Technological Innovation as Regulatory Arbitrage

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Motivation

- Technological innovation tends to expand PPF
  - arguably most important driver of material prosperity
- BUT, not all innovations improve social welfare
- **This paper:** innovations may undermine public goods
  - hence, "tech innovation as reg. arbitrage"

Some Considerations...

- productive activities generate private & public goods
- regulation often requires firms to supply public goods
- incentive to adopt technologies that are harder to regulate

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Regulatory Arbitrage?

Regulatory arbitrage arises from "the difficulty of jamming square-pegged technologies into round-shaped regulation." (Todisco, 2015)

Figure:
Technical representation of the regulatory process.

Regulatory Arbitrage?

Wedge between **de jure** and **de facto** regulation...

- Gig platforms
  - e.g. Uber, Handy
  - worker misclassification, safety, traffic
- Rental platforms
  - e.g. Airbnb
  - property tax avoidance, "shadow hotels"
- Digital assets / Crypto
  - circumvent financial regulation
  - social value?
- Social media
  - undermines journalism
  - "truth" as a public good

Preview of Results

- Tractable framework to study innovation & reg. arbitrage
  - public goods are underprovided in equilibrium
  - existence of socially unproductive innovation
  - conditions for when innovation is desirable
- Characterize optimal regulation
  - with full instruments, regulation achieves first-best
  - how to regulate technologies that don't exist yet?
  - simple rule to correct for arbitrage
- Dynamic growth model
  - possibility of permanently low productivity growth
  - ineffective regulation as an stable steady-state
  - characterize constrained efficient regulation

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Static Model Setup

- Representative agent with quasi-linear utility, $\gamma \in (0,1)$

$$u = \gamma \log y + z$$

- Two consumption goods:
  - **private good** (y)
  - **public good** (z)

- One factor $\bar{\ell} = 1$, can be used in...
  - Private production: $y = \theta_v \ell_y$
  - Public production: $z = \ell_z$

- "Menu" of technologies $v \in V$

Basic Setup

First-Best Allocation

$$\max_{v \in V, \ell_y, \ell_z} \gamma \log(\theta_v \ell_y) + \ell_z \qquad \text{s.t.} \quad \ell_y + \ell_z \leq 1$$

- labor allocation:

$$\ell_y^* = \gamma \qquad \ell_z^* = 1 - \gamma$$

Competitive Equilibrium (Laissez-faire)

$$\max_{v \in V, \ell_y, \ell_z} p\theta_v \ell_y - \ell_y$$

- labor allocation:

$$\ell_y^* = 1 \qquad \ell_z^* = 0$$

Competitive Equilibrium with Regulation

Regulation

Policymaker sets the share of labor employed in the production of public goods $\tau \in [0, 1]$ – **de jure** regulation

Technology Bundle

A technology $v \in V$ is described by a bundle $\mathcal{T}_v = (\theta_v, \delta_v)$ where:

- $\theta_v \in \mathcal{R}^+$ denotes private good **productivity**
- $\delta_v \in [0, 1]$ captures the **effectiveness of regulation**

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Competitive Equilibrium with Fixed Regulation

Firm Problem:

$$\max_{v \in V, \ell} \; p\theta_v(1 - \delta_v \tau)\ell - \ell$$

- $\delta_v \tau$ – de facto regulation of using technology $v \in V$
- θ_v – productivity of technology $v \in V$
- ℓ – total labor employed by firm
- $y = \theta_v(1 - \delta_v \tau)\ell$ – private good output

Competitive Price

$$p = \frac{1}{\theta_v(1 - \delta_v \tau)}$$

Public Good Supply

$$z = \delta_v \tau \ell$$

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Competitive Equilibrium with Fixed Regulation

Competitive Equilibrium

For a given regulation $\tau \in [0, 1]$, an equilibrium consists of:

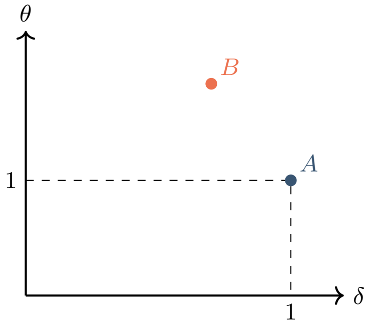
- Competitive price p
- Technology choice $v \in V$
- Labor allocation ℓ_y, ℓ_z
- Such that firms optimize
- Markets clear

