The Great Accretion And The Great Depression

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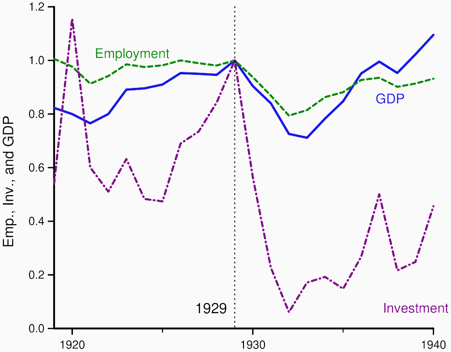
Introduction and Motivation

- **1920s**: Period of unprecedented prosperity (Roaring Twenties, **Great Accretion**).
  - Peak of the Second Industrial Revolution.
  - Electrification, diffusion of the automobile and the plane, the petrochemical industry, etc..
- This ended in **1929** with the onset of the **Great Depression**.
  - Blamed on bad monetary policy, stock market crashes, tariffs, etc.
  - These mechanisms sound more like *reaction to* and *propagation of* some earlier trigger.

Evidence - GDP, Employment and Investment

- Strong investment and GDP growth up to 1929.
- Flat (or mildly declining) employment during the 1920s.
- Massive crash during the Great Depression.
  - output down by 29%, employment by 18% in 1933.



Our Paper

Integrated theory of the 1920s and early '30s:

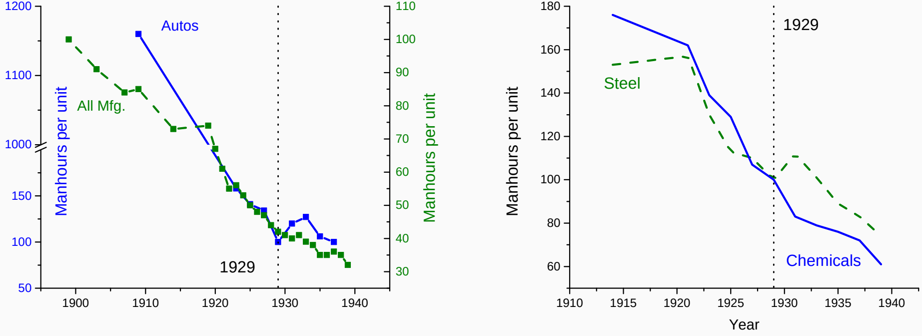
- **1920s**:
  - process innovation starts to far outpace product innovation.
  - expectation of continued product innovation and demand $\implies$ over-accumulation of capital.
- **1929**:
  - realization that product innovation has stalled $\implies$ satiation in demand.
  - continued process innovation $\implies$ lower demand for labor.

Research Question

Could the dynamics of the 1920s have *contributed* to causing the Great Depression?

Evidence - Process Innovation

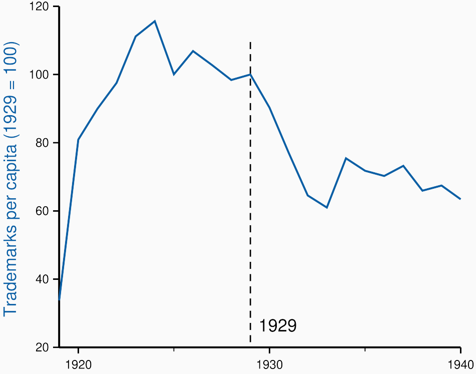
- Rapid decline in the number of manhours required to produce a car.
  - Electrification and the assembly line provide a huge boost.
- Trend common to all manufacturing and continuing up to 1929 and beyond.

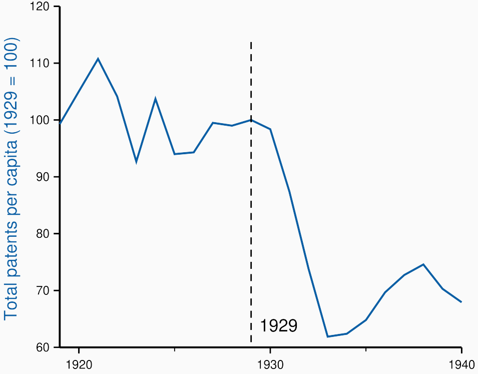


Evidence - Product Innovation

Full Series

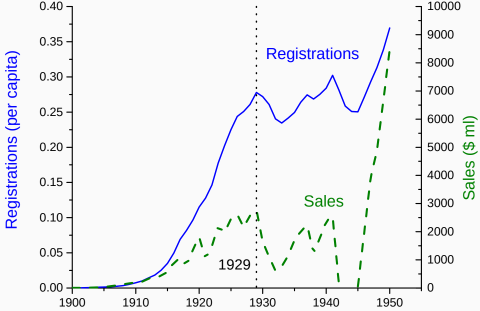
- Flow of new products (proxied by trademarks and patents) stalls around the mid-1920s.

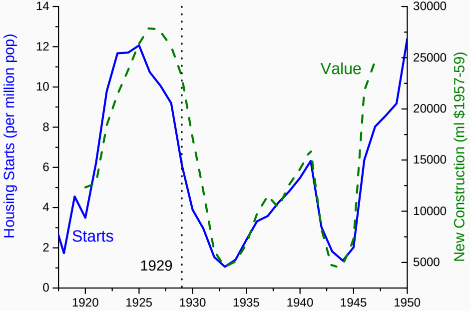




Evidence - Demand Saturation

- Demand for durables like autos and housing peaks during the late 1920s.





