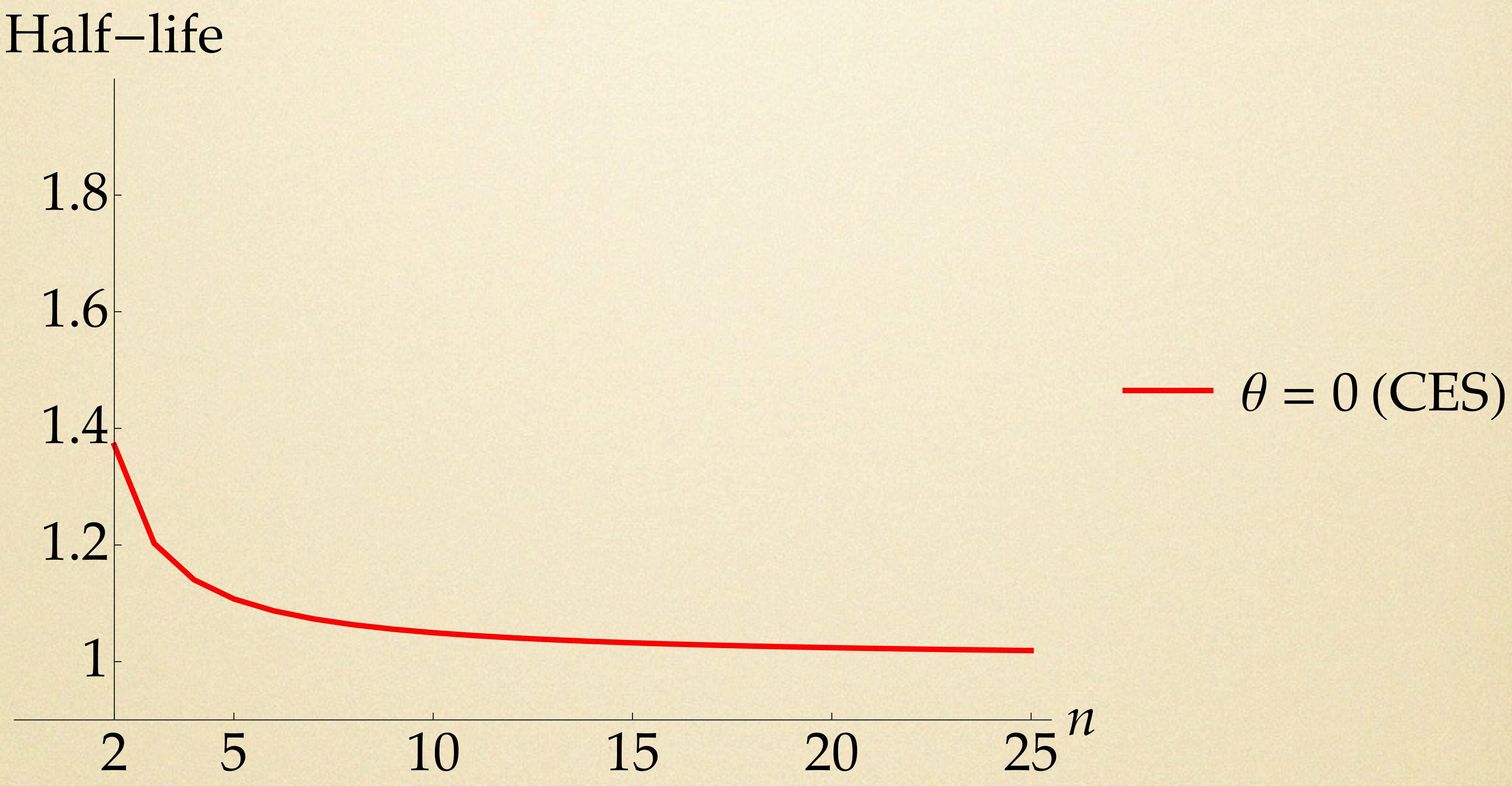
- What to hold fixed?

1. Preferences (η, θ) ← **Start here**

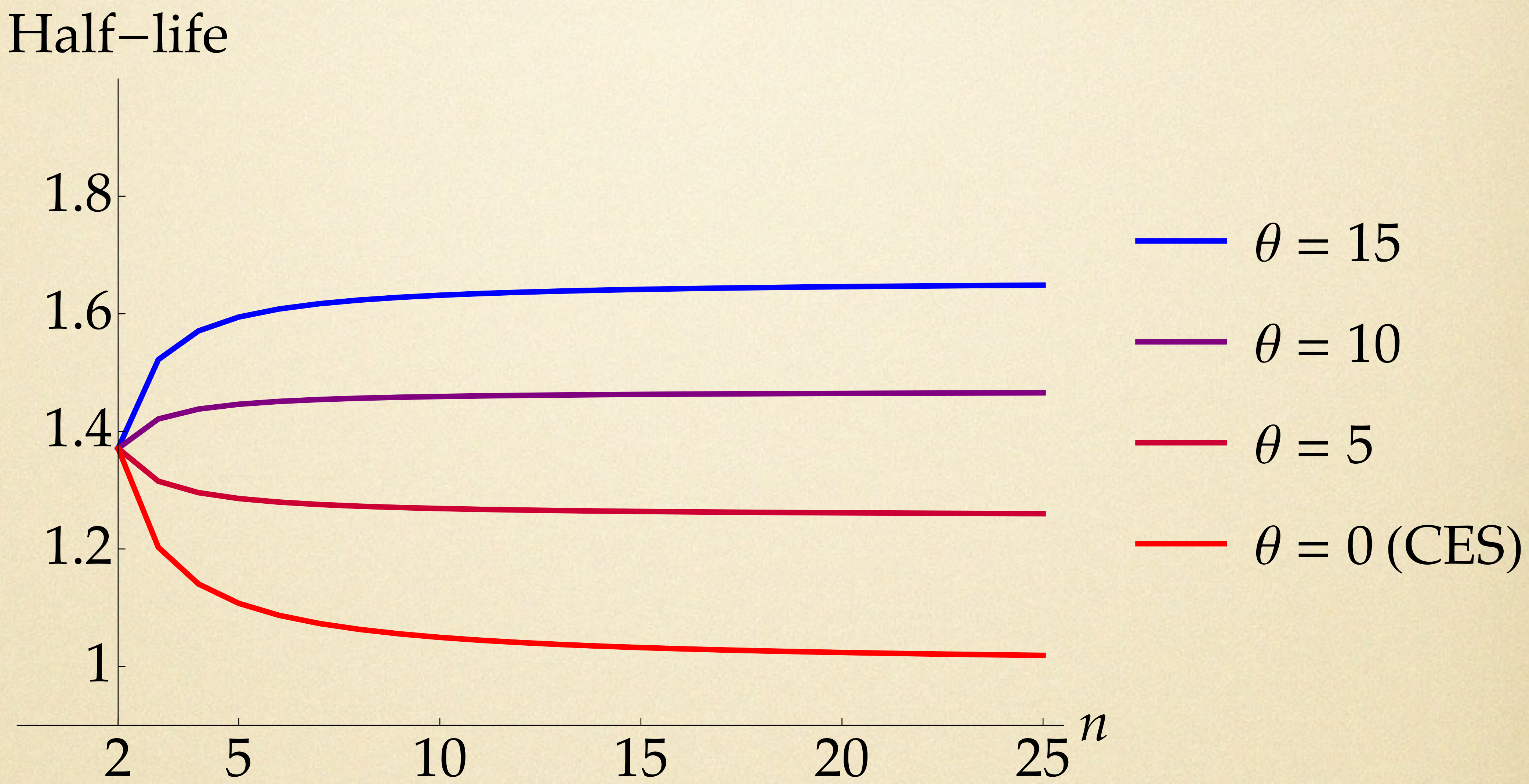
3. Calibrate: evidence on pass-through

5. Local elasticities of demand (ϵ, Σ)

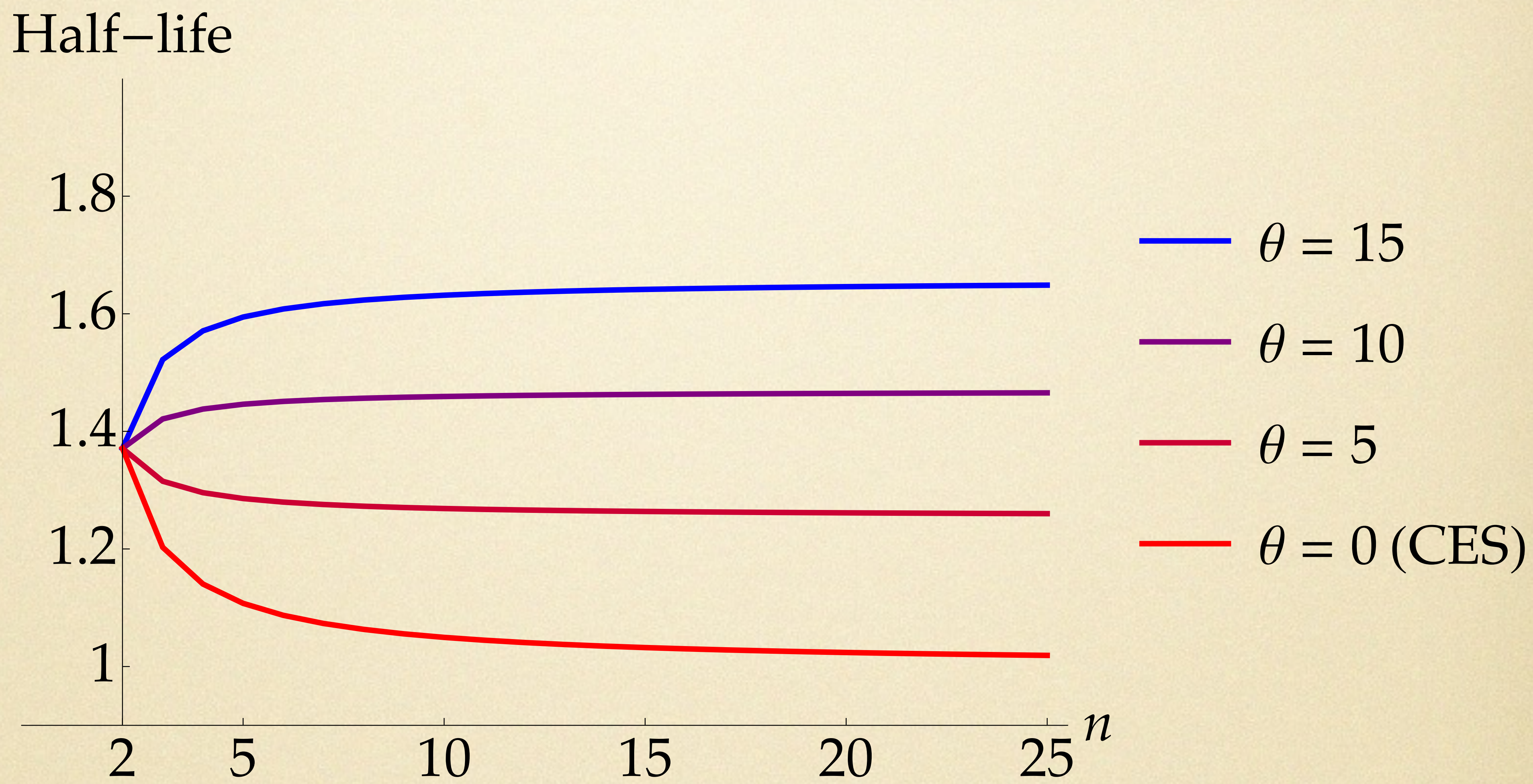
Half-Life



Kimball Demand



Kimball Demand



- Low θ: greatest stickiness at n=2
- High θ: lowest stickiness at n=2!
- Duopoly is knife-edge: half-life stuck at CES level…
  … Kimball can't help n=2!

