Evolution of industrial heuristics: costly innovators versus cheap imitators

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Outline

- Introduction
- Theoretical framework
- A preliminary model: costly innovative versus cheap sluggish firms (innovation as costs reduction).
- The benchmark model: introducing imitation as an externality (innovation as costs reduction).
- An extended model: innovation that also affects demand (innovation as costs reduction and product differentiation).
Main references and questions

1. Innovation and imitation as routines or heuristics (Schumpeter 1942; Nelson and Winter, 1982; Dosi, 1988).
2. Conlisk’s costly optimizers and cheap imitators (1980).
4. Technology is a non-rival partially excludable good (Romer, 1990).
5. The discrete choice model (Brock and Hommes, 1997).

- What are the dynamic effects of innovation and imitation?
- Are there stable equilibria where innovators and imitators coexist?
- How can one type be driven out of the market?
- Is the dynamics with product differentiation substantially different from costs reduction? Is economic coherence always preserved?
Assumptions and definitions

- An industry with \( N \gg 1 \) firms (price takers) offering the same good. Fraction \( n_{\text{INN}} = \frac{N_{\text{INN}}}{N} \) innovate, \( n_{\text{IM}} = 1 - n_{\text{INN}} \) imitate.
- If innovate, produce \( S_{t}^{\text{INN}}(p_t) \). If imitate, produce \( S_{t}^{\text{IM}}(p_t) \).
- Total supply: a weighted average of the two types’ contributions:

\[
S(p) = n_{t}^{\text{INN}} S_{t}^{\text{INN}}(p_t) + n_{t}^{\text{IM}} S_{t}^{\text{IM}}(p_t)
\]

- Discard effects of technological advance: focus on the relative effects of innovation and imitation interplay and relative changes of price.
- Production costs are \( c(q) = \frac{q^2}{2s} \Rightarrow S_{t}^{h}(p_t) = s^{h} p_t \) (linear supply).
- Innovation gives access to \( s = s_{\text{INN}} \) for one period, at a cost \( C \). Imitation gives \( s = s_{\text{IM}} \) with \( s_{\text{INN}} > s_{\text{IM}} \), but it is free.
- Discard uncertainty of innovation investment.
The discrete choice mechanism

- Demand is linear and homogeneous, $D(p) = a - dp$, with $p$ the price.
- At time $t$ the market clears in a Walrasian equilibrium:
  \[ a - dp_t = n_t^{\text{INN}} s^{\text{INN}} p_t + n_t^{\text{IM}} s^{\text{IM}} p_t \]

How agents chose whether to innovate or imitate? Bounded rationality of choices (Brock and Hommes, 1997), based on past experience:

\[ n_t^{\text{INN}} = \frac{e^{\beta \pi_t^{\text{INN}}}}{e^{\beta \pi_{t-1}^{\text{INN}}} + e^{\beta \pi_{t-1}^{\text{IM}}}} = \frac{1}{1 + e^{-\beta \Delta \pi_{t-1}}} \]

The difference of profits $\Delta \pi_t = \pi_t^{\text{INN}} - \pi_t^{\text{IM}}$ is a fitness measure.

\[ \pi_t^{\text{INN}} = \frac{1}{2} s^{\text{INN}} p_t^2 - C, \quad \pi_t^{\text{IM}} = \frac{1}{2} s^{\text{IM}} p_t^2 \]

The intensity of choice $\beta$ measures the degree of rationality.
Costly innovators versus cheap sluggish firms

Innovators get \( s^{INN} = se^{bC} \), imitators get \( s^{IM} = s \), where \( b > 0 \) is the benefit of innovation. If all innovate price attains a minimum \( p^{*}_{INN} \), if all imitate price is maximum \( p^{*}_{IM} \). Example: \( s = 1 \) and \( e^{bC} = 3 \).
Two examples

Innovators’ fraction time series (first with $\beta = 2$, second with $\beta = 2.4$).

Why cyclical dynamics? Like a minority game: if $n^{INN} \uparrow$ then $p \downarrow$. But then $\pi^{INN} \downarrow$ as well. Because of $C$, at some point $\pi^{INN} < \pi^{IM}$. Then firms start choosing imitation. And $p \uparrow$ again, and the story repeats.

(Cars Hommes and Paolo Zeppini)
Long run analysis, bifurcation diagrams

Long run value of $n_t^{INN}$ (after 300 periods): changing $\beta$ (first) and changing $b$ (second).

Notice: with increasing $b$, the innovators’ fraction initially grows, then gets cyclical, then falls. This is a result of the double effect of innovation: it increases innovators’ profits and lowers the price.

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Adding imitation externality

1. Imitators enjoy innovation outcome $s^{\text{INN}}$ up to a factor $\mu \in [0, 1]$.
2. Imitation works better the more innovators around: $s^{\text{IM}} = \mu n^{\text{INN}} s^{\text{INN}}$.

Market equilibrium: $a - dp_t = n_t^{\text{INN}} se^{bC} p_t + (1 - n_t^{\text{INN}}) \mu n_t^{\text{INN}} se^{bC} p_t$. 

(Cars Hommes and Paolo Zeppini)
The effect of replicability

Long run value of $n^{INN}$ with changing $\beta$ for $\mu = 0.7$ (only period doubling) and for $\mu = 0.27$ (period doubling and period halving).

If $\mu$ is low enough the SS returns stable for large values of $\beta$. A larger $\mu$ makes the instability region larger. Imitation is destabilizing.
Memory to capture persistence

Fitness is a weighted sum of all past profits: $U_t^h = wU_{t-1}^h + (1 - w)\pi_t^h$ (before $w = 0$). Examples of long run values and time series ($w = 0.5$):

Irregular behaviour for large sets of parameters values. Firms can show prevalence of innovating behaviour with irregular jumps to imitation.
Product differentiation beside costs reduction

Innovation reduces substitutability $\sigma_t = \sigma(1 - n_t^{INN})$, demand rotates:

$$\frac{a - dP_t}{1 + \sigma(1 - n_t^{INN})} = n_t^{INN} se^{bC} p_t + (1 - n_t^{INN}) \mu n_t^{INN} s p_t$$
Irregular dynamics in the industry

Price and types’ fraction may not converge to stable equilibria or cycles. Examples: time series of $n^{INN}$ for $\sigma = 20$. Bifurcation diagram wrt $\beta$.

On the left example: prevalence of imitation with jumps to innovation.
The supply effect and the demand effect of innovation

Long run value of innovators’ fraction $n^{\text{INN}}$ and price $p$ with changing $\mu$.

The demand effect may outweigh the supply effect, as here: average price goes down with increased replicability, but also innovators’ fraction goes down on average. Innovation does not drive $p$ down anymore.
Conclusions

A theoretical model of the endogenous dynamics of demand and supply due to the interplay between innovators and imitators.

- **Innovation as costs reduction:**
  - double effect on innovation profits: one direct effect and a price effect
  - innovation benefits may have a negative effect on number of innovators
  - imitation is destabilizing
  - coherent dynamics unless we introduce memory.

- **Innovation as costs reduction and product differentiation:**
  - the supply effect vs the demand effect
  - the total effect of innovation on price is not univocal
  - coherence is lost, irregular behaviour even without memory.