Model - Outline

- Modeled after *Yorukoglu [2000]*.
- On the surface, standard monopolistic competition.
- **Two sources of technological progress** (fully exogenous):
    - labor productivity growth (*process innovation*) $\Longrightarrow$ standard Neoclassical growth model;
    - expansion of varieties (*product innovation*) $\Longrightarrow$ à la *Romer [1990]*.
- **Key features** of the model:
    - *extensive margin*: upper bound on available number of varieties.
    - *intensive margin*: lower bound on consumption of each variety.

Model - Household

- Standard preferences with Dixit-Stiglitz aggregator and endogenous labor

$$U\left(\left\{\{c_{jt}\}_{j=0}^{N_t}, N_t, l_t\right\}_t\right) = \max_{\substack{c_{jt}\in\{0,[\mathfrak{c},\infty)\},\\ N_t\leqslant\mathfrak{N}_t}} \sum_{t=0}^{\infty}\beta^t\left[\alpha\log\left(\left(\int_0^{N_t} c_{jt}{}^{\theta}dj\right)^{\frac{1}{\theta}}\right) - (1-\alpha)\frac{l_t^{1+\chi}}{1+\chi}\right], \quad \theta<1,$$

with:

  - **minimum consumption level**: $c_{jt} \in \{0, [\mathfrak{c}, \infty)\}$
  - **upper bound on available varieties**: $N_t \leqslant \mathfrak{N}_t$

- Capital is the only means of saving:

$$\underbrace{\int_0^{N_t} p_{jt}c_{jt}di}_{\text{Consumption Expenditures}} + \underbrace{[k_{t+1}-(1-\delta)k_t]}_{\text{Savings}} = \underbrace{w_t l_t}_{\text{Labor Income}} + \underbrace{r_t k_t}_{\text{Capital Income}} + \underbrace{\Pi_t}_{\text{Profits}}.$$

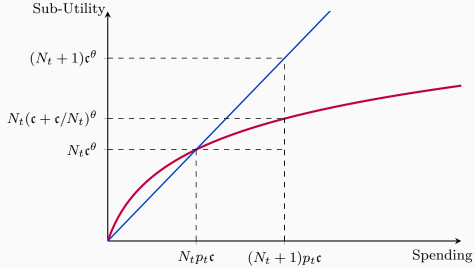
Model - Household's FOCs

- In a symmetric equilibrium ($c_{jt} = c_t$), the FOCs are

$$\left[\frac{\partial}{\partial N_t}\right]: \quad \frac{1}{\theta}\frac{\alpha}{N_t} \geqslant \lambda_t p_t c_t \qquad \text{(Extensive Margin)}$$

$$\left[\frac{\partial}{\partial c_t}\right]: \quad \frac{\alpha}{N_t} \leqslant \lambda_t p_t c_t \qquad \text{(Intensive Margin)}$$

- Since $\theta < 1$, both cannot hold at the same time with equality!



Model - Production Side

Two sectors:

- Intermediate good, produced under perfect competition, using capital and labor

$$m_t = k_t^{\gamma} \left(z_t l_t\right)^{1-\gamma}.$$

  Process innovation works through growth in TFP z_t.

- Final varieties, (*potentially*) produced under monopolistic competition to maximize

$$\underbrace{\pi_{jt}}_{\textbf{Profits}} = \max_{p_{jt}} \underbrace{D_{jt}\left(\mathbf{p}_t\right) p_{jt}}_{\textbf{Total Revenue}} - \underbrace{m_{jt}}_{\textbf{Production Costs}} \qquad \text{sub. to } \; o_{jt} = m_{jt}$$

$\Longrightarrow$ Intensive margin ($c > \mathfrak{c}$, $N = \mathfrak{N}$) $\Longrightarrow$ standard mark-up rule for price ($p = 1/\theta = 1$).

$\Longrightarrow$ Extensive margin ($c = \mathfrak{c}$, $N < \mathfrak{N}$) $\Longrightarrow$ varieties are perfect substitute $\Longrightarrow$ perfect competition ($p = 1$).

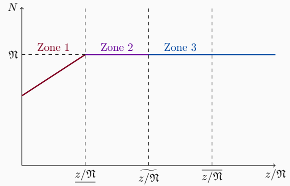
  - **Note**: intermediate (not knife-edge) case, where both constraints bind $\Longrightarrow$ market power ($p > 1$).

- Market clearing: $$m_t = \int_0^{\mathfrak{N}_t} m_{jt} dj + \left(k_{t+1} - (1-\delta) k_t\right)$$

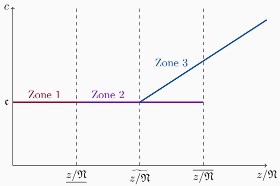
Model - Consumption Zones

Zone 1 Zone 2 Zone 3

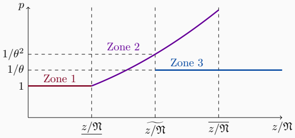
The equilibrium can be summarized into three zones of consumption: **extensive margin** (Zone 1), **shackled margins** (Zone 2), and **intensive margin** (Zone 3).



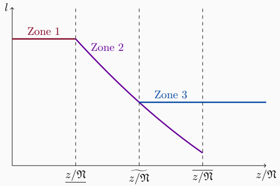
(a) Extensive margin



(b) Intensive margin



(c) Price



(d) Employment

Model - Balanced Growth Path

Let $\mathbf{g}_z$ denote the growth rate of productivity, $\mathbf{g}_{\mathfrak{N}}$ the growth rate of available varieties.

