INNOVATION AND THE EVOLUTION OF INDUSTRIES: HISTORY-FRIENDLY MODELS

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Why history friendly models?
Characteristics of these models
The models developed so far
What we have learned
VARIETY IN THE EVOLUTION OF INDUSTRIES

From the empirical cases and the historical analyses of semiconductors, computers, pharmaceuticals, aircraft, chemicals, textiles, and so many other industries it is evident that:

- the evolution of industries presents a wide variety of patterns
- a rich set of factors can be identified: various types of capabilities, innovative users, vertical and horizontal boundaries of firms, actors such as universities or government, specific institutions, and so on.
CAN EXISTING MODELS ADDRESS EXAMINE THESE EVOLUTIONS?

NO

A. Evolutionary models à la Nelson–Winter 1982

These models have microeconomic learning processes; selection with heterogeneous population of firms; de-strategising conjectures; processes of experimentation and imperfect trial and error

Nelson and Winter, 1982; Dosi, Kaniovski and Winter, 1999

Recognition of some stylized facts and development of an evolutionary model able to reproduce those phenomena (i.e. the relationship between innovation and concentration; diffusion curves)

Very abstract models.

Focus on some generic basic properties of industrial structure and dynamics
B. Industry life cycle models

They mainly focus on the relationship between product and process innovation, entry and firm growth, exit, industrial concentration.

Basic model of industry life cycle derived from the evidence of the auto industry (Klepper, 1996)

Different industry life cycles and divergence from the standard model due to factors such as the characteristics of demand, technological discontinuities, the type of competition and innovation, pre-entry experience and first mover advantages, as in several models by Klepper and associates.
HOW TO MODEL

a) THE EVOLUTION OF DIFFERENT INDUSTRIES
b) THE VARIETY OF FACTORS AFFECTING EVOLUTION?

- In sum, except for some versions of the standard industry life cycle model, there are no models which focus on the evolution of industries and on the factors that have been identified and examined by historical analyses and case studies.

- This has been the initial original motivation for the development of history-friendly models (HFM).
The first HFM was published in 1999 (ICC, 1999)

A book on HFM by Malerba, Nelson, Orsenigo and Winter is on its way (CUP, 2014)

Here I want to present the motivation of these models, the broad features, the building steps, the main blocks, what we have learned so far and the road ahead, and finally present an example of a HFM
WHAT ARE HFMs?

- HFMs are agent based simulation models which aim to capture in stylised form qualitative theories about mechanisms and factors affecting innovation and industry evolution.

- These mechanisms and factors are put forth by empirical research in industrial organization, business strategy and organization and by the histories of industries.

- They aim at establishing a link between empirical evidence, developing stand alone simulation models and formal theory.

- HFMs aim to explore whether particular mechanisms and forces built into the model can generate (explain) the patterns examined.

- HFMs are guided by verbal explanations and appreciative theorizing.
THE MAIN FEATURES OF HFM

- HFM are evolutionary models: firms are boundedly rational agents; their behavior is guided by routines; learning is a key process; heterogeneity of agents and capabilities characterizes the industry.

- These models aim to analyze factors affecting the (short-run and long-run) dynamics of technology, innovation, market structure, industry architecture and industrial leadership.

- HFM are complex dynamic stochastic systems.

- Non linearities are present.

- Bottom up perspective: aggregate properties are emergent out of the repeated interaction among agents.
THE STEPS IN HFM

- Study of the characteristics of the phenomenon under examination (innovation, evolution of the industry...). Identification of the main features to be analyzed and of the appreciative explanatory model, and consequently also of the hypotheses to be examined and tested.

- Development of the model. Translation of the theoretical structure into the programming language (variables, methods and algorithm) of the model. Repeated process of internal verification of the correctedness of the computer implementation, and balance between accuracy of the model and explanatory power.

- Runs, calibration, analysis of the results and sensitivity analysis

Good surveys are Garavaglia, 2009 and Yoon 2009
It is not the purpose of history-friendly modeling to produce simulations that closely match the quantitative values observed in the histories under investigation.

The goal is to match overall patterns in qualitative features, in particular the trend behaviour of the key descriptors of industry structure and performance of a sector.

In a sense, HFMs represent also an abstraction from the specific motivating historical episode.

The goal is to feature some particular causal mechanisms that have been proposed by the appreciative theories for the empirical phenomena under examination.

So, HFMs do not attempt detailed quantitative matching to historical data, nor detailed calibration of the parameters.
There is some common sense guidance and some basic learning from the case studies in the choice of the plausible orders of magnitude of the parameters.