Changing n

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Changing n

- What to hold fixed?

1. Preferences (η, θ)

3. Calibrate: evidence on pass-through ⟵ **Next up**

5. Local elasticities of demand (ϵ, Σ)

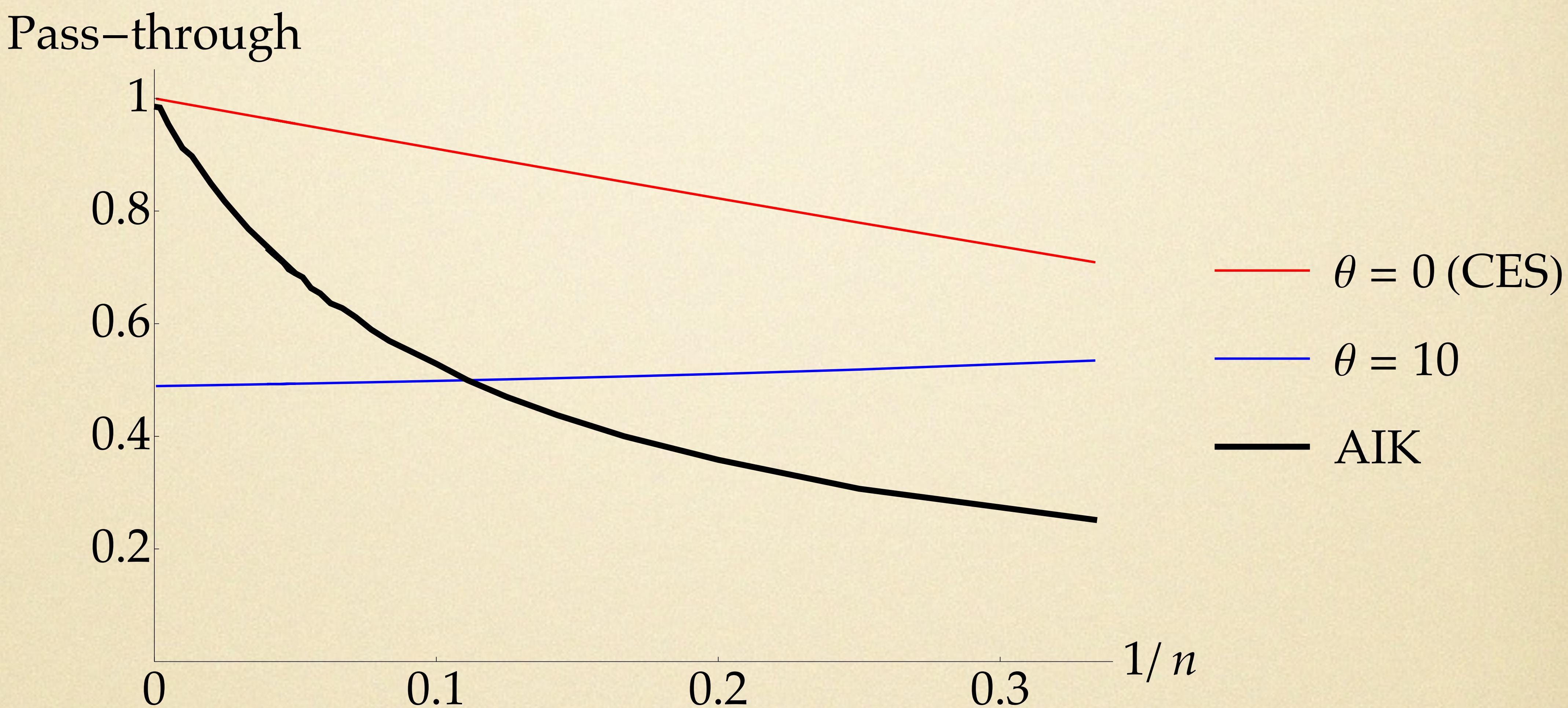
Pass-Through

- Amiti-Itskhoki-Konings
- Evidence own-cost pass-through…
  - high for small firms
  - low for large firms

- Here: Fix elasticity, set super-elasticity to match…

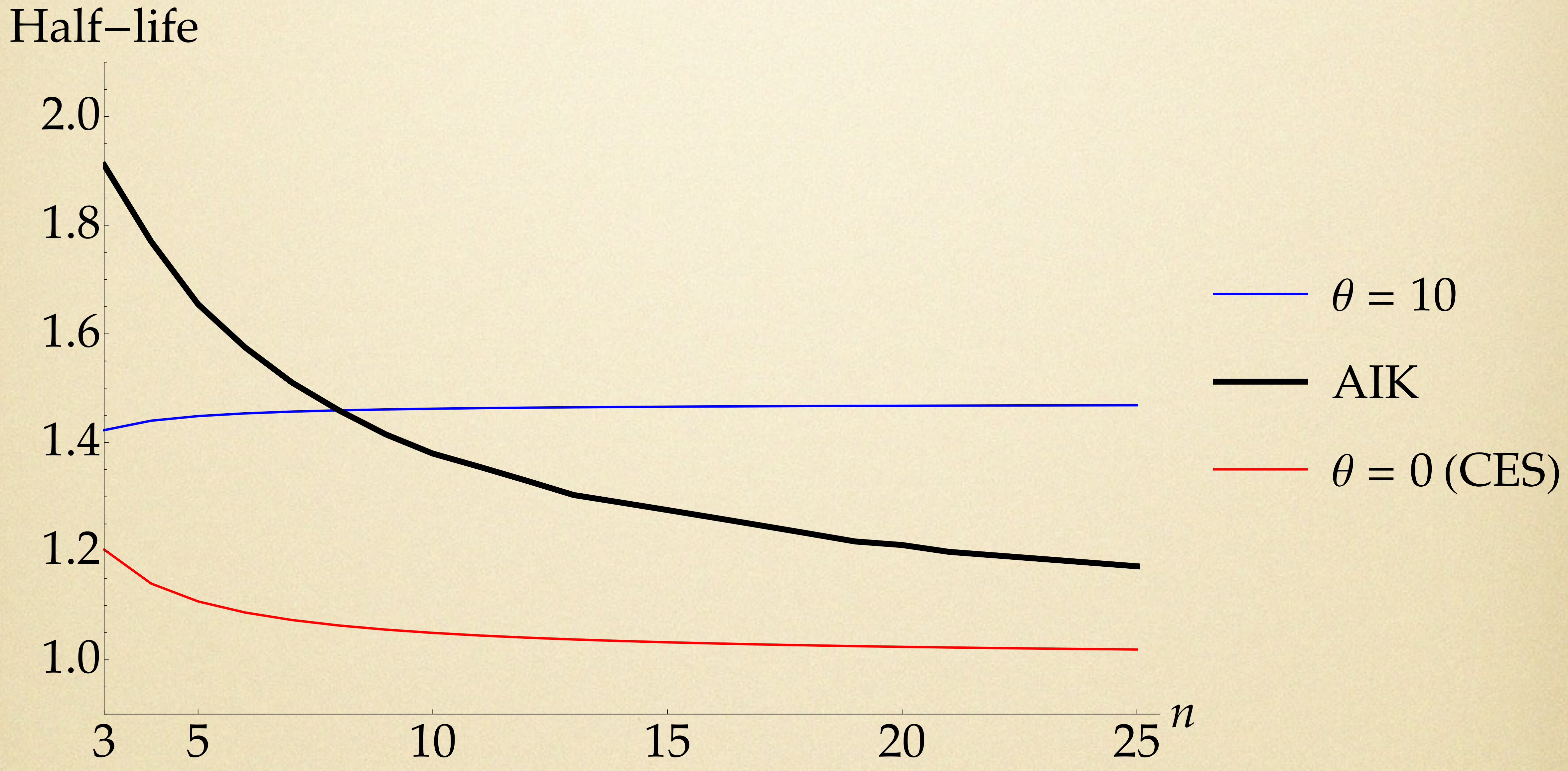
pass-through = f(market share)

Pass-Through



pass-through = f(market share)

Half-life



- National HHI 0.05 to 0.1 (e.g., Gutierrez-Philippon): MP 15% stronger

Passthrough

$$\Delta \log p_{it} = \hat{\alpha}\Delta \log mc_{it} + \hat{B}\,\frac{\sum_{j\neq i}\Delta \log p_{jt}}{n-1} + u_{it}$$

$$\hat{\alpha} \approx \frac{1}{1+s(\eta-1)}$$

Amiti et al Regression

Passthrough

$$\Delta \log p_{it} = \hat{\alpha} \Delta \log mc_{it} + \hat{B} \frac{\sum_{j \neq i} \Delta \log p_{jt}}{n-1} + u_{it}$$

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$$\tilde{p}_i = \alpha \widetilde{mc}_i + B \frac{\sum_{j \neq i} \tilde{p}_j}{n-1} + \gamma \sum_{j \neq i} \widetilde{mc}_j$$

Our Model Extension

Passthrough

$$\Delta \log p_{it} = \hat{\alpha} \Delta \log mc_{it} + \hat{B} \frac{\sum_{j \neq i} \Delta \log p_{jt}}{n-1} + u_{it}$$