Result

- ***Zone 1 (Extensive Margin)*** If $g_{\mathfrak{N}} \geqslant g_z \geqslant 1$, there exists a BGP where all aggregate variables grow at rate g_z, $c_t = \mathfrak{c}$, and $N_t \leqslant \mathfrak{N}_t$.
- ***Zone 2 (Shackled Margins)*** If $g_{\mathfrak{N}} = g_z \geqslant 1$, there exists a BGP where all aggregate variables grow at rate g_z, $c_t = \mathfrak{c}$, and $N_t = \mathfrak{N}_t$.
- ***Zone 3 (Intensive Margin)*** If $g_z \geqslant g_{\mathfrak{N}} \geqslant 1$, there exists a BGP where all aggregate variables grow at rate g_z, $c_t \geqslant \mathfrak{c}$ grows at rate $g_z/g_{\mathfrak{N}}$, and $N_t = \mathfrak{N}_t$.

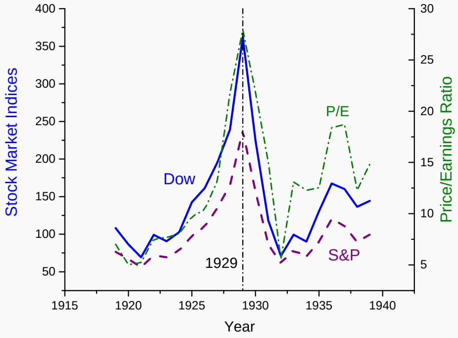
Note: zone 2 BGP is knife-edge in growth rates, **not** in the level of $z/\mathfrak{N}$.

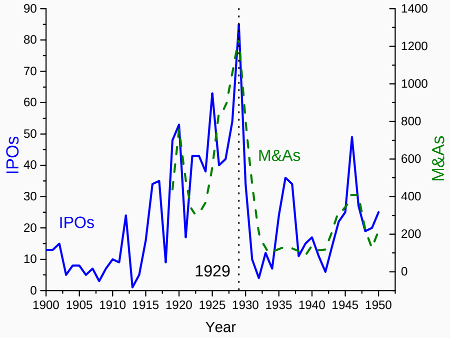
- Along a transition path (e.g, Zone 1 $\rightarrow$ Zone 3), the economy spends time in Zone 2.

Evidence - Business Optimism

How did investors react to the apparent slowdown in product innovation during the ’20s?

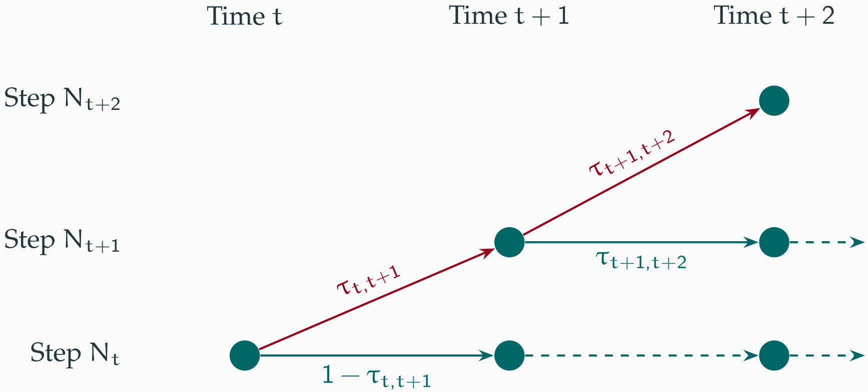
- Huge run-up in stock market until 1929.
  - We can think of it as a proxy for people’s expectations about future growth.
- IPOs and M&As paint a similar picture.





Rational Exuberance

- Inspired by *Zeira [1999]*.
- At any date t, agents attach some probability to further product innovation in the future ($\tau_{t,t+j}$), and some to a stall ($1 - \tau_{t,t+j}$).



Simulation - Rational Exuberance

Formally:

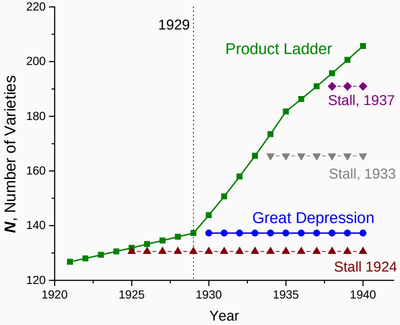
- At any date $t \leqslant T$,
  - product innovation can continue on diagonal path $\{\mathfrak{N}_t^{\uparrow}\}_{t=1}^{T}$.
  - product innovation can stop permanently (**the crash**): stall path $\{\mathfrak{N}_{\bar{t}-1}^{\rightarrow}\}_{t=1}^{T}$.
- $\boldsymbol{\tau_{t,t+1}}$: belief that a move up to N_{t+1} in period $t+1$ will occur.
- $\boldsymbol{\pi_{t,T}^{t} = \prod_{i=1}^{T-t} \tau_{t+i-1,t+i}} < 1$: belief that a stall will not occur (with 1 for $t > T$).

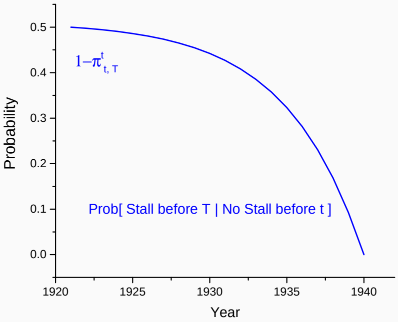
$\implies$ Every time the economy climbs one step, agents grow more optimistic of climbing the entire ladder.

