Hysteresis, the Big Push, and Technological Adoption

Sebastián Amador

University of California, Davis

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Introduction

- Conventional view: GDP $=$ Trend $+$ Cycle
  - Trend$=$ f(supply side factors)
  - Cycle$=$ f(demand shocks and monetary policy).
  - Ideas $\rightarrow$ TFP.
- Alternative view
  - Relationship between the cycle and the trend.
  - Hysteresis: temporary shocks may have long run effects.
  - Ideas $\rightarrow$ implementation process $\rightarrow$ TFP.

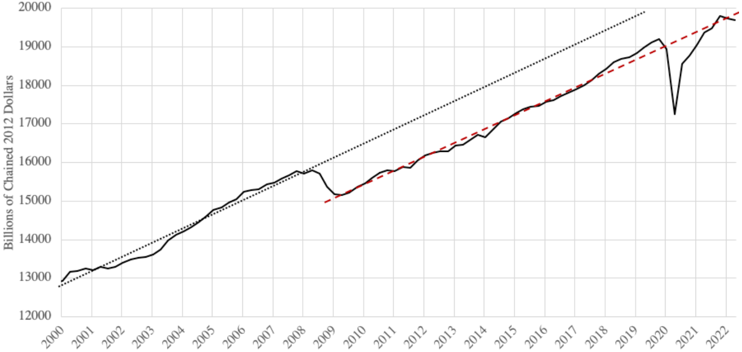


Figure: **United States Real GDP and Linear Trend (Source: FRED)**

This paper

- **Question:** which supply-side factors determine if a temporary shock has permanent effects?
- Focus on the **adoption** and **abandonment** of a technology by firms with heterogeneous costs.
- **Why not R&D?** supply-side scarring, relavance for non-R&D intensive economies.
- Coordination failure in the share of adopters (multiple equilibria, Big Push).
- Equilibrium selection: history of shocks $\rightarrow$ hysteresis may appear.
  - **Key feature:** if adoption threshold $>$ exit threshold $\rightarrow$ hysteresis.
  - Typical in stochastic settings when there is an option value of waiting for a high draw.

"In 1899 and 1900, electric vehicles outsold all other types of cars"

Figure: **Edison and electric car, 1913, (Source: National Museum of American History)**

"[...] it would take more than 60 years before turbines of that size would be built [again]"

Figure: **100 kW turbine in Crimea 1931, (Source: Potter, 2020)**

Results

Hysteresis depends on:

- Elasticity of substitution between input varieties.
  - More sustituability/markups $\rightarrow$ more hysteresis.
- Barriers to adoption.
  - Higher entry costs $\rightarrow$ more hysteresis.
- Shock size.
  - Larger shocks $\rightarrow$ more hysteresis.

On the possibility of reverse hysteresis (positive shocks $\rightarrow$ positive long-run effect):

- Complementarity in adoption vs. decreasing profits for late adopters.
- It is relatively more expensive to adopt the higher the adoption share (holding costs constant).
- **Reverse hysteresis** more likely in less technologically advanced economies.
- **Friedman's (1964) plucking model** more likely in economies near/on the technological frontier.

Related Literature

- **Relationship between cycle and trend:** Cerra, Fatás, & Saxena (forthcoming); Elfsbacka Schmöller, 2022; Garga & Singh, 2020; Anzoategui, Comin, Gertler, & Martinez, 2019; Bianchi, Kung, & Morales, 2019; Benigno & Fornaro, 2018; Aguiar & Gopinath, 2007;
- **Hysteresis non-linearity:** Jordá, Singh, & Taylor (2021); Amador (2022); Aikman, Drehmann, Juselius, & Xing, (2022).
  - Hysteresis is asymmetric (no reverse hysteresis).
  - Hysteresis seems to be driven by the largest episodes.
- **Output fluctuations as coordination failures:** Rosenstein-Rodan (1943); Murphy et al., (1989); Ciccone (2002); Diamond (1982); Kiyotaki (1988); Cooper & John (1988); Durlauf (1991); Fajgelbaum, Schaal, & Taschereau-Dumouchel (2017); Schaal & Taschereau-Dumouchel (2018), Choi & Shim (2022).

Contribution

- Parsimonious supply side model of hysteresis consistent with empirical evidence on asymmetry and non-linearity.
- Supply-side explanation for Friedman's (1964) plucking model.