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$$\tilde{p}_i = \alpha \widetilde{mc}_i + B \frac{\sum_{j \neq i} \tilde{p}_j}{n-1} + \gamma \sum_{j \neq i} \widetilde{mc}_j$$

Our Model Extension

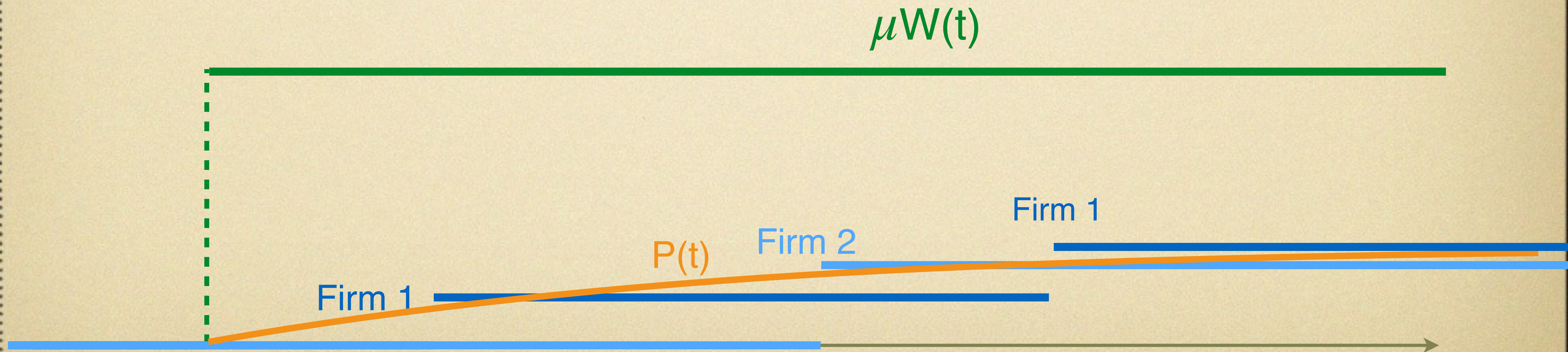
Result.

$$\hat{\alpha} = \frac{n\alpha + B - 1}{\alpha + B + n - 2}$$

Mapping Model $\rightarrow$ Regression

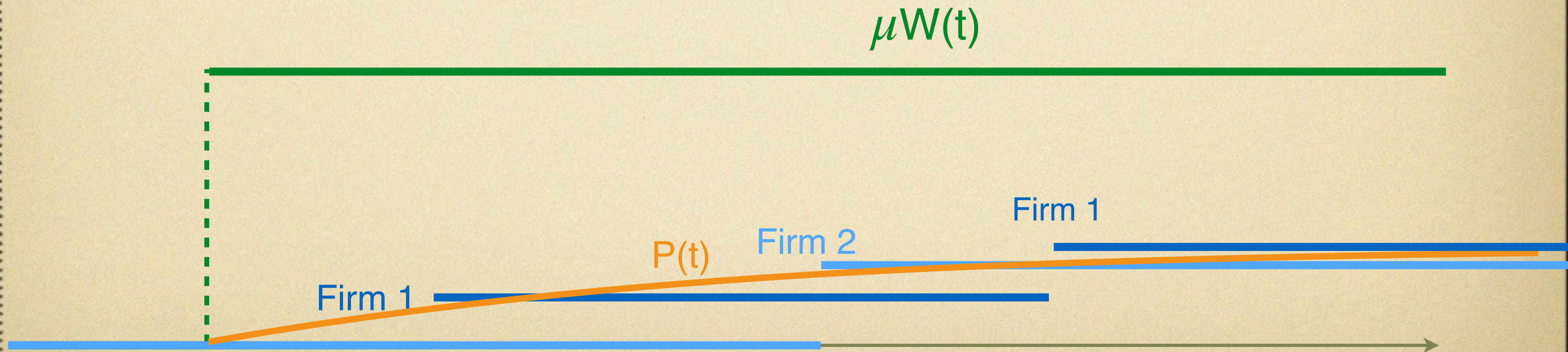
3. Inspecting Mechanism

Inspecting Mechanism



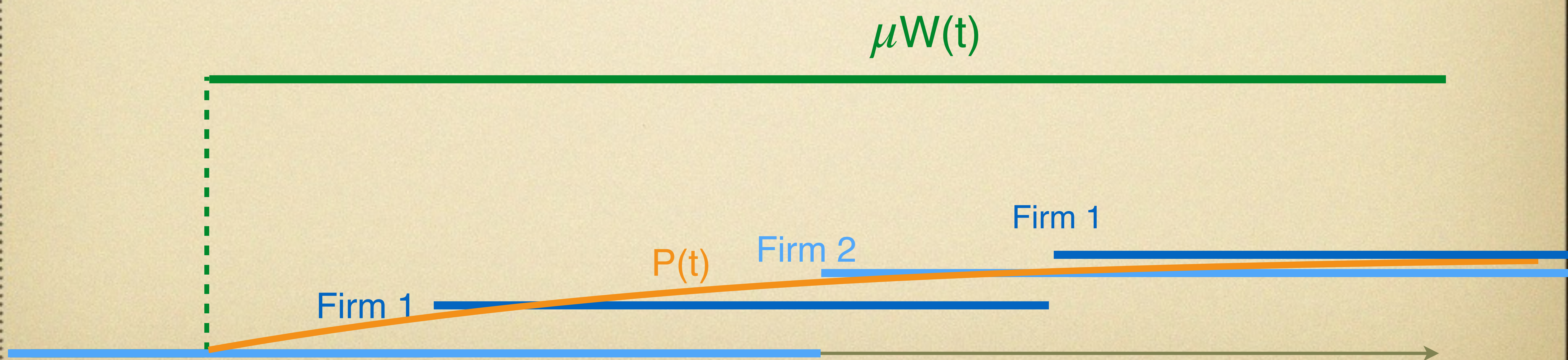
Inspecting Mechanism

- Two effects with finite *n*…
  - feedback: firm i cares about others' prices
  - strategic: firm i can affect others' prices



Inspecting Mechanism

- Two effects with finite n…
  - feedback: firm i cares about others' prices
  - strategic: firm i can affect others' prices
- Feedback effect with $n = \infty$
  - inputs from other firms
  - Kimball (1995) demand