Simulation - Rational Exuberance

- Under diagonal path $\{\mathfrak{N}_t^{\uparrow}\}_{t=1}^{T}$:
  - Slow growth between 1921 and 1929 ($0 < g_{\mathfrak{N}} < g_z$).
  - Strong growth after 1929 to catch up with process gains and converge to zone 1 BGP.
- The economy crashes between 1929 and 1930.

Justification | Simulation Parameters





Simulation - Euler Equation

The rational expectations Euler equation reads

Detailed Algorithm

$$\underbrace{\lambda_t^{\uparrow}}_{\textbf{MC}} = \underbrace{\beta\tau_{t,t+1}\lambda_{t+1}^{\uparrow}\left[\gamma k_{t+1}^{\gamma-1}\left(z_{t+1}l_{t+1}^{\uparrow}\right)^{1-\gamma} + (1-\delta)\right]}_{MB_k^{\uparrow}\text{: Increase in varieties } (\mathfrak{N}_{t+1} > \mathfrak{N}_t)} +$$

$$\underbrace{\beta\left(1-\tau_{t,t+1}\right)\lambda_{t+1}^{\rightarrow}\left[\gamma k_{t+1}^{\gamma-1}\left(z_{t+1}l_{t+1}^{\rightarrow}\right)^{1-\gamma} + (1-\delta)\right]}_{MB_k^{\rightarrow}\text{: Permanent stall in varieties } (\mathfrak{N}_{t+1} = \mathfrak{N}_t)}$$

Mechanism fueling **over-accumulation of capital**:

- Expectation of future product innovation ($\mathfrak{N}\uparrow$) $\implies$ relative productivity $z/\mathfrak{N}\downarrow$

$\implies$ consumption along the extensive margin (Zone 1) more likely

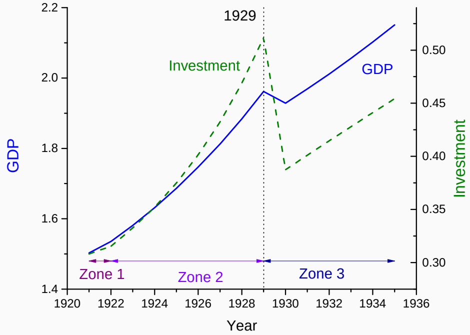
$\implies$ higher marginal utility of consumption ($\mathbb{E}[\lambda_{t+1}]\uparrow$) $\implies$ higher investment ($k_{t+1}\uparrow$)

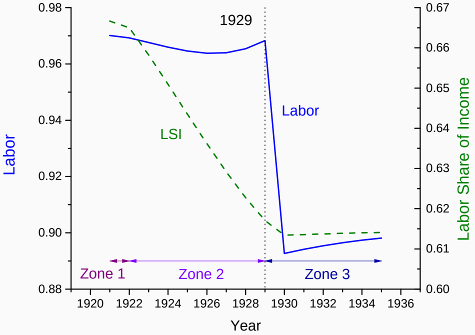
Simulation - Rational Exuberance: Results

- **1920s**: slow product innovation $\mathfrak{N} \uparrow$ + sustained process innovation ($z/\mathfrak{N} \downarrow$)

$\Longrightarrow$ increased optimism wrt future product innovation $\Longrightarrow$ GDP and investment boom.

$\Longrightarrow$ low demand growth and high TFP $\Longrightarrow$ steady employment and falling labor share.



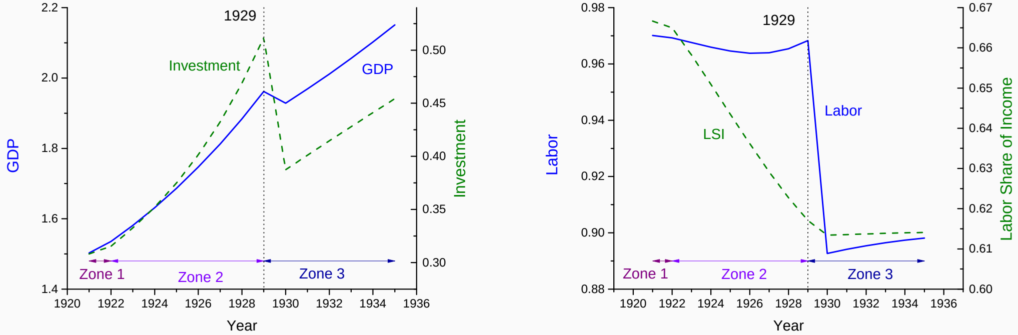


Simulation - Rational Exuberance: Results

- **Post-1929**: no product innovation $\mathfrak{N}$ + fast (relative) process innovation ($z/\mathfrak{N} \downarrow\downarrow$)

  $\Longrightarrow$ too much capital given marginal utility $\Longrightarrow$ GDP and investment crash.

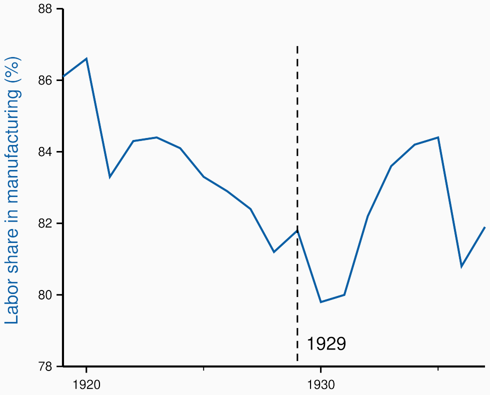
  $\Longrightarrow$ very low marginal utility (stuck in Zone 3) $\Longrightarrow$ large crash in employment.