Consumer Welfare:

$$W(\tau; \theta_v, \delta_v) = \gamma \log(\theta_v(1 - \delta_v \tau)) + \delta_v \tau$$

Example: 2 Technologies

Figure: Innovation in reg. effectiveness - productivity space (δ, θ)



- Two technologies:
- $\boldsymbol{A}$: low prod. / no arbitrage
- $\boldsymbol{B}$: high prod. / + arbitrage

Tech B will be adopted if:

$$(\theta - 1) + (1 - \delta)\tau > 0$$

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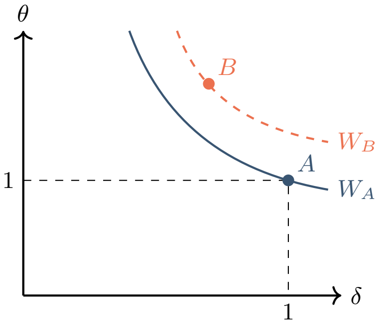

- Innovation **increases** welfare

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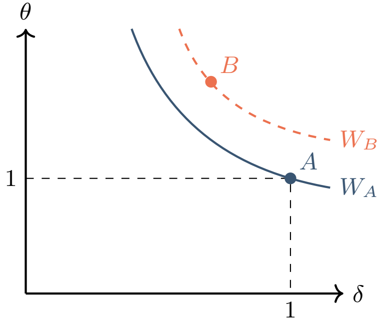

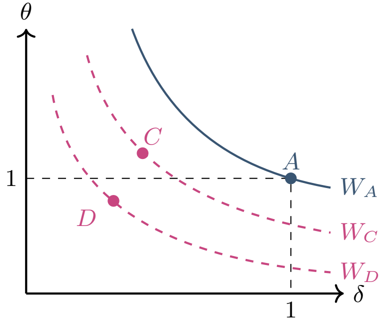

- Innovation **increases** welfare
- Innovation **decreases** welfare

(Constrained) Efficient Regulation

The regulator solves...

$$\max_{\tau \leq 1} \gamma \log(\theta_v(1 - \delta_v \tau)) + \delta_v \tau$$

Proposition

For a given technology $v \in V$, the regulator's optimal regulation satisfies:

$$\hat{\tau}_v = \left\{ \frac{1 - \gamma}{\delta_v}, 1 \right\}$$

There are 2 regimes:

- $\delta_v \geq 1 - \gamma \Rightarrow$ unconstrained, attains first-best
- $\delta_v < 1 - \gamma \Rightarrow$ legal max binds $\tau = 1$

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Desirability of Technical Change

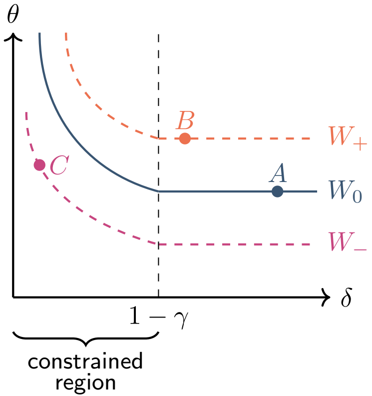
Unconstrained regulation

- Innovation always desirable
- $\hat{\tau}$ "undoes" arbitrage

Constrained regime

- **legal maximum** binds
- Innovation only desirable if

$$d\theta > \frac{\theta}{\gamma}\left(\frac{\gamma}{1-\delta} - 1\right)$$



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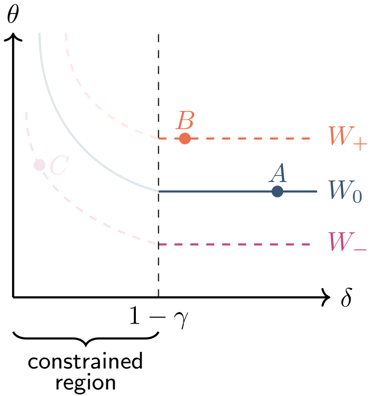