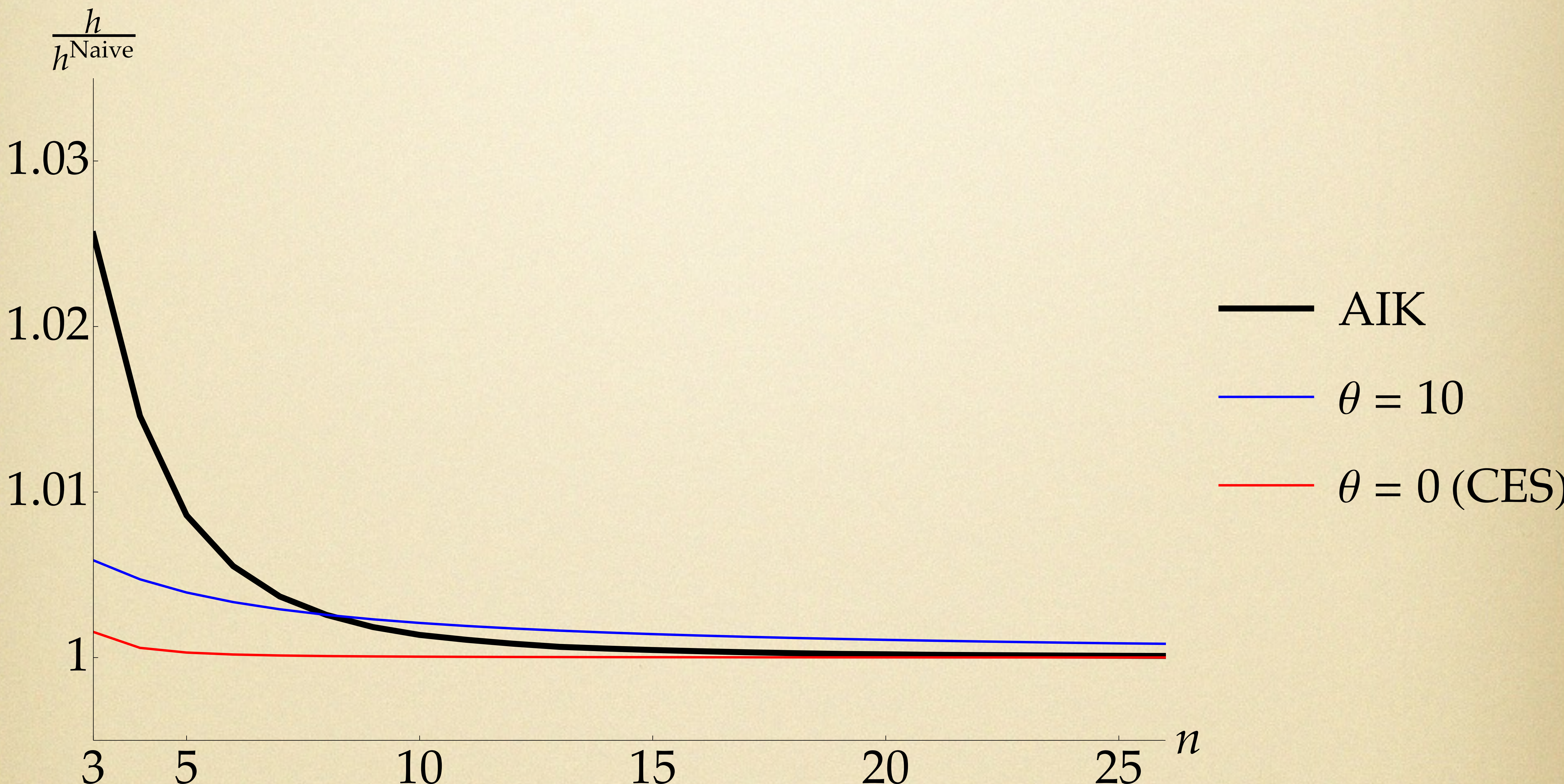


Inspecting Mechanism

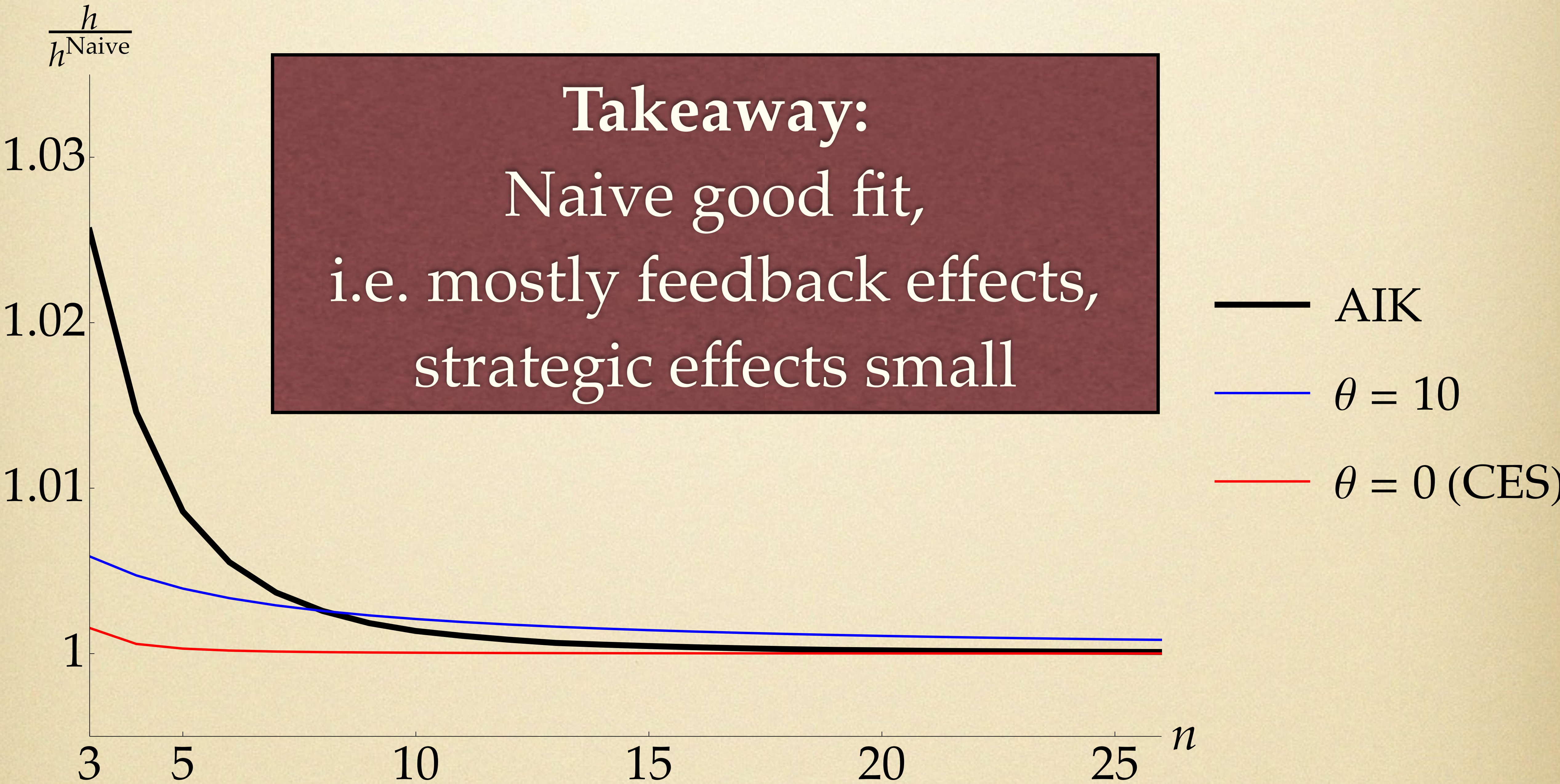
- Compare...
  - Markov with n firms
  - Naive equilibrium with n firms

    Equivalent to $n = \infty$ with modified Kimball preferences to match elasticity and superelasticity

Small strategic effects

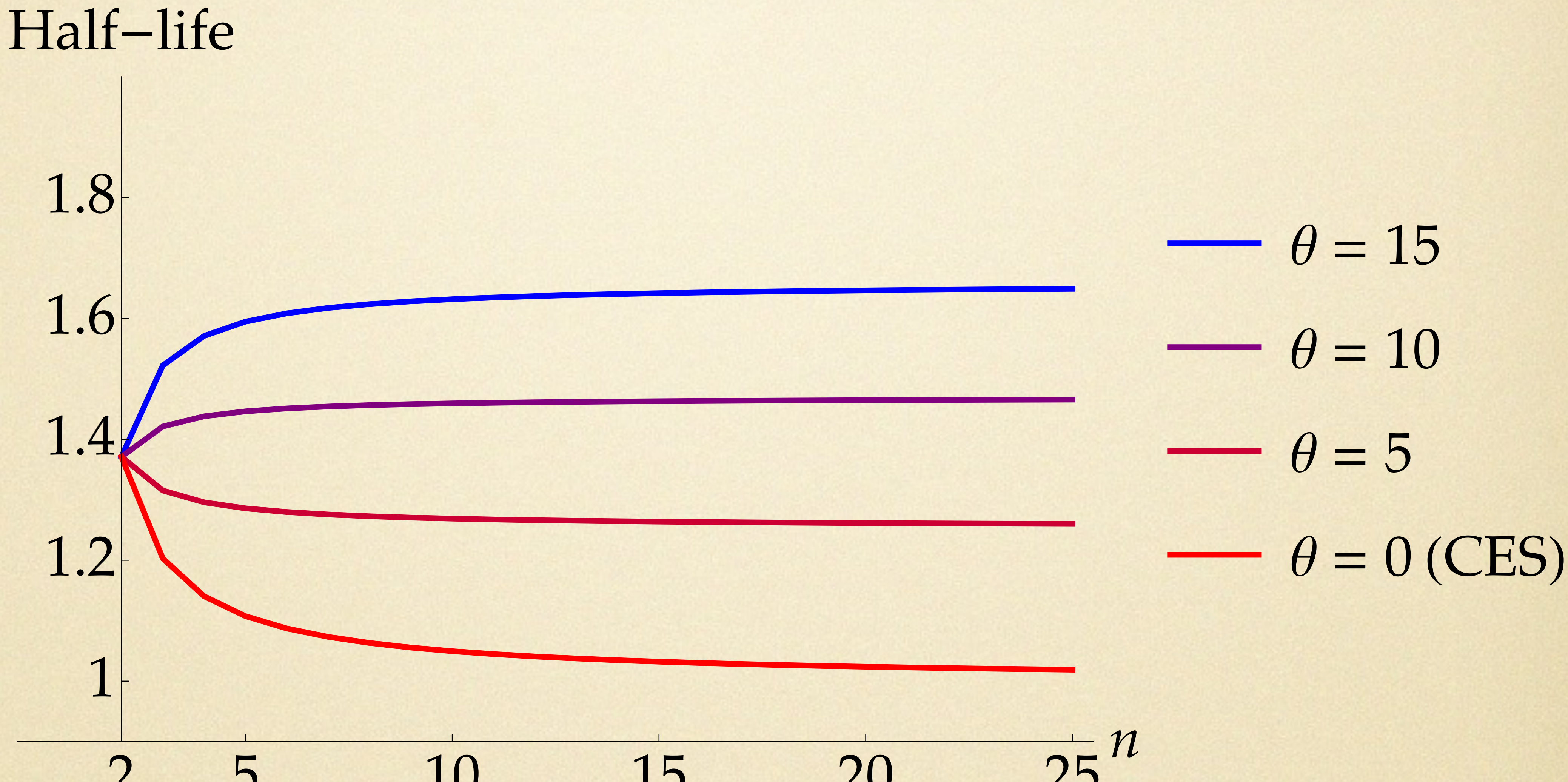


Small strategic effects



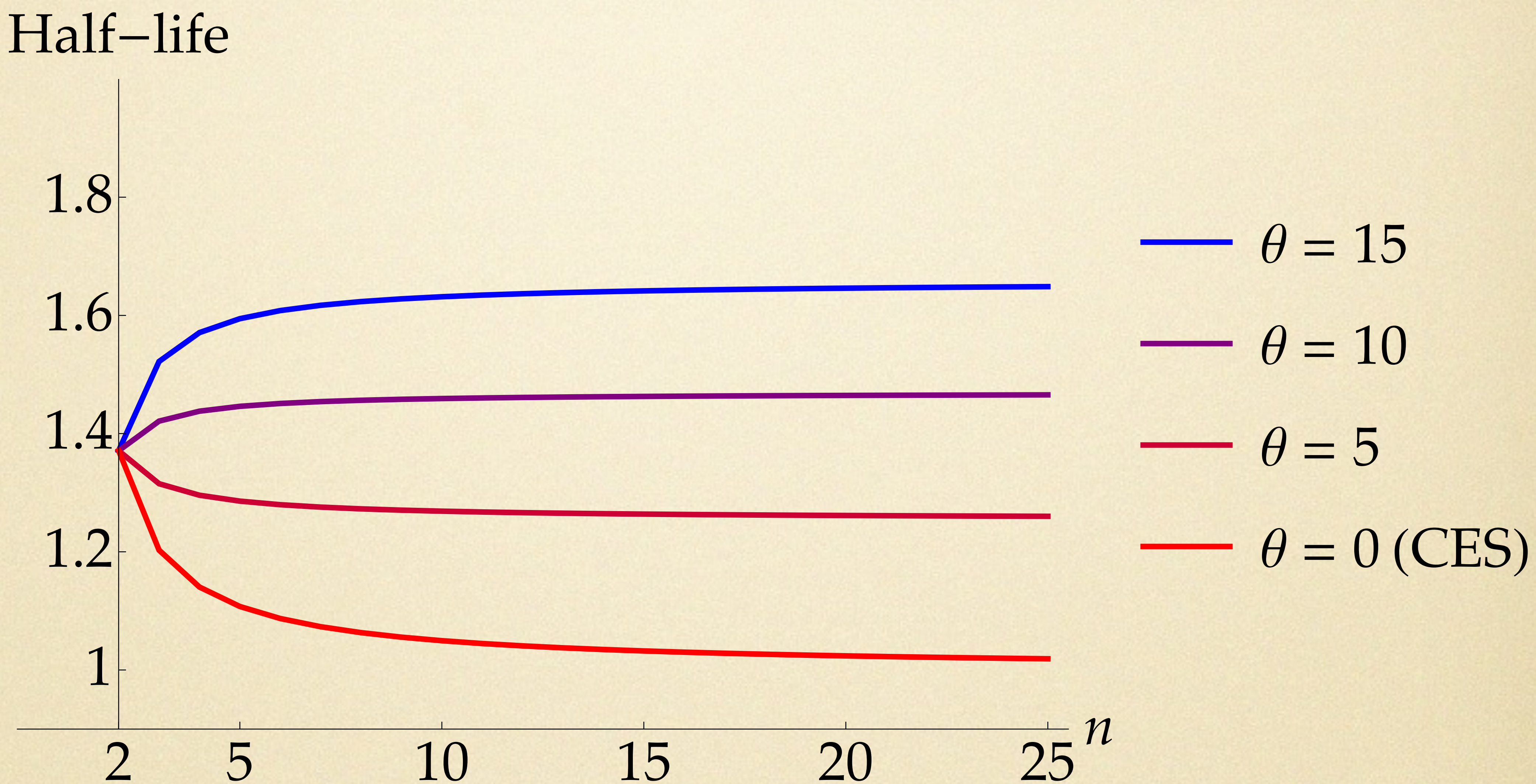
Takeaway:
Naive good fit,
i.e. mostly feedback effects,
strategic effects small

Back to Kimball Demand



$$\theta < \frac{(\eta - 1)^2}{\eta + 1}$$

Back to Kimball Demand



- Small strategic effects…
  - … use naive model for comparative statics
  - half-life decreases with *n* if $\theta < \frac{(\eta - 1)^2}{\eta + 1}$

Naive and Static Nash

- Naive…
  - ignore own impact
  - anticipation of dynamics of future
- Static Nash…
  - best response to fixed prices
  - simple function of primitives
- In paper: provide useful formula…

$$B^{\text{Naive}} = f\left(B^{\text{Nash}}, \frac{\lambda}{\rho}\right)$$

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- What to hold fixed?