Evidence - Labor Share in the Data

- The model has a strong prediction of falling labor share during the 1920s (Zone 2).
  - Constrained output ($C = \mathfrak{N}\mathfrak{c}$) $\implies$ as TFP $z \uparrow$, then labor demand $\mathfrak{l} \downarrow$.
- Historical evidence confirms this prediction.

Profit Share



Simulation - Rational Exuberance with Adjustment Costs

- Frictionless reallocation of the intermediate good $\Longrightarrow$ relatively small GDP crash.
- **Q.** Can the model generate a Great Depression-sized crash?
- After a crash at time τ, **add**:
  - **internal adjustment costs**: costly reallocation of intermediate good between varieties:

$$A\left(o_{i,\tau}\right)=\frac{\phi}{\kappa}\left(\frac{o_{i,\tau}^{exp}}{1-\eta}-o_{i,\tau}\right)^{-\kappa},$$

    where $o_{i,\tau}^{exp}=D\left(\mathbf{p}^{exp}\right)$ was expected demand for period $t=\tau$ at $t-1$.
  - **external adjustment costs**, on aggregate TFP:

$$z_{\tau}=\frac{g_z z_{\tau-1}}{\left(\mathbf{o}_{\tau}^{exp}/\mathbf{o}_{\tau}\right)^{\omega}}, \qquad \textbf{(Impact Effect)}$$

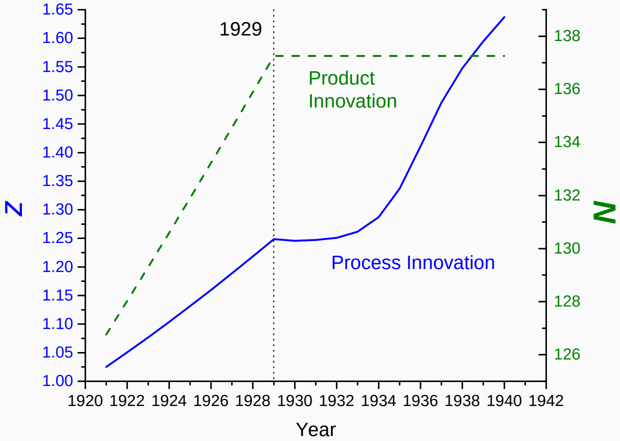
    and

$$z_{t+1}=g_z^{t-\tau}z_{\tau}^{exp}+\underbrace{\frac{1}{1+e^{\rho((t-\tau)-\bar{t})}}}_{\textbf{Logistic Persistence Parameter}}\left(z_t-g_z^{t-\tau}z_{\tau}^{exp}\right), \quad t>\tau. \qquad \textbf{(Propagation)}$$

Simulation - Rational Exuberance with Adjustment Costs

- The crash happens in 1929.

$\Longrightarrow$ no product innovation + persistent slowdown in TFP growth.

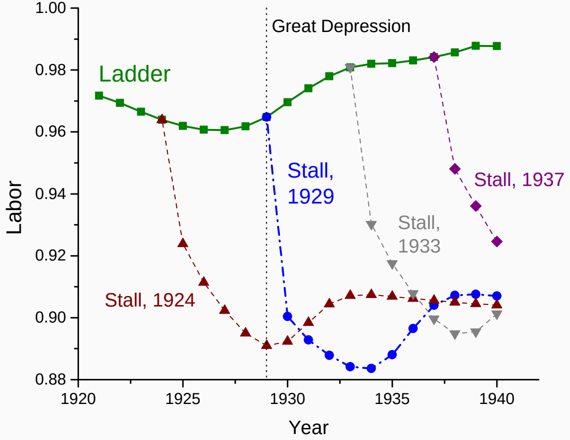


Simulation - Rational Exuberance with Adjustment Costs

- Agents foresee that a stall can happen at any possible date along the ladder.

$\Longrightarrow$ Perfect foresight after a crash.

  - Realized one happen in 1929.

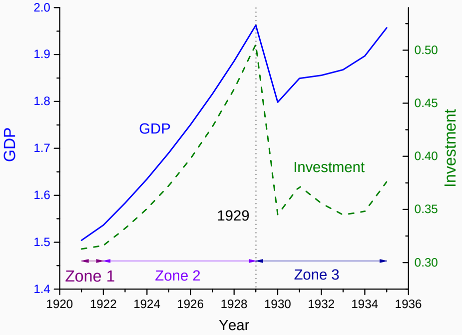


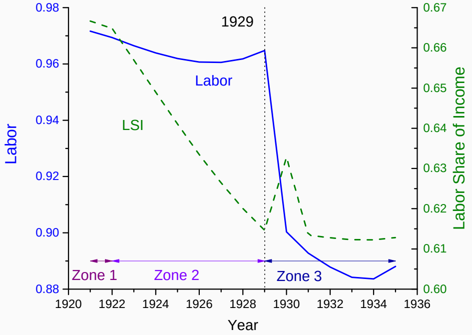
Simulation - Rational Exuberance with Adjustment Costs

- **Post-1929**: permanent stall in product innovation $\mathfrak{N}$ + fast process innovation ($z/\mathfrak{N}\downarrow$)

$\Longrightarrow$ costly reallocation of intermediate good allocated to expected varieties + TFP crash

$\Longrightarrow$ large and persistent drop in GDP ($\sim$ to actual Great Depression)





Conclusions

Main **hypothesis**:

- Product innovation slowed down during the ’20s, leading to **demand saturation**.
- Persistent expectation of new products fueled **capital over-accumulation**.
- Unfulfilled belief led to sudden correction and **crash**, worsened by process innovation.