Model

- Time is discrete and goes on forever.
- The economy:
  1. Representative household.
     - $\mathbb{E}\sum_{t=0}^{\infty}\rho^t U(C_t)$; $U(C_t) = \ln C_t$; $P_t C_t \leq W_t + \Pi_t$.
  2. Final good sector.
     - $Y_t = \left(\iint_{j,k} y_{j,k,t}^{\frac{\sigma-1}{\sigma}} \mathrm{d}j\mathrm{d}k\right)^{\frac{\sigma}{\sigma-1}}$; (j,k); $P_t = \left(\iint_{j,k} p_{j,k,t}^{1-\sigma}\mathrm{d}j\mathrm{d}k\right)^{\frac{1}{1-\sigma}}$.
  3. Intermediate goods sector (continuum of varieties).
- Final good used for consumption and to pay for the cost of adopting and operating a modern technology.
- Resources used in adoption are not used for any other purpose.

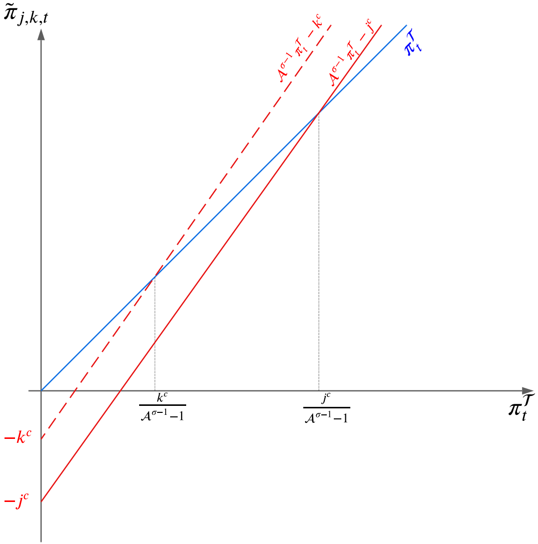
Intermediate goods producer

- Unit mass of firms indexed by adoption/abandonment thresholds (j, k).
- Varieties produced by monopolist choosing traditional $(\mathcal{T})$ or a modern $(\mathcal{M})$ technology.
- Production function $y_{j,k,t} = A_{j,k,t} l_{j,k,t}$
- Productivity: $A_{j,k,t} = e^{a_t} u_{j,k,t}$
  - Shock: $a_t = \psi a_{t-1} + \varepsilon_t^a$,
  - If in the $\mathcal{T}$-sector, then $u_{j,k,t} = 1$
  - If in the $\mathcal{M}$-sector then $u_{j,k,t} = \mathcal{A} > 1$.

Partial equilibrium

- Firm quantity and pricing decisions are independent of j and k.
- **Proposition 1:** Prices, $p^i_{j,k,t}$, and quantities, $y^i_{j,k,t}$, will be symmetric across all firms in each type $i \in \{\mathcal{T}, \mathcal{M}\}$:
  - $\phi^{\mathcal{T}}_t = \frac{W_t}{e^{a_t}}$; $\phi^{\mathcal{M}}_t = \frac{\phi^{\mathcal{T}}_t}{\mathcal{A}}$; $y^{\mathcal{T}}_t = \left(\frac{\sigma}{\sigma-1}\phi^{\mathcal{T}}_t\right)^{-\sigma} Y_t$; $y^{\mathcal{M}}_t = \left(\frac{\sigma}{\sigma-1}\frac{\phi^{\mathcal{T}}_t}{\mathcal{A}}\right)^{-\sigma} Y_t$
- **Gross** profits in the $\mathcal{M}$-sector will be a linear function of profits in the $\mathcal{T}$-sector.
  - $\pi^{\mathcal{T}}_t = \left(\frac{1}{\sigma-1}\right)\left(\frac{\sigma}{\sigma-1}\right)^{-\sigma}\left(\frac{1}{\phi^{\mathcal{T}}_t}\right)^{\sigma-1} Y_t$
  - $\pi^{\mathcal{M}}_t = \mathcal{A}^{\sigma-1}\pi^{\mathcal{T}}_t$
- **Proposition 2:** Let the final good, Y_t, be the numéraire $(P_t = 1 \forall t)$. Given a share of firms in the modern sector, m_t, and the optimal choices of prices and quantities for firms in each sector, it is possible to derive functions for aggregate quantities (in terms of m_t and a_t).