1. Preferences (η, θ)

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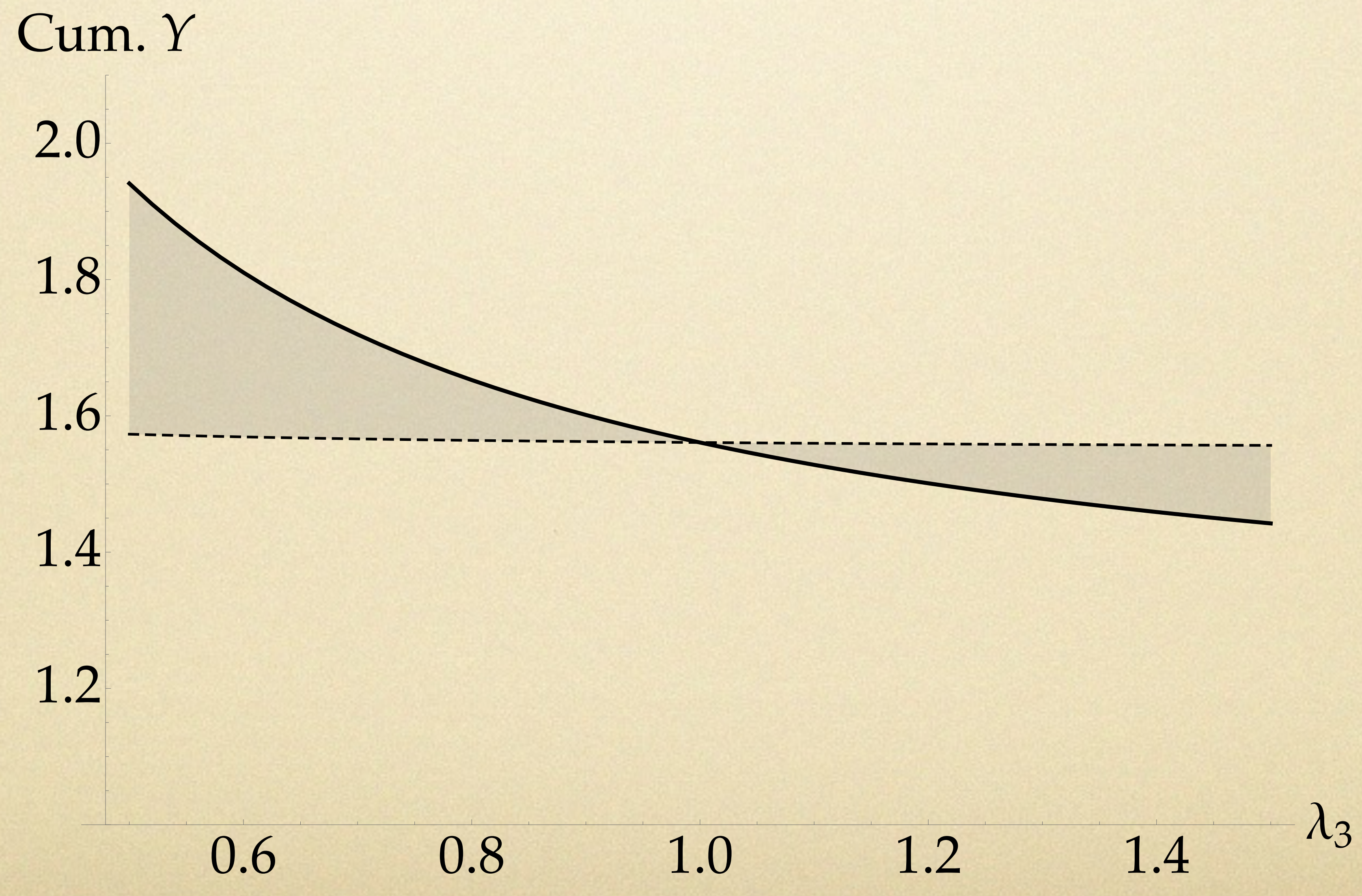
5. Local elasticities of demand (ϵ, Σ) ← **Related to Naive/Kimball Results**

Heterogeneity

- Heterogeneity…
  - across sectors
  - within sector (extension)

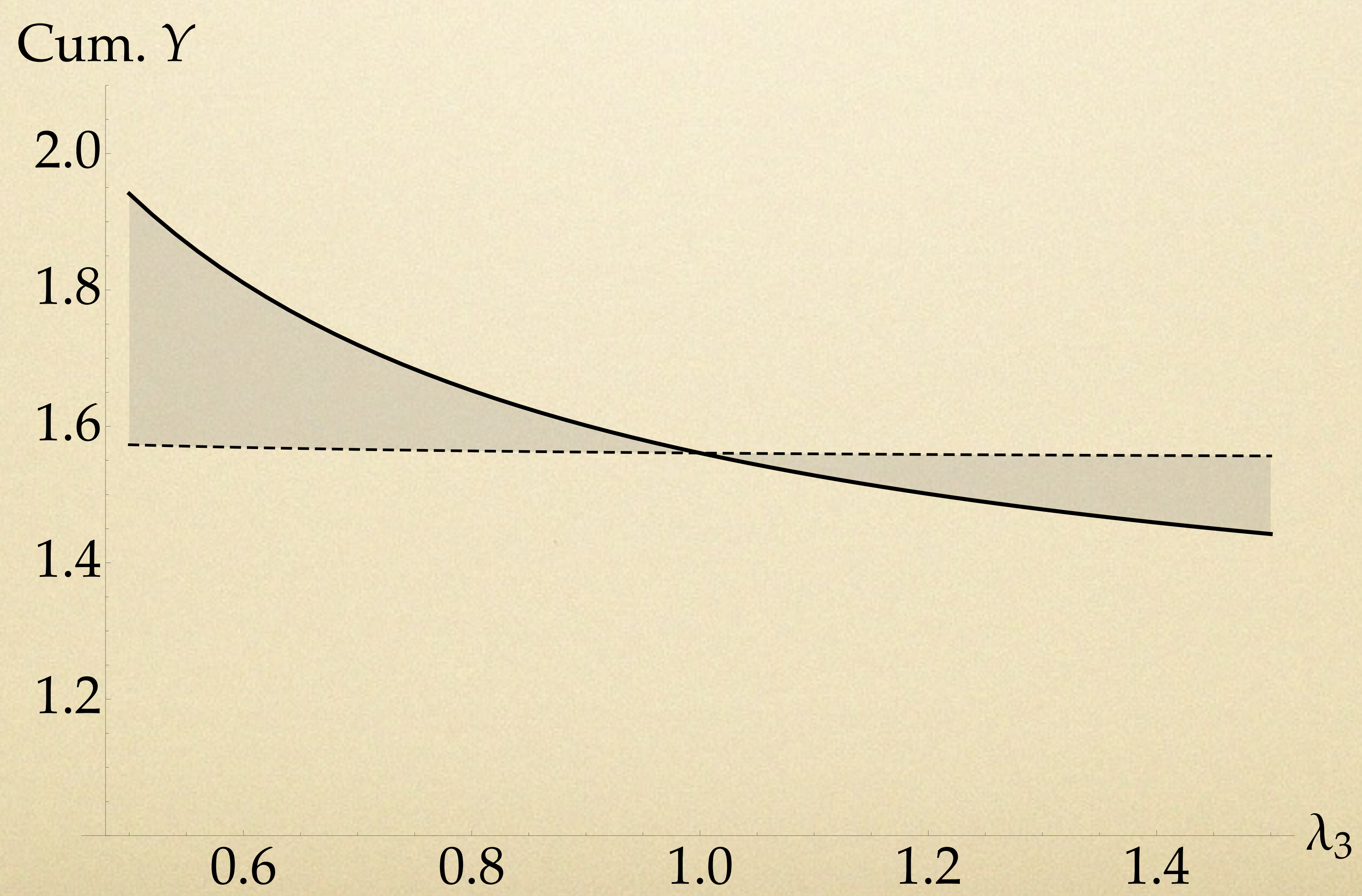
Sectoral Heterogeneity



Sectoral Heterogeneity

- Cumulative output effect is proportional to

$$\mathbf{E}\left[\frac{1}{\lambda_s}\right]\mathbf{E}\left[\frac{1}{1-B_s}\right]+\mathbf{Cov}\left(\frac{1}{\lambda_s},\frac{1}{1-B_s}\right)$$