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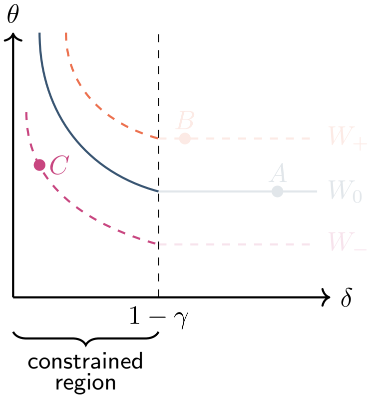
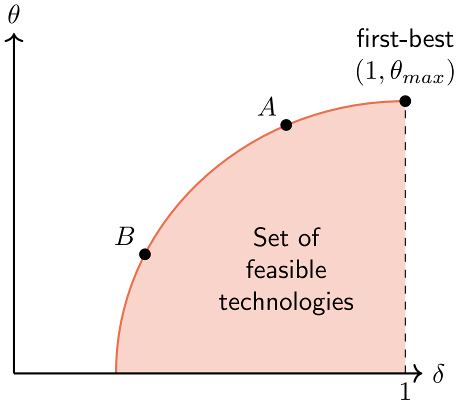


Technology Choice



Technology Frontier

$$\theta^\alpha + \beta\delta^{-\alpha} \leq F$$

Competitive Choice of Technology

Firm chooses $\mathcal{T} = (\theta, \delta)$ in order to minimize unit costs:

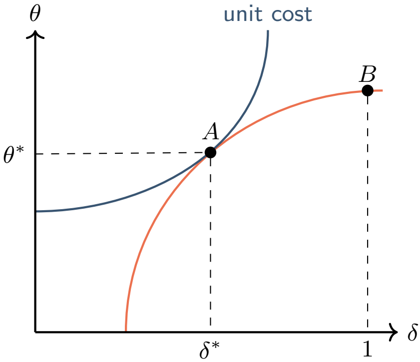
$$\min_{\theta,\delta} \frac{1}{\theta(1-\delta\tau)} \quad \text{s.t.} \quad \theta^{\alpha} + \beta\delta^{-\alpha} \leq F$$

taking regulation $\tau \in [0,1]$ as given.

Solution:

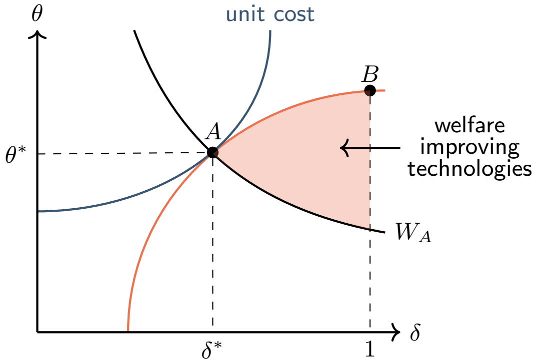
$$\delta^*(\tau) = \left(\frac{\beta}{\tau F}\right)^{\frac{1}{1+\alpha}} \qquad \theta^*(\tau) = \left[F - \beta\delta^*(\tau)^{-\alpha}\right]^{\frac{1}{\alpha}}$$

Competitive Equilibrium



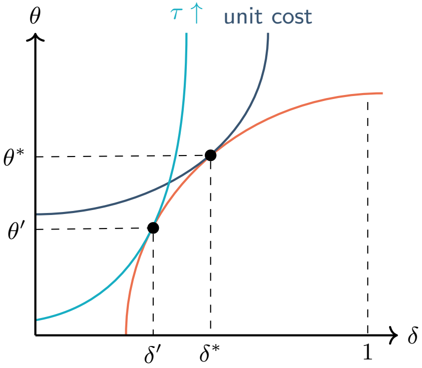
- A: Competitive technology (θ^*, δ^*)
- B: First-best $(\theta_{max}, 1)$

Competitive Equilibrium



- $W_A = W(\theta^*, \delta^*)$: indifference curve for technology A
- Competitive equilibrium is generically inefficient
- **Intuition:**
  - Private incentive to weaken regulation
  - $\downarrow$ supply of public goods

Effects of Regulation



Proposition (Regulation-induced technical change)

An increase in regulation (i) decreases productivity and (ii) weakens the effectiveness of regulation.

$$\frac{d\theta^*}{d\tau} < 0 \qquad \frac{d\delta^*}{d\tau} < 0$$

Regulatory Games

Endogenize regulation:
Consider 3 alternative regulatory regimes...

- Naive Regulation
  - Timing: Simultaneous move
  - Equilibrium: Nash
- Sticky Regulation
  - Timing: Regulator sets τ first
  - Equilibrium: Stackelberg
- Adaptive Regulation
  - Timing: Firm chooses technology (θ, δ) first
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Regulatory Games: Naive Regulation

Regulation is said to be "naive" if the regulator sets regulation τ and the firm chooses technology (θ, δ) simultaneously.