Model:

- Incorporates process and product innovation.
- Shows the mechanism can generate a 1929-sized crash.

Thank you!

Find the full paper at www.stefanocravero.com

References

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Model - Zone 1: Perfect Competition

Back

Zone 1 (*Extensive Margin*):

$$\left[\frac{\partial}{\partial N_t}\right]: \quad \frac{1}{\theta}\frac{\alpha}{\mathbf{N_t}} = \lambda_t p_t \mathfrak{c} \qquad \text{(Interior, Extensive Margin)}$$

$$\left[\frac{\partial}{\partial c_t}\right]: \quad \frac{\alpha}{\mathbf{N_t}} < \lambda_t p_t \mathfrak{c} \qquad \text{(Corner, Intensive Margin)}$$

- consumption is at the lower bound for all varieties that get consumed:

$$c = \mathfrak{c}, N \leqslant \mathfrak{N};$$

- goods are perfect substitutes and the agent consumes a random subset;
- final good producers are **perfectly competitive**, hence $p = 1$.

Graph Labor Condition

Model - Zone 2: Inelastic Demand

Back

Zone 2 (*Shackled Margins*) :

$$\left[\frac{\partial}{\partial N_t}\right]: \quad \frac{1}{\theta}\frac{\alpha}{\mathfrak{N}} = \lambda_t \mathbf{p_t} \mathfrak{c} \qquad \text{(Interior, Extensive Margin)}$$

$$\left[\frac{\partial}{\partial c_t}\right]: \quad \frac{\alpha}{\mathfrak{N}} < \lambda_t \mathbf{p_t} \mathfrak{c} \qquad \text{(Corner, Intensive Margin)}$$

- household consumes all varieties at the lower bound: final output is pinned down

$$N = \mathfrak{N}, c = \mathfrak{c};$$

- at $p = 1$, $\partial/\partial N > 0$ and the upper bound on varieties binds;
- the agent is willing to pay a higher price for each good:

Graph Labor Condition

$$p = \frac{\text{marginal utility of an extra variety}}{\text{marginal utility of income}} > 1$$

Model - Zone 3: Monopolistic Competition

Back

Zone 3 (*Intensive Margin*):

$$\left[\frac{\partial}{\partial N_t}\right]: \quad \frac{1}{\theta}\frac{\alpha}{\mathfrak{N}} > \lambda_t p_t c_t \qquad \text{(Corner, Extensive Margin)}$$

$$\left[\frac{\partial}{\partial c_t}\right]: \quad \frac{\alpha}{\mathfrak{N}} = \lambda_t p_t c_t \qquad \text{(\textbf{Interior, Intensive Margin})}$$

- household consumes all the varieties:

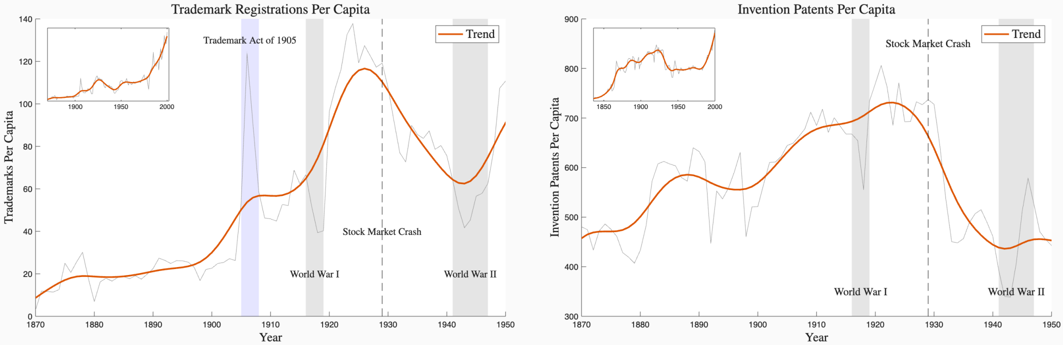
$$N = \mathfrak{N}, c \geqslant \mathfrak{c};$$

- final good producers are **monopolists** and charge fixed mark-up:

$$p = 1/\theta.$$

Graph Labor Condition

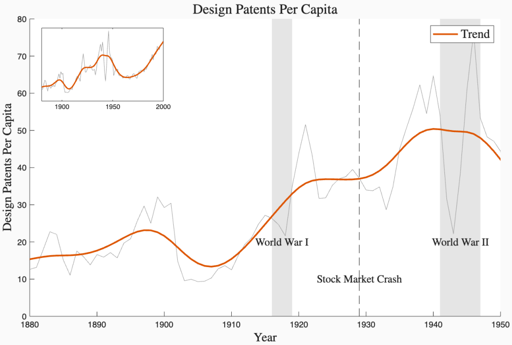
More on Product Innovation (1/2)

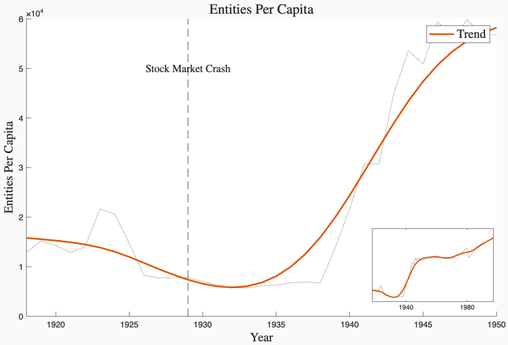


Design Patents (*left*) and Entities (*right*). Source: *Historical Statistics* (2006).