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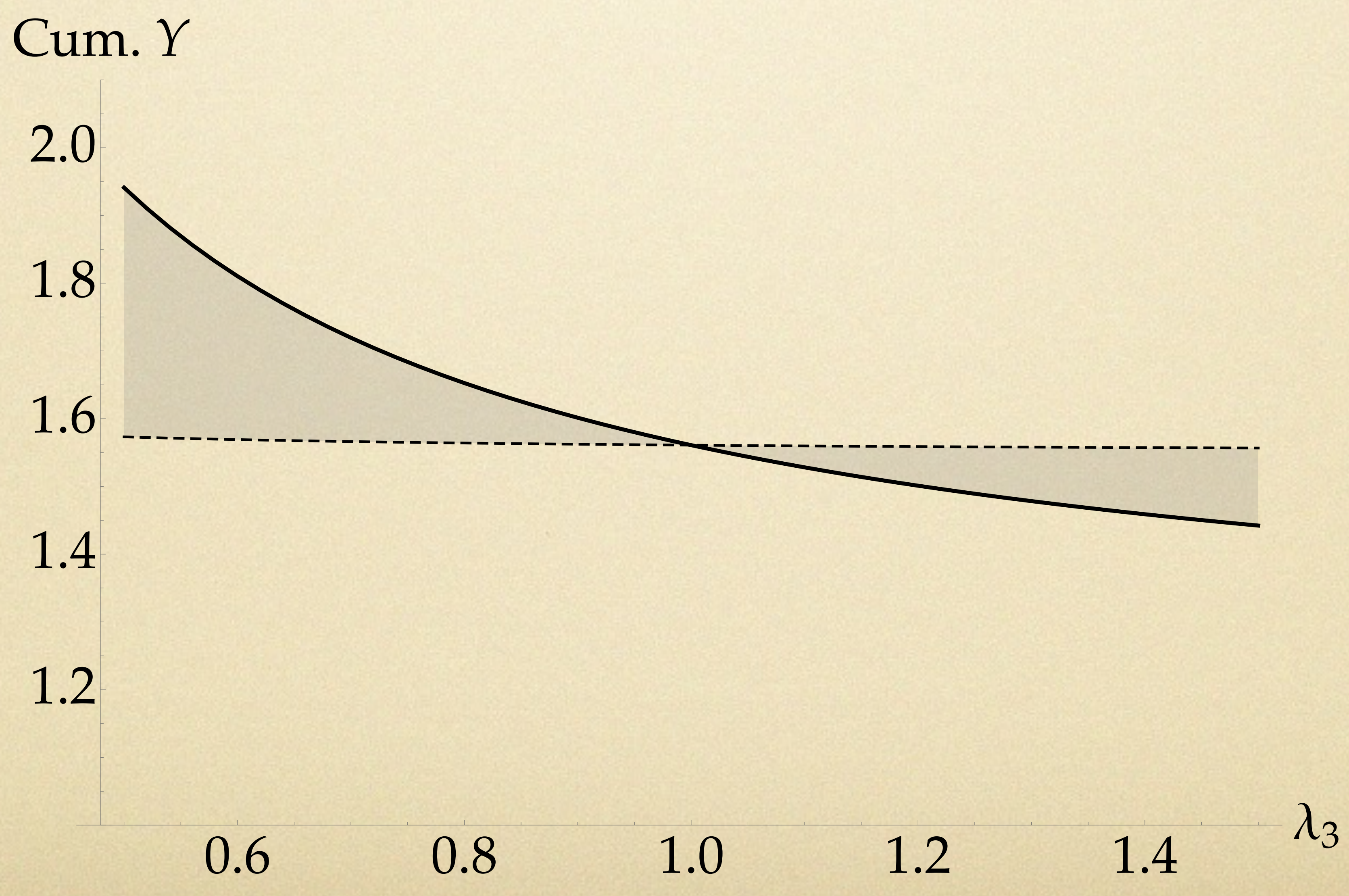
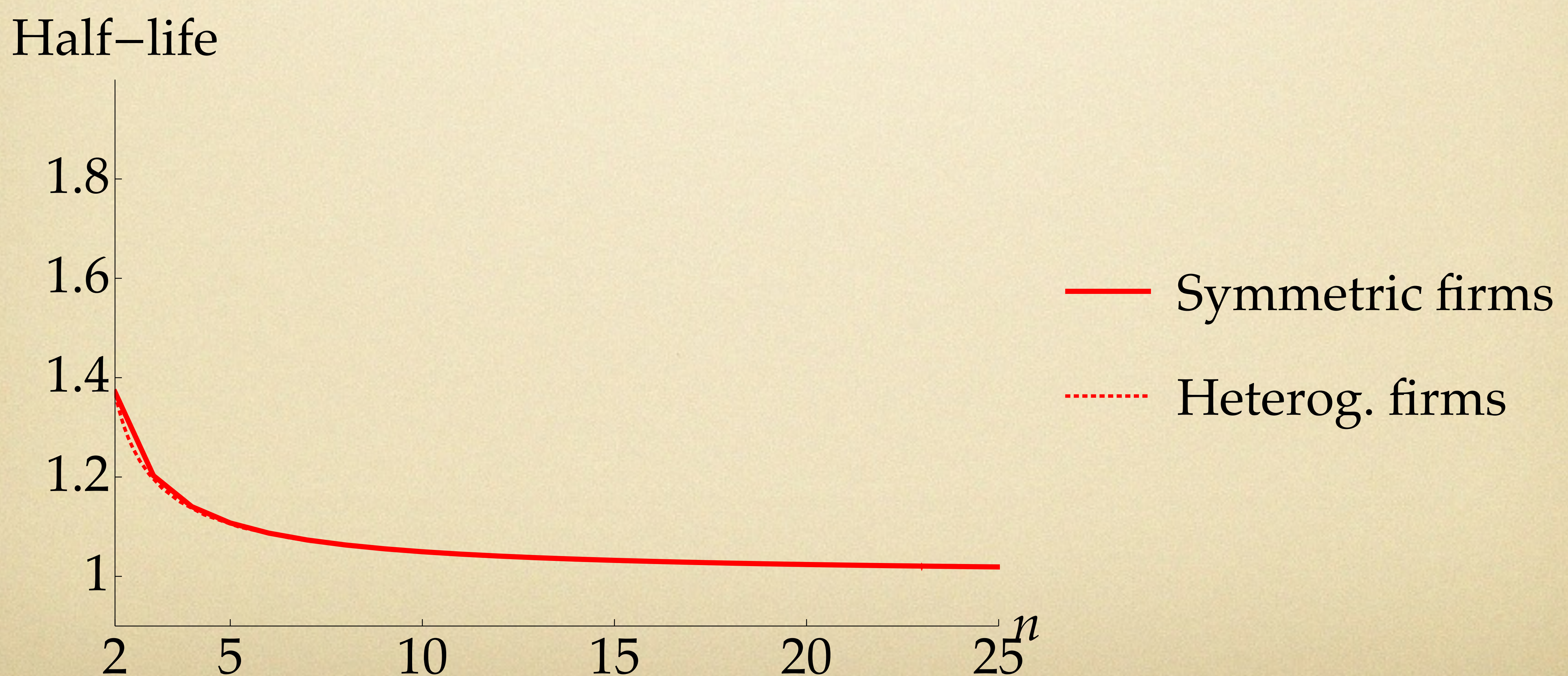
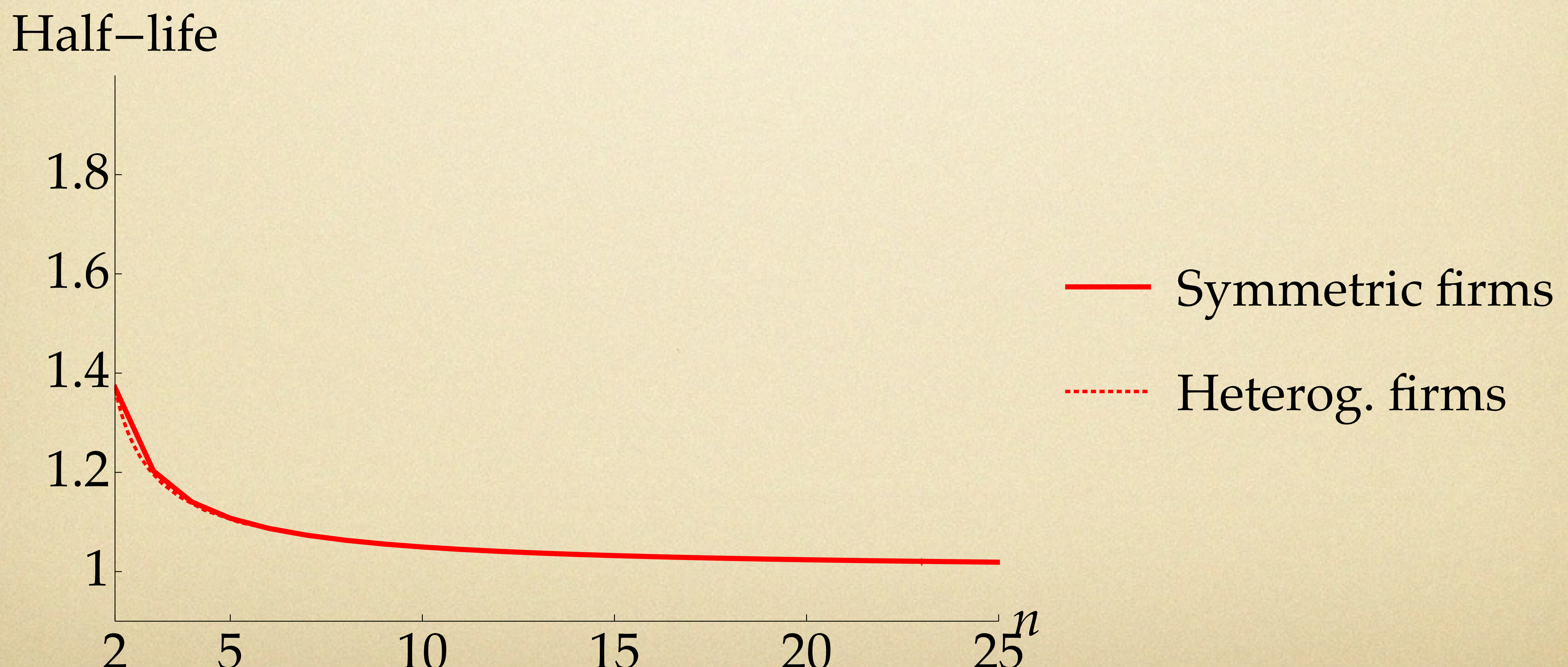
- Example: Two sectors, $n = 3$ and $n = 20$, keeping average duration fixed at 1