- Regulation is set according to:

$$\tau_n(\theta, \delta) = \text{argmax } W(\theta, \delta, \tau) \quad \text{s.t.} \quad \tau \in [0, 1]$$

- Technology is chosen according to:

$$\mathcal{T}_n(\tau) = \arg\min \frac{1}{\theta(1 - \delta\tau)} \quad \text{s.t.} \quad \text{tech frontier}$$

- Nash equilibrium: $\tau_n(\theta_n, \delta_n)$ and $\mathcal{T}_n(\tau_n)$

Regulatory Games: Sticky Regulation

Regulation is said to be "sticky" if the regulator is the first-mover and *internalizes the competitive choice of technology*.

- First, technology is chosen according to:

$$\mathcal{T}_s(\tau) = \arg\min \frac{1}{\theta(1-\delta\tau)} \quad \text{s.t.} \quad \text{tech frontier}$$

- Second, regulation solves:

$$\max_{\tau \in [0,1]} W(\theta, \delta, \tau) \quad \text{s.t.} \quad \mathcal{T}_s(\tau)$$

- Stackelberg equilibrium: $\tau_s(\theta_s, \delta_s)$ and $\mathcal{T}_s(\tau_s)$

Regulatory Games: Equilibria

Naive & Sticky

Two possibilities:

- Regulation implements first-best when

$$\gamma \geq 1 - \frac{\beta}{F}$$

- Otherwise, equilibrium features:
  - excessive regulation & arbitrage
  - sub-optimal productivity
  - **intuition:** # distortions > # instruments
- Sticky regime **underregulates** relative to naive ($\tau_s < \tau_n$)
  - implies $\theta_s > \theta_n$
  - $W_s > W_n$

Regulatory Games: Equilibria

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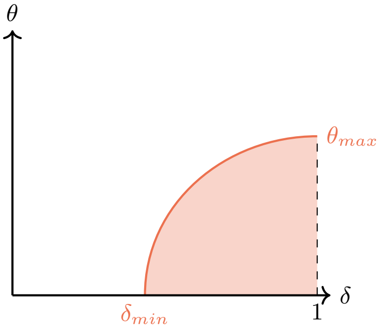
Technological Change



Two benchmarks:

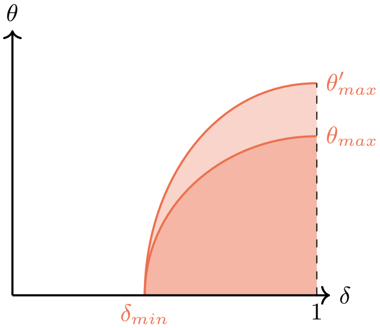
- Productivity enhancing:
  - $d\theta_{max} > 0$
  - $d\delta_{min} = 0$
- Arbitrage enhancing:
  - $d\theta_{max} = 0$
  - $d\delta_{min} < 0$

Proposition (Welfare effect of technical change)

When regulation can attain the first-best, technical change always (weakly) enhances welfare. Otherwise, technical change has the following effects:

- **productivity** enhancing tech change always **increases** welfare
- **arbitrage** enhancing tech change always **reduces** welfare

Technological Change



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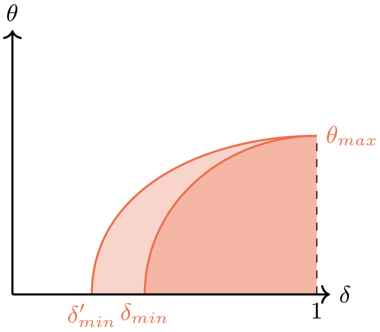

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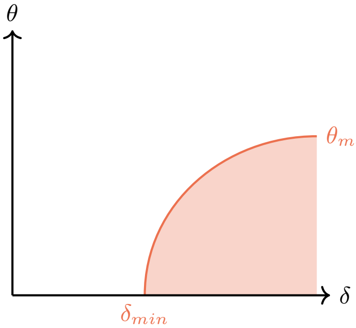

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Innovation & Regulatory Dynamics

Consider an infinite horizon economy...