Intermediate goods producer



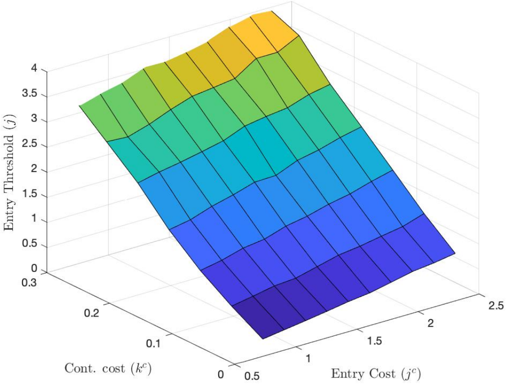
Adoption operator:

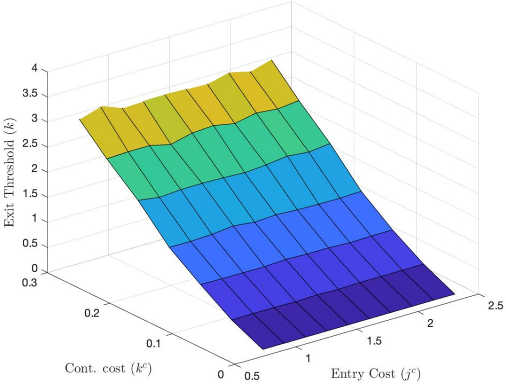
$$\gamma_{j,k,t} = \begin{cases} 1 & \text{if } \gamma_{j,k,t-1} = 0, \text{ and } \pi_t^{\mathcal{T}} > j \\ 1 & \text{if } \gamma_{j,k,t-1} = 1, \text{ and } \pi_t^{\mathcal{T}} > k \\ 0 & \text{if } \gamma_{j,k,t-1} = 0, \text{ and } \pi_t^{\mathcal{T}} < j \\ 0 & \text{if } \gamma_{j,k,t-1} = 1, \text{ and } \pi_t^{\mathcal{T}} < k \end{cases}$$

How the optimal thresholds are obtained for each firm?

- $\tilde{\pi}_t = \gamma_{j,k,t}\left(\mathcal{A}^{\sigma-1}\pi_t^{\mathcal{T}} - \gamma_{j,k,t}\gamma_{j,k,t-1}k^c - \gamma_{j,k,t}\left(1-\gamma_{j,k,t-1}\right)j^c\right) + \left(1-\gamma_{j,k,t}\right)\pi_t^{\mathcal{T}}$
- $V_0 = E_0\left\{\sum_{t=1}^{\infty}\beta^t\tilde{\pi}_t(a_t, m_t, \gamma_{j,k,t}|\gamma_{j,k,t-1})\right\}$
- $\max_{\gamma_{j,k,t}} \tilde{\pi}_t + \beta E\left\{V_{t+1}(a_{t+1}, m_{t+1}, \gamma_{j,k,t+1}|\gamma_{j,k,t})\right\}$
- Optimal threshold j:
  $\tilde{\pi}_t(\gamma_{j,k,t}=0) + \beta E\left\{V_{t+1}(a_{t+1}, m_{t+1}|\gamma_{j,k,t+1}=\gamma_{j,k,t}=0)\right\} = E\left\{V_t(a_t, m_t|\gamma_{j,k,t}=1)\right\}$
- Optimal threshold k:
  $\tilde{\pi}_t(\gamma_{j,k,t}=1) + \beta E\left\{V_{t+1}(a_{t+1}, m_{t+1}|\gamma_{j,k,t+1}=\gamma_{j,k,t}=1)\right\} = E\left\{V_t(a_t, m_t|\gamma_{j,k,t}=0)\right\}$
- Assumption: firms expect $\pi_t^{\mathcal{T}}$ to behave as a random walk **bounded in the long-run** with i.i.d. disturbances.
- Expectations are derived from simulations to obtain j and k.

How the optimal thresholds are obtained for each firm?