Within Sector Heterogeneity

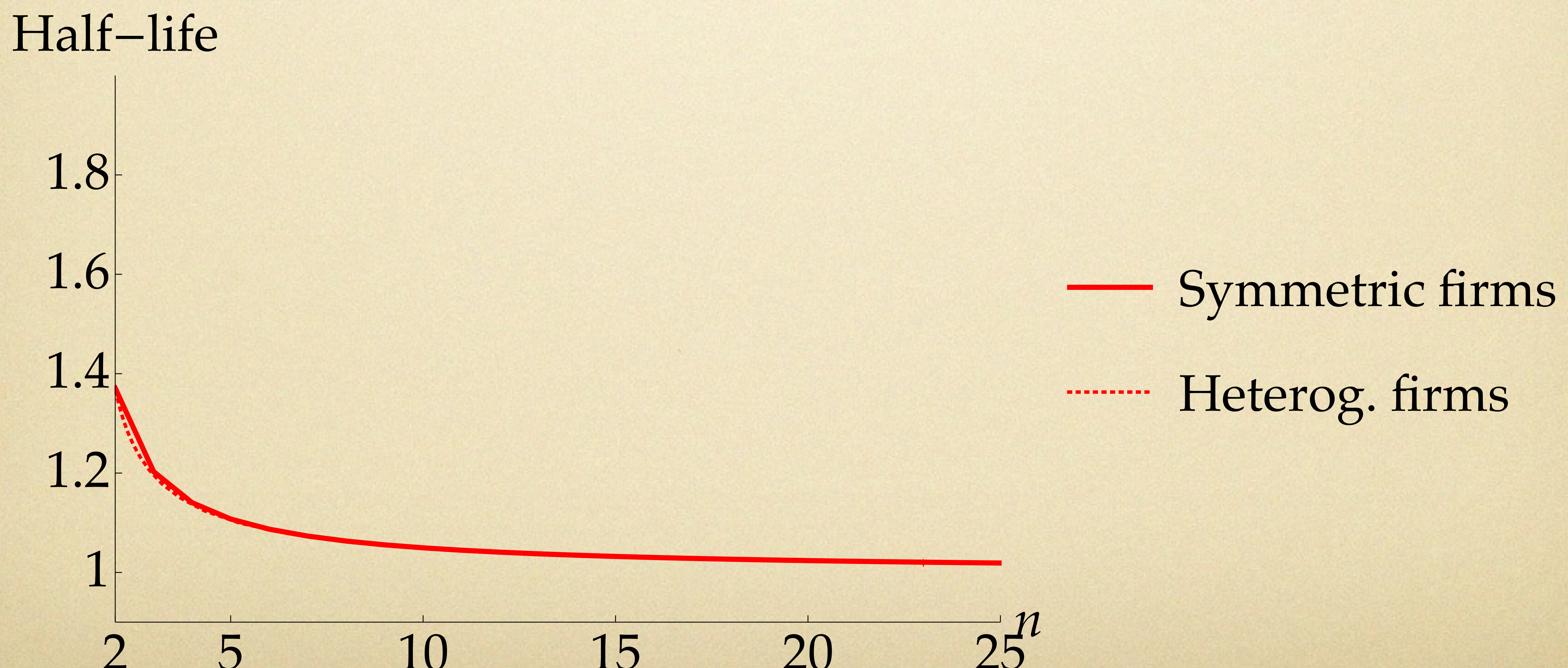


Within Sector Heterogeneity



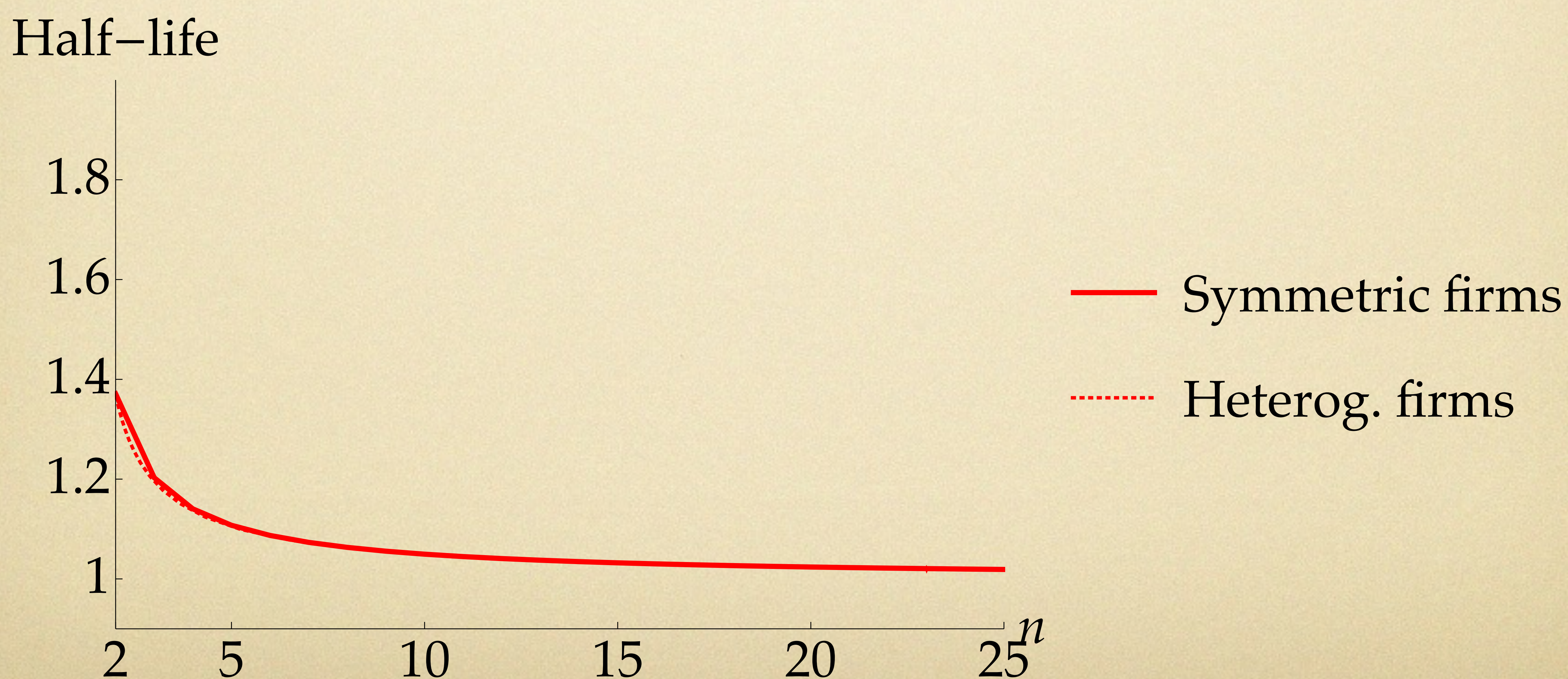
Within Sector Heterogeneity

- Many ways to attain a given HHI instead of 1/n



Within Sector Heterogeneity

- Many ways to attain a given HHI instead of 1/n
- Example:
    - 25 firms, 2 type of firms, 23 type A, 2 type B
    - vary relative productivity A vs B



4. Phillips Curve

Phillips Curve

$$\pi(t) = \int_0^\infty \gamma^{mc}(s)\, mc(t+s)\, ds + \int_0^\infty \gamma^{c}(s)\, c(t+s)\, ds + \int_0^\infty \gamma^{R}(s)\, (R(t+s) - \rho)\, ds$$

$\gamma^{mc}(s), \gamma^{c}(s), \gamma^{r}(s) =$ linear combinations of $\{e^{-\nu_j s}\}_{j=1}^{7}$

- Oligopolistic NKPC
  - Higher order ODE (≤ 7): inflation persistence
  - Not just Marginal Cost (mc): demand (c), interest rates (R)
  - Generally, not equivalent to lower λ

Phillips Curve

- Standard NKPC

$$\dot{\pi} = 0.05\pi - 1.05mc$$

- Oligopoly with $n = 3$ (AIK calibration)
  - MPE

$$\dot{\pi} = 0.07\pi - 0.27\, mc$$
$$+1.33\ddot{\pi} + 0.44\dot{mc} + 0.03(r - \rho)$$

  - Naive

$$\dot{\pi} = 0.05\pi - 0.25mc$$

Phillips Curve

- Standard NKPC

$$\dot{\pi} = 0.05\pi - 1.05mc$$

- Oligopoly with $n = 3$ (AIK calibration)
  - MPE

$$\dot{\pi} = 0.07\pi - 0.27\,mc$$

$$+1.33\ddot{\pi} + 0.44\dot{mc} + 0.03(r - \rho)$$

  - Naive

$$\dot{\pi} = 0.05\pi - 0.25mc$$

Good approximation?

3-Eq Oligopoly NK

- Euler equation + Taylor Rule

$$\dot{c} = \sigma^{-1}\left(r - \pi - \rho - \epsilon^r\right)$$

$$r = \rho + \phi\pi + \epsilon^m$$

- AR(1) ϵ^r, ϵ^m shocks fit basic Phillips curve…
  - exactly with $\kappa \approx \kappa^{\text{Naive}}$
- Other shocks fit very well…
  - zero lower bound
  - News shocks

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Takeaway: basic NK Phillips curve excellent approximation!