- Preferences:

$$\sum_{t=0}^{\infty} \rho^t \left(\gamma \log y_t + z_t\right)$$

- Private good:

$$y_t = \theta_t \ell_t^y$$

- Public good:

$$z_t = \ell_t^z$$

- Aggregate resource constraint:

$$\ell_t^y + \ell_t^z \leq 1$$

- Direction of innovation is endogenous (next slide)

Innovation & Regulatory Dynamics

Innovation

An innovation is a technology bundle $\mathcal{T}_t = (\theta_t, \delta_t)$ satisfying:

- **Laws of motion:**

$$\theta_t = \eta_t \theta_{t-1}$$
$$\delta_t = \min\left\{1\,,\,\left(\frac{1+a}{\varphi_t}\right)\delta_{t-1}\right\}$$

  where $\eta_t, \varphi_t \geq 1$ are choice variables and $a \in [0,1]$.

- **Tech expansion frontier:**

$$g \geq \eta_t^{\varepsilon} + \beta \varphi_t^{\varepsilon}$$

- Regulatory loopholes are closed at exogenous rate $(1+a) > 1$

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Note: (θ, δ) are now state variables!

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First-Best Allocation

The planner solves:

$$\max_{\ell_t^y, \eta_t, \varphi_t} \sum_{t=0}^{\infty} \left(\gamma \sum_{j=0}^{t} \log(\eta_j \theta_0) + \gamma \log \ell_t^y + 1 - \ell_t^y \right) \quad \text{s.t.} \quad g \geq \eta_t^{\varepsilon} + \beta \varphi_t^{\varepsilon}$$

Solution:

- Labor allocation:

$$\ell_t^y = \gamma \qquad \ell_t^z = 1 - \gamma$$

- Max productivity growth:

$$\eta_{max} = (g - \beta)^{\frac{1}{\varepsilon}}$$

- No transition dynamics $\Rightarrow$ BGP for $t = 1, 2, \ldots$

Decentralized Innovation: Market Structure

Competitive fringe

- Employ vintage technology $\mathcal{T}_{t-1} = (\theta_{t-1}, \delta_{t-1})$
- Competitive price:

$$p_t^* = \frac{1}{\theta_{t-1}(1 - \delta_{t-1}\tau_t)}$$

Monopolist

- Chooses direction of innovation
- Limit pricing strategy $p_t = p_t^*$
- Sole producer in equilibrium $\Rightarrow$ earns monopoly rents

Decentralized Innovation: Market Structure

Price markup:

$$\mu_t = \left(\frac{\eta_t}{\varphi_t}\right)\left(\frac{\varphi_t - (1+a)\tau\delta_{t-1}}{1 - \tau\delta_{t-1}}\right)$$

- $+$ with productivity growth η_t
- $+$ with rate of arbitrage φ_t
- $+/-$ with regulation τ

Decentralized Innovation: Equilibrium

The monopolist solves:

$$\max_{\eta_t, \varphi_t} \left(\frac{\eta_t}{\varphi_t}\right) \left(\frac{\varphi_t - (1+a)\tau\delta_{t-1}}{1 - \tau\delta_{t-1}}\right) \qquad \text{s.t.} \quad g \geq \eta_t{}^{\varepsilon} + \beta\varphi_t{}^{\varepsilon}$$

for given τ and δ_{t-1}

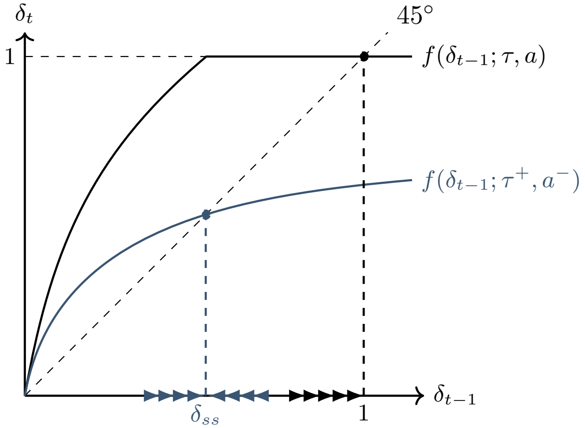
Rate of arbitrage

$$\varphi_t^* = \left[\frac{g(1+a)\tau\delta_{t-1}}{\beta}\right]^{\frac{1}{1+\varepsilon}}$$

Productivity growth

$$\eta_t^* = (g - \beta(\varphi_t^*)^{\varepsilon})^{\frac{1}{\varepsilon}}$$

Decentralized Innovation: Arbitrage Dynamics



BGP with perfect regulation ($\delta_{ss} = 1$)