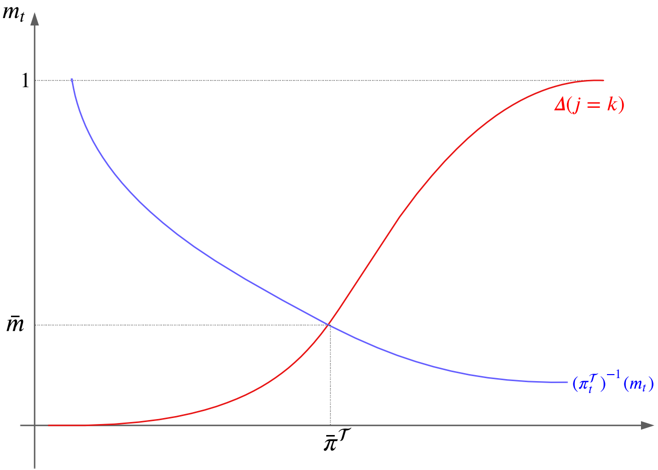
Equilibrium

Definition 1: An equilibrium is C_t, L_t ; $\gamma_{j,k,t}$, $y^i_{j,k,t}$,$l^i_{j,k,t}$, $i \in \{\mathcal{M}, \mathcal{T}\}$; $p^{\mathcal{T}}_{j,k,t}$, $p^{\mathcal{M}}_{j,k,t}$, $P_t\left(a^t\right)$, W_t; and m_t, such that;

1. The household maximizes utility.
2. All intermediate producers maximize their profits net of technological costs.
3. The final good producer solves its problem.
4. Prices clear all markets.
5. m_t satisfies:
   - $m_t = \int\limits_{j \geq k}\int \delta(j,k)\gamma_{j,k,t}\mathrm{d}j dk$.
   - where $\delta(j,k)$ is the joint density of j and k.
   - and; $\gamma_{j,k,t} = \begin{cases} 1 & \text{if } u_{j,k,t} = \mathcal{A} \\ 0 & \text{if } u_{j,k,t} = 1 \end{cases}$

What if $j = k \ \forall (j, k)$?

Figure: **Single steady state equilibrium when $j = k$**

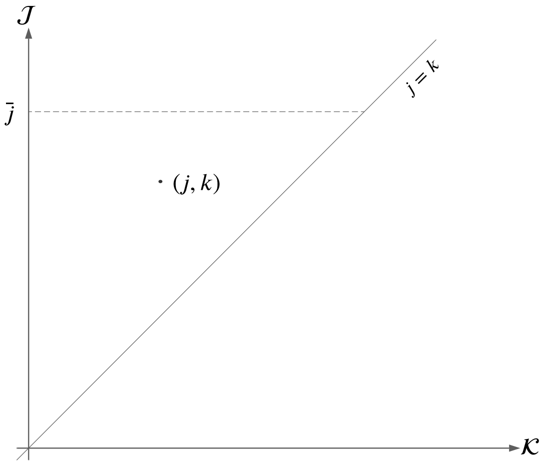


What if $j \geq k$?

- Multiple steady state equilibria (intuition: two CDFs instead of one).
- Path dependence.
- Possibility of hysteresis (graphic proof).

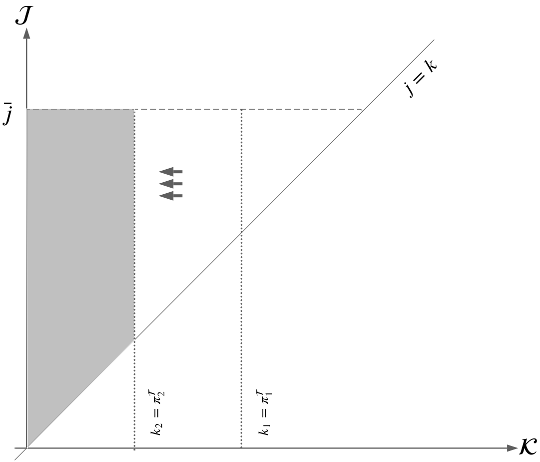
What if $j \geq k$?

Figure: **The $j \geq k$ half plane** $(t = 0)$



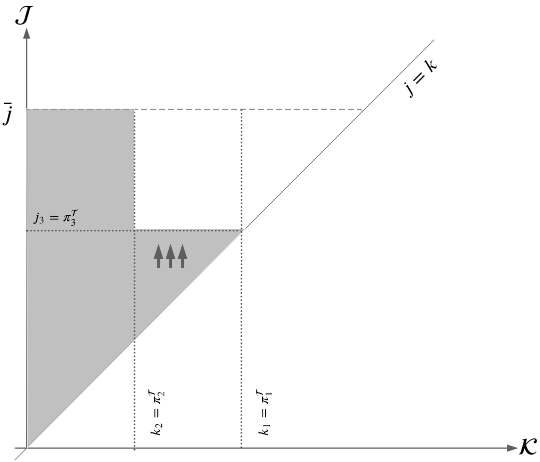
What if $j \geq k$?