3 equation Oligopoly NK

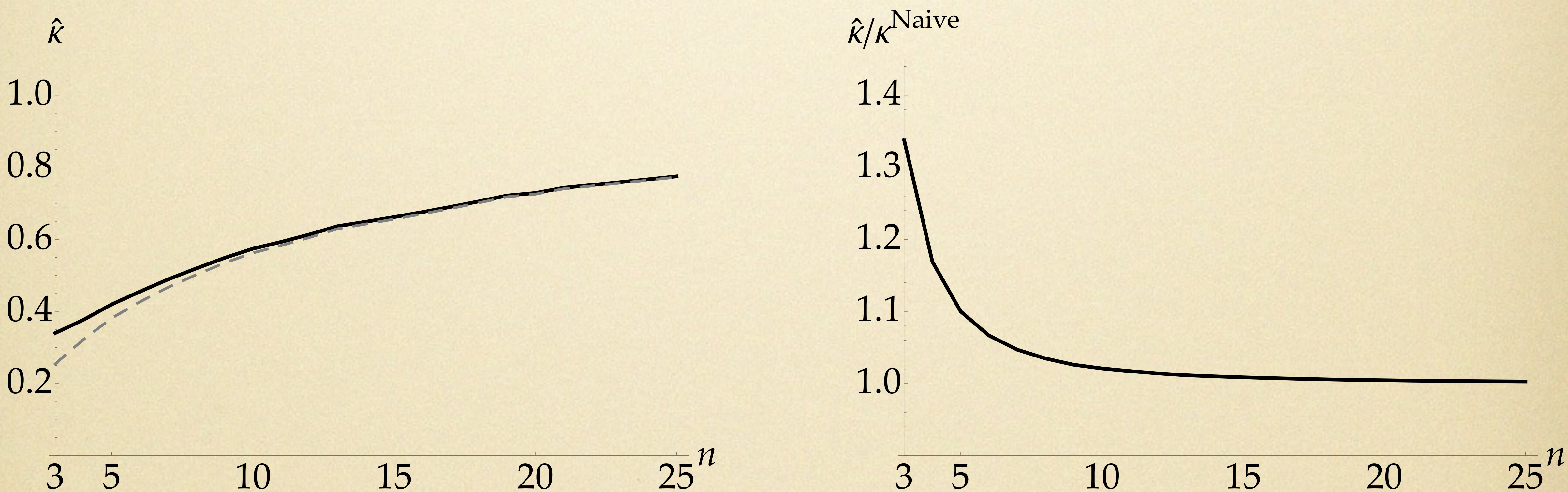
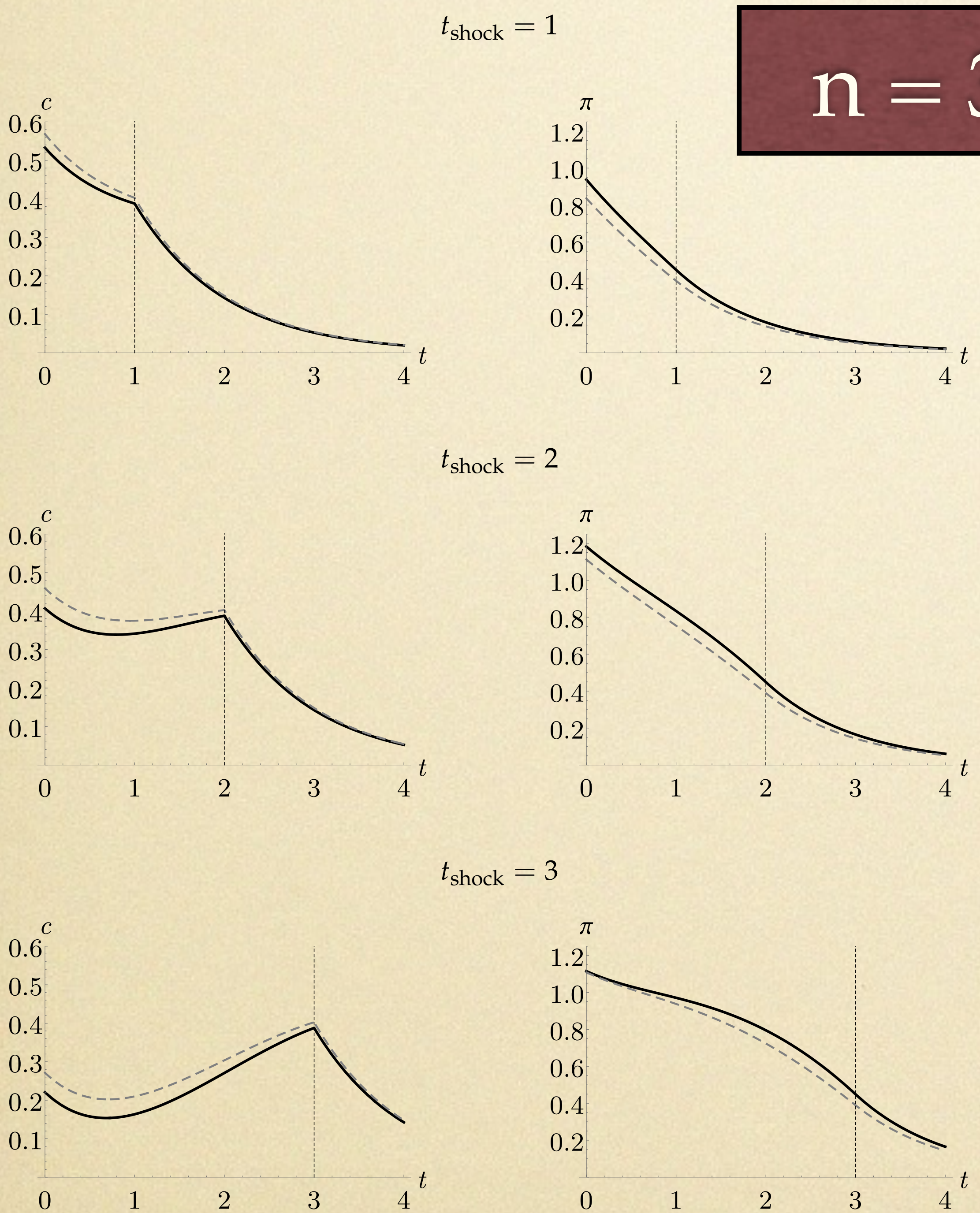


Figure 8: Effective slope of the Phillips curve $\hat{\kappa}$, strategic vs. naive oligopoly.

News and ZLB

n = 3 firms



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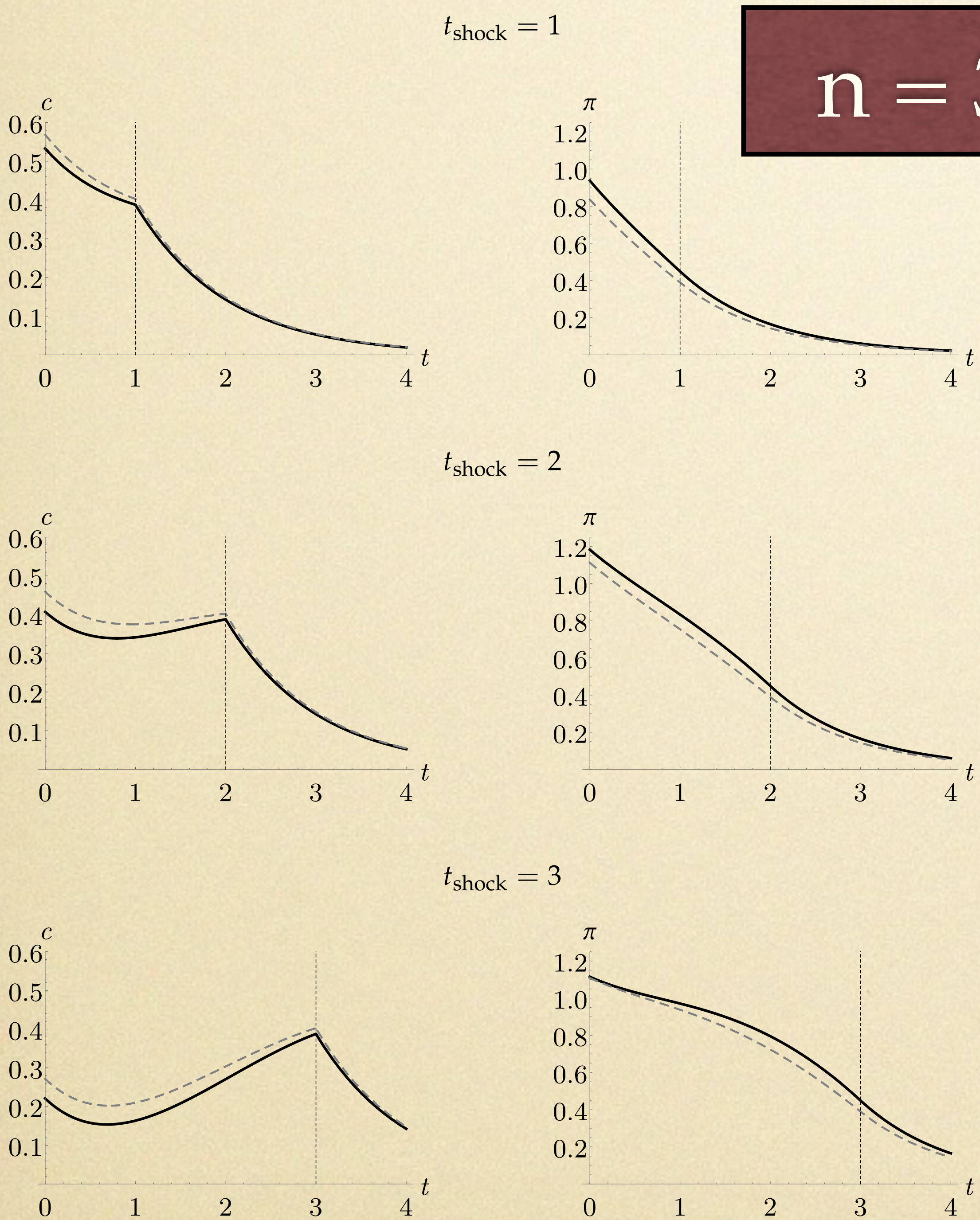

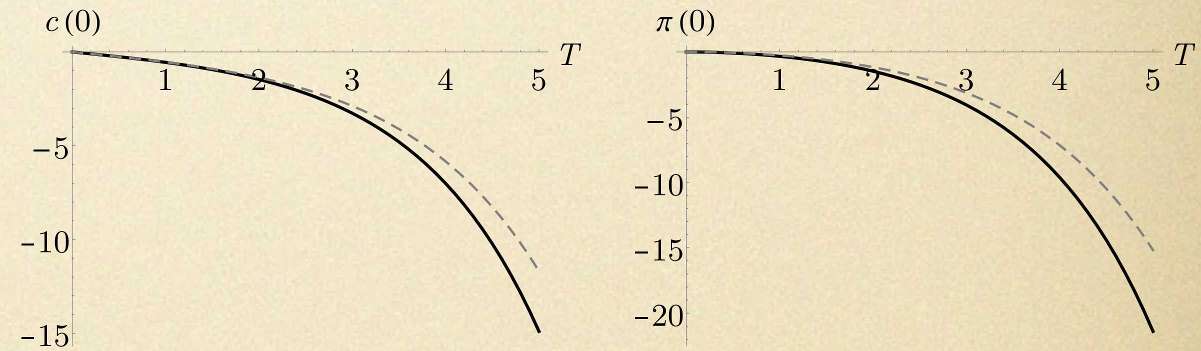

Figure A.10: Date-0 consumption and inflation in a liquidity trap lasting from $t = 0$ to $t = T$, for different values of T.

Note: $n = 3$ firms with AIK calibration. Solid black line: Strategic oligopoly. Dashed gray line: Naive model. c and π denote log-deviations from steady state values in %.

Summary

- Results…

1. Oligopoly tractable!
2. Sufficient statistic formula
3. Comparative Statics in n:
   big amplification when calibrated to pass-through
4. Naive/Kimball connection
5. Standard NK Phillips curve good fit

Teaser: Future Work

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- Non-Markov equilibria? Trigger strategies

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- Abreu-Pearce-Stachetti methods?

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