Moreover some of the dimensions known as relevant are not easily measurable, for example some rules and behaviors.

Some value choices for parameters involve implicit unit choices for variables, which means that the quantitative variables are at the end somewhat arbitrary. However the relations among parameters have to be made with a view to consistency.

So the methodology is different from the one by Werker and Brenner (2004) in which models are constructed using detailed empirical data on assumptions and on implications.
RUNS THAT MATCH AND THAT DO NOT MATCH THE QUALITATIVE FEATURES OF THE HISTORICAL PATTERNS

- Once the model is developed and the basic runs done, HFMs test the possibility of different outcomes if the parameter values of some key variables are changed.
- More than developing different histories, this is a way of testing the causation mechanism which are present in the model.
- For example, if the model proposes and the simulations show that one of the reason for industrial concentration is the presence of a high bandwagon effect at the demand level, would industrial concentration be lower if the bandwagon parameter is significantly smaller?
- This is particularly useful as a normative tool in order to examine different policies or socio-economic settings.
 WHICH DIMENSIONS, ACTORS AND PROCESSES EXAMINED IN EMMPIRICAL ANALYSES DO THESE MODELS TAKE INTO ACCOUNT? (1)

- Opportunity conditions and technological discontinuities
- Capabilities of various types
- Learning and search processes
- Established firms
- Entrants
- Vertical and horizontal structure of production and innovation
- Demand: consumers
- Demand: industrial users
- Institutions and other non-firm organizations such as public authorities and universities
- Cooperation and vertical interactions (such as user-producer)
- Competition and selection
INNOVATION AND INDUSTRY EVOLUTION:
HISTORY FRIENDLY MODELS
Malerba Nelson Orsenigo and Winter CUP 2014

- Part 1:
  - C. 1 the subject matter
  - C. 2 methodology

- Part 2: models of industries
  - C.3 Computers
  - C.4 Computers and semiconducors
  - C. 5 Pharmaceuticals

- Part 3: Conclusions
C. 3 The computer industry (1950–1985)
Cumulativeness and increasing returns along different product trajectories. Technological and market discontinuities. Bandwagon effects at the demand level.
Emergence and consolidation of concentration in some product segments, entry and competition in others, depending on the level of bandwagon effects.
C. 4 The coevolution of the semiconductor and computer industries (1950s–1985).
High opportunity conditions and major technological and market discontinuities in two vertically linked industries.
Specialization and vertical integration as co-determined by the dynamics of capabilities, technology and firm size in the upstream and downstream industries.

C. 5 The pharmaceutical industry (from the early period to molecular biology)
Low cumulativeness of technological advances, segmented demand and presence of IPR regimes.
Generation of low level of overall concentration in the era of random screening. Low level of overall concentration also after the biotechnology revolution, but change in the composition of the industry with new actors.
WHAT DID WE LEARN? (1)

From all these models, we have learned that the following factors affect the short-term and long term dynamics of innovation and market structure and more broadly the evolution of industries

- **FIRMS CAPABILITIES:**
  Learning processes
  Level, types and distribution of capabilities

- **TECHNOLOGICAL REGIMES:**
  Technological regimes in terms of technological opportunities, knowledge accessibility, cumulativeness and appropriability
WHAT DID WE LEARN? (2)

- DEMAND:
  Homogeneous, bandwagon and network effects, segmentation, experimental customers, new demand, user-producer relationships

- INSTITUTIONS:
  Universities, public policy (including competition policy and IPR)

The joint analysis of capabilities, technological regimes, demand and institutions provide a systematic analysis of the dynamic effects of the main factors affecting innovation, market structure and the evolution of industries
WHAT DID WE LEARN (3)

In addition, HFM have greatly progressed our understanding of three key issues in industrial dynamics and industry evolution:

- **THE VERTICAL STRUCTURE OF PRODUCTION AND INNOVATION**: The vertical structure of production and the division of innovative labor is the result of the level and distribution of capabilities, technological regimes, demand conditions and the institutional environment. At the same time it is a major factor affecting their changes.

- **SELECTION**: Selection processes are not totally exogenous. They emerge out of the interaction among individual firms. Exit rules are as important as entry conditions.