Figure: $(t = 1)$



What if $j \geq k$?

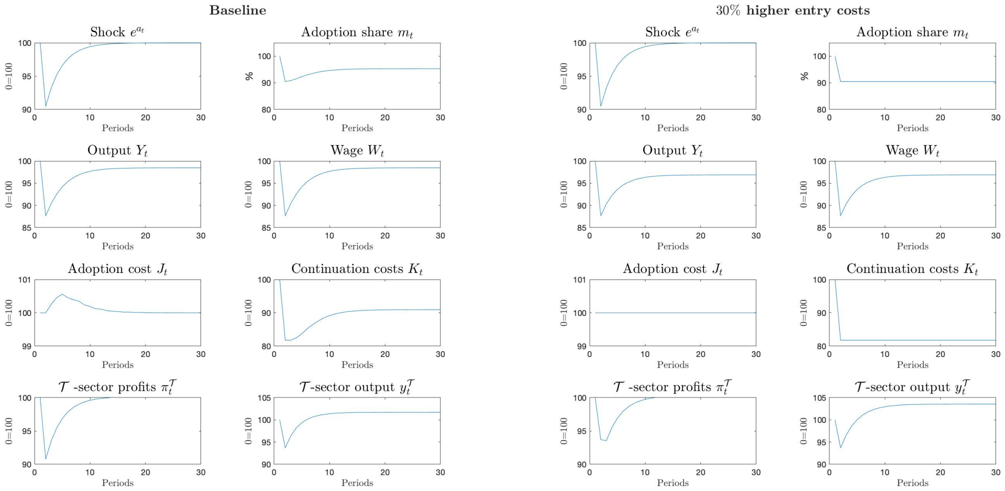
Figure: $(t = 2)$



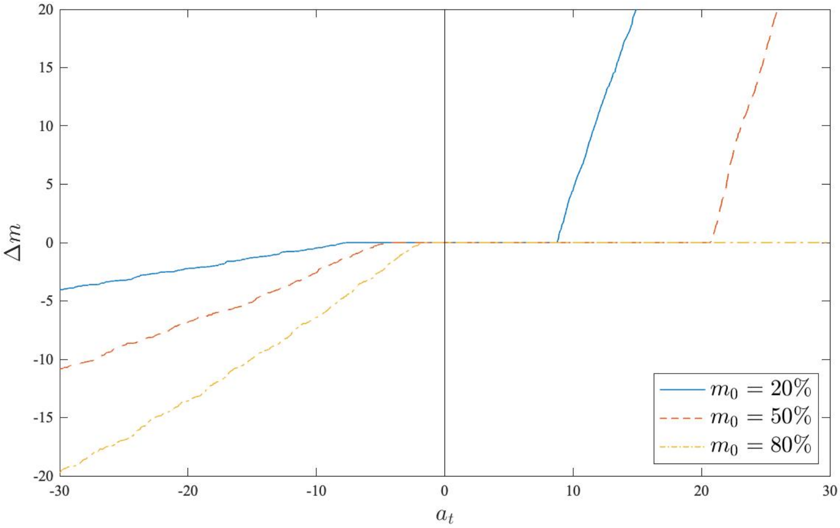
Computational exercises

1. Explore how different parameters affect hysteresis.
   - Barriers to entry (cost).
   - Shock size.
   - Distance to the technological frontier.
   - Elasticity of substitution/markups.
2. Asymmetries in hysteresis effects (reverse hysteresis and Friedman's plucking model).