More on Product Innovation (2/2)

Back

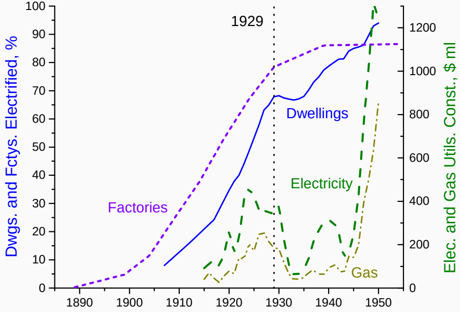


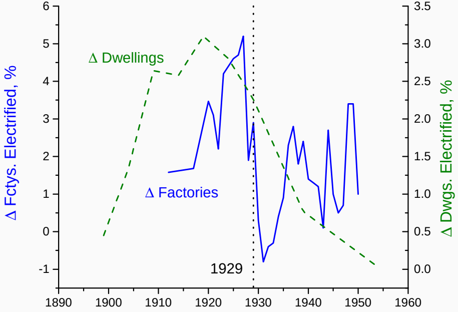


Design Patents (*left*) and Entities (*right*). Source: *Historical Statistics* (2006).

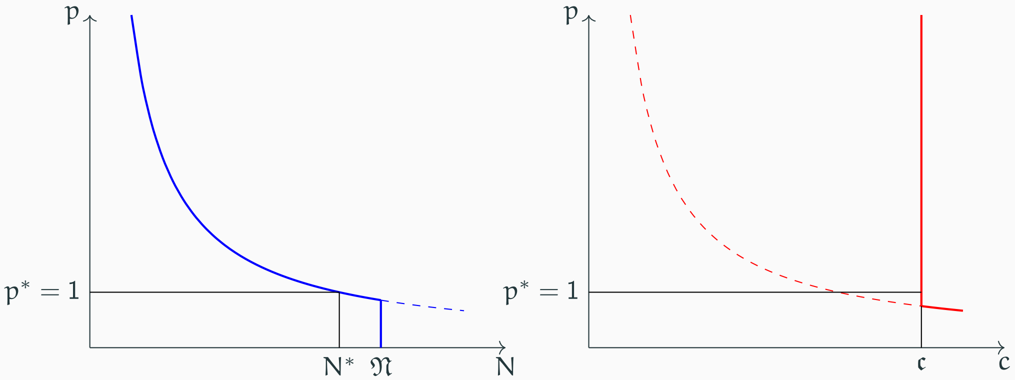
More on Satiation - Electrification

Back



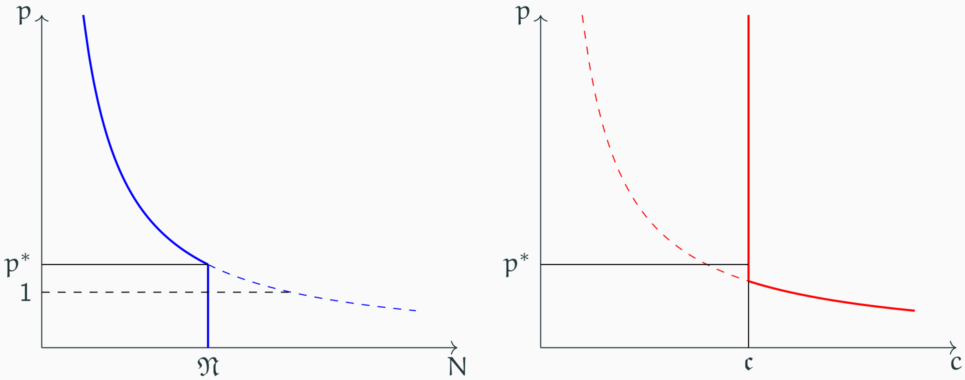


Model - Graphical Representation of Zone 1



Model - Graphical Representation of Zone 2

Back

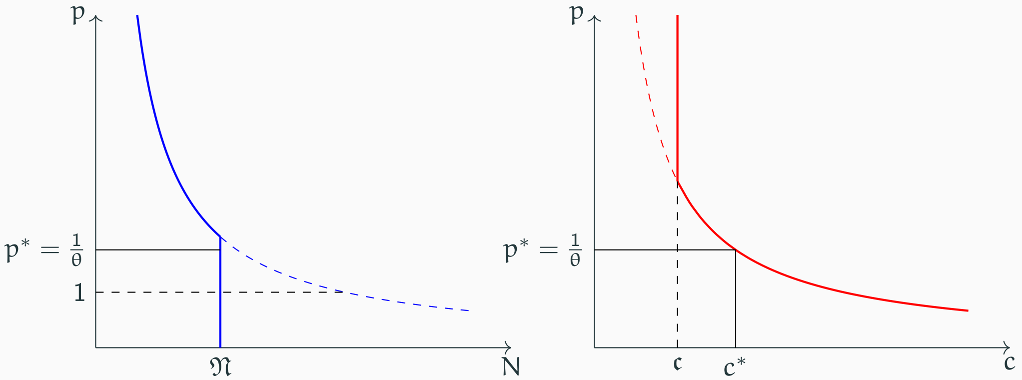


Model - Graphical Representation of Zone 3

Back

When does the economy switch to zone 3?

- If at $p = \frac{1}{\theta}$, household maximization implies $N^* = \mathfrak{N}$ and $c^* > \mathfrak{c}$.