- **EFFECTS OF PUBLIC POLICIES**: There are major interdependent, dynamic and un-intended effects of public policies.
THE ROAD AHEAD (1)

In the future, HFMs may develop along the following lines

- Expansion of industries examined

The so-called traditional industries
Agro-food
Environmental sector (Oltra Saint Jean)
Services

- Comparisons of industry evolution across countries

Emerging countries
Catch up (Lee and Kim, Yoon)
THE ROAD AHEAD (2)

- Enrichment of the models

  Institutions (Murmann and Brenner)
  Spin-offs and entrants (Capone)
  Origin and emergence of an industry

- Inside the firm

  Organization
  Behavioral rules
The third one involves a comparison among HFMs that may identify “in an inductive way” some general properties and some general hypotheses that may apply to a wide range of empirical dynamic phenomena that share some common factors.

In a sense, HFMs force to recognize and model what is different and sector specific in industrial change but also what are the broad similarities and regularities in industry evolution.
A history-friendly model of catch-up
Joint work with Fabio Landini

With Fabio Landini, we have developed a history-friendly simulation model of catch-up, which is general enough to investigate the role of different windows of opportunities and of the speed and type of domestic firms learning.

We have examined firms in two countries: a leader country and a follower country.
Firms in both countries learn. Learning is cumulative and systemic.
Firms may sell in one country only or on both countries.
Three types of windows are examined: technology, demand and policy.
Windows open at a certain time during the evolution of an industry.
The main results of the Landini and Malerba HFM

- Windows of opportunities do affect catch-up. When they are absent or too small, catch up is very difficult to succeed.

- In the case of a technology-based window, the size of the window matters in a non-trivial way.

- Learning is an important factor in catching up, particularly when new opportunities are created.

- Catching up greatly benefits from the combination of different windows at the same time. Policy intervention is important in favoring the exploitation of technology-based and demand-based windows.
AS A WAY OF CONCLUSION

- In sum, HFMs play a key bridging role between general and abstract theories and detailed case studies.

- Because they play this bridging role, they also provide a main message to the two camps: the theorists and the historians/empirical scholars.

- To the theorists, HFMs suggest that abstract and general modelling should take into account some degree of realism and contain empirical foundations.

- To the historian/empirical scholars, HFMs suggest some degree of formal discipline and modelling of the empirical analyses and historical works, so that rigorous and consistent explanations of industry evolution could be developed.
AN EXAMPLE: A HISTORY FRIENDLY MODEL

OF THE CHANGING VERTICAL SCOPE OF FIRMS IN

THE COMPUTER AND SEMICONDUCTOR INDUSTRIES

Malerba, Nelson, Orsenigo and Winter ICC 2008
MOTIVATION

Understanding the determinants of firms’ specialization and vertical integration

- in related industries

- in uncertain and dynamic environments,

- characterized by technological discontinuities.

Major factors: capabilities, technical change and market size

Co-evolutionary processes
1. The history of the industries
2. The conceptual framework
3. History-friendly models
4. The main structure of the model
5. The baseline simulation
6. Counterfactual analyses
7. What did we learn?
Focus on:

- the history of the American industry
- standard components
- vertical integration of system producers into component R&D and production (upstream vertical integration)

The model does not discuss

- Second sourcing
- Intermediate organizational forms (such as R& networks and partial integration)
Three main periods examined:

a. Mainframes and transistors as their main SC components

Emergence of IBM as monopolist in mainframes

b. Introduction of the integrated circuit (IC)

c. Introduction of microprocessors (MP) and birth of the personal computer (PC) industry
Vertical integration and specialization patterns

Early in the history of the computer industry, most computer producers were not vertically integrated. Then some became vertically integrated.

With the introduction of the integrated circuit, IBM was fully integrated into IC, because of coordination advantages (IC embedded system elements), fears of leakages of strategic information and security of supply reasons.

With the introduction of microprocessors (MP), IBM and other vertically integrated producers dis-integrated from the large scale production of standard semiconductors and moved to specialization, because they faced a major technological discontinuity and quite large and competent MP firms.
Relevant variables evidenced from history:

- **COMPETENCES:**
  
  accumulation of competences in specific technological or market domains (IBM, Intel)
  
  coordination and integration capabilities;

- **TECHNOLOGICAL DISCONTINUITIES**
  
  if major, there is destruction of established competences

- **SIZE OF FIRMS** (which affects R&D expenditures and security of supply)

- **SIZE OF DEMAND**

- **MARKET STRUCTURE** of two vertically related industries
Propositions on

Vertical integration

Vertical integration of system producers will take place
- if component capabilities and system capabilities are related in terms of knowledge
- if the capabilities of coordinating and integrating components and systems into new products are relevant.

In addition, if technological change in systems has a major discontinuity,
- vertical integration will take place because of the misalignment of the capabilities of system producers and component producers.
Proposition on specialization

Specialization of system firms will take place if component and system companies are quite different in their knowledge and competences.

In addition, when technological