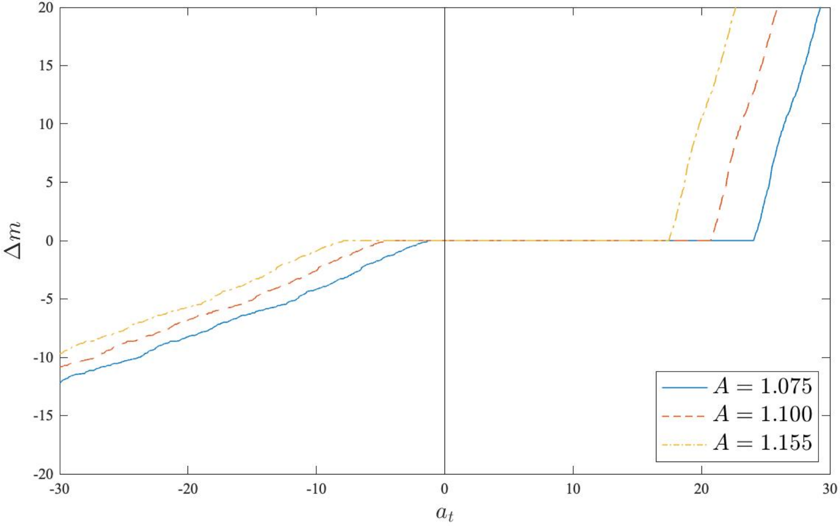
Hysteresis depends on entry costs j^c



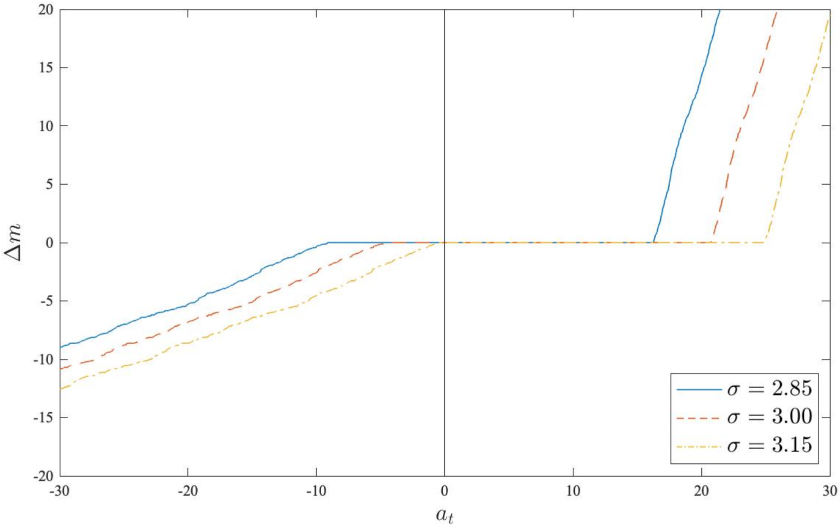
Hysteresis depends on shock size and adoption share



Hysteresis depends on productivity of new technology

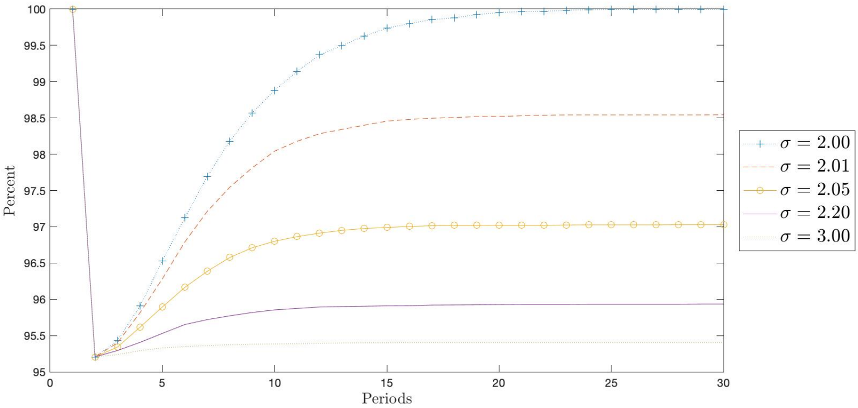


Hysteresis depends on markups



Hysteresis depends on elasticity of substitution (markups)

Figure: Response of m_t to a -15% shock for different values of σ (markup $\frac{\sigma}{\sigma-1}$)



Conclusion

- Theoretical supply-side framework for hysteresis.
- Relevant for drops in trend and for non-R&D intensive economies.
- Defines a set of conditions for the possibility of reverse hysteresis.
- Novel equilibrium selection criterion based on history of shocks.
- Key mechanism based on heterogeneous adoption and abandonment thresholds.
- Results:
  - Hysteresis depends non-linearly on the size of the shock.
  - Hysteresis depends on market power (markups, entry costs).
  - Reverse hysteresis more likely in economies far away from the technological frontier.
  - Friedman's plucking model more likely for economies on the technological frontier.