BGP with persistent weak regulation ($\delta_{ss} < 1$)

$$\delta_t = min\left\{1\ ,\ \left(\frac{\beta}{\tau g}\right)^{\frac{1}{1+\varepsilon}}((1+a)\delta_{t-1})^{\frac{\varepsilon}{1+\varepsilon}}\right\}$$

Decentralized Innovation: Productivity Dynamics

Productivity θ_t converges to stable BGP

- **Case 1:** perfect regulation ($\delta_{ss} = 1$)
  - BGP: max productivity growth $\eta^{BGP} = \eta_{max}$
  - No transition dynamics
- **Case 2:** weak regulation ($\delta_{ss} < 1$)
  - BGP: low productivity growth $\eta^{BGP} < \eta_{max}$
  - $\eta_t \to \eta^{BGP}$ from below along transition path

Max productivity BGP obtains when:

$$\frac{\tau}{(1+a)^{\varepsilon}} \leq \frac{\beta}{g}$$

Optimal Regulation

$$\max_{\{\tau_t \in [0,1]\}_0^\infty} \sum_{t=0}^{\infty} \rho^t \left[\gamma \log \theta_t + \gamma \log (1 - \delta_t \tau_t) + \delta_t \tau_t\right]$$

subject to

- Implementability constraints $\eta^*(\tau_t, \delta_{t-1})$, $\varphi^*(\tau_t, \delta_{t-1})$
- Laws of motion (θ_t, δ_t)

Let $x_t = \tau_t \delta_t$. Solution pinned down by:

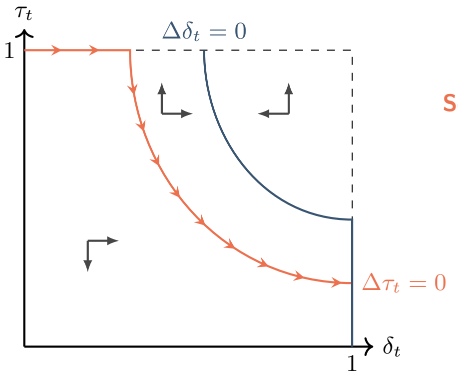
- FOC:

$$\gamma \frac{x_t}{1 - x_t} \left(1 + \varepsilon + \frac{1}{1-\rho}\right) - \varepsilon x_t = \rho \left[\gamma \frac{x_{t+1}}{1 - x_{t+1}} \left(1 + \varepsilon + \frac{1}{1-\rho}\right) - \varepsilon x_{t+1}\right]$$

- LoM for δ_t:

$$\delta_t = \min\left\{1\,,\, \xi x_t^{-\frac{1}{\varepsilon}} \delta_{t-1}\right\}$$

Optimal Regulation



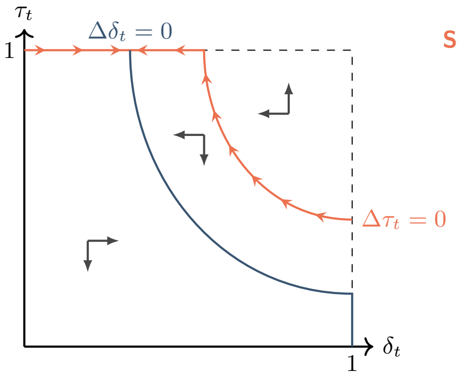
Solution:

- τ_0 jumps to **saddle path**
- target constant $\tau_t \delta_t = \tilde{x}$
- converge to BGP with η_{max}

Intuition:

- Smooth consumption of public good
- 2nd-best regulation: underregulate to ensure $\delta_t \to 1$
- 1st-best regulation: choose τ_t and innovation $\mathcal{T}_t$ directly

Optimal Regulation: Imperfect Regulation Trap



Solution:

- Converge to BGP with:
  - $\delta_{ss} < 1$
  - $\eta_{BGP} < \eta_{max}$
- Trap occurs when:

$$\tilde{x} \geq (1 + a) \left(\frac{\beta}{g} \right)^{\frac{1}{\varepsilon}}$$

Intuition:

- Socially desirable level of public good is not feasible
- Implies high regulation & high arbitrage

Conclusion

- Recent technological innovations may not be socially desirable
- Inherent difficulty of regulating new technologies
- Second-best regulation is plausible real world case
- Implies scope for direct steering of technological change