Model - Labor Conditions

Back

- **Zone 1 and 2**:

$$\left[\frac{\partial}{\partial l_t}\right]: \quad \frac{\alpha}{\theta}\frac{1}{N_t \mathfrak{c}}\frac{w_t}{p_t} \;=\; (1-\alpha) l_t^{\chi}$$

  - Since $p_t^{Z2} > p_t^{Z1} = 1$, labor supply will be lower in zone 2 than in zone 1, *ceteris paribus*.

- **Zone 3**:

$$\left[\frac{\partial}{\partial l_t}\right]: \quad \alpha \frac{1}{\mathfrak{N}_t c_t}\frac{w_t}{1/\theta} \;=\; (1-\alpha) l_t^{\chi}$$

  - Since $\theta < 1$ (lower marginal utility of consumption), labor supply will be lower in zone 3 than in zone 1, *ceteris paribus*.
  - The relationship between zone 2 and 3 is ambiguous (at the switching point):
    - lower marginal utility of consumption in zone 3;
    - potentially higher real wage.

Intuition for Transition

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- Process innovation goes on throught the entire transition path.
- This makes agents **more optimistic** about innovation in general.
- Agents progressively **revise down the belief of a stall** as the economy moves up along the diagonal.

Solution Algorithm

- Solution algorithm: **nested multiple shooting**.
  - T **deterministic** stall paths $\Longrightarrow$ find $\{MB_k^{\rightarrow}\}_{t=1}^{T}$ given $\{k_{t+1}\}_{t=1}^{T}$.
  - **stochastic path** $\Longrightarrow$ find $\{k_{t+1}\}_{t=1}^{T}$ given initial condition k_0 and $\{MB_k^{\rightarrow}\}_{t=1}^{T}$.
- Terminal conditions:
  - Rebound path converges to a zone 1 BGP ($g_{\mathfrak{N}} \geqslant g_z$).
  - Stall paths converge to a zone 3 BGP ($0 = g_{\mathfrak{N}} < g_z$)

Solution Algorithm - Detailed Description

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Rewrite the Euler equation as

$$MC_t^{\uparrow}\left(k_t^{\uparrow}, k_{t+1}^{\uparrow}\right) = \beta\left(1-\phi_{t+1}^{t+1}\right) MB_{t+1}^{\uparrow}\left(k_{t+1}^{\uparrow}, k_{t+2}^{\uparrow}\right) + \beta\phi_{t+1}^{t+1} MB_{t+1}^{\rightarrow}\left(k_{t+1}^{\uparrow}, K_{t+1}^{\rightarrow}\left(k_{t+1}^{\uparrow}\right)\right), \quad (1)$$

a second-order difference equation in $k_t^{\uparrow}$, $k_{t+1}^{\uparrow}$, and $k_{t+2}^{\uparrow}$.

Algorithm:

0. Let the initial condition be $\bar{k}_0$ and the terminal ones be $\bar{k}_T^{\uparrow} = k_T^{BGP1}$ and $\bar{k}_T^{\rightarrow} = k_T^{BGP3}$.

1. Guess value $k_1^{\uparrow}$ and:

   1.1 solve for $\{k_{\tau+2}^{\rightarrow}\}_{\tau=t}^{T-2}$ through multiple shooting iterating forward the second-order difference equation

   $$MC_{t+1}^{\rightarrow}\left(k_{t+1}^{\rightarrow}, k_{t+2}^{\rightarrow}\right) = \beta MB_{t+2}^{\rightarrow}\left(k_{t+2}^{\rightarrow}, k_{t+3}^{\rightarrow}\right),$$

   given initial condition $k_1^{\uparrow}$ and terminal condition k_T^{BGP3}.

   1.2 solve for $\left\{k_{t+2}^{\uparrow}\right\}_{t+0}^{T-2}$, using (1) and $K_{t+1}^{\rightarrow}\left(k_{t+1}^{\uparrow}\right)$.

2. Check for convergence ($k_T^{\uparrow} - k_T^{BGP1} < \epsilon$), otherwise update guess $k_1^{\uparrow}$ and restart from step 1.

Simulation - Parameter Values

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Table 1: Parameter Values

Parameter	Value	Basis
	Preferences	
α	0.5	$\approx$ 75% consumption share
θ	0.9	$\approx$ 11% mark-up rate
χ	1.33	Chetty et al. [2011]
β	0.96	Standard
	Technology	
γ	1/3	Standard
δ	0.08	Standard
	Technological Progress	
g_z	1.025	GDP growth rate 1921–1929
$g_{\mathfrak{N}}^{1921-1929}$	1.01	
	Adjustment Costs	
ϕ	2×10^{-6}	GDP decline 1929–1930
κ	5×10^{-3}	
ω	0.9	

Profit Share

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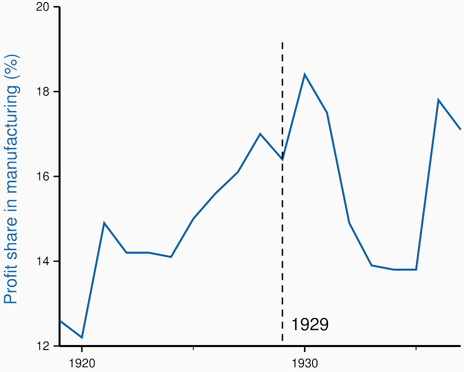
- The model predicts a rising profit share over the 1920s (Zone 2).
  - As upper bound on varieties ($\mathfrak{N}$) starts to bind, producers gain market power.
  - Historical evidence confirm this prediction.



Profit share computed as entrepreneurial income plus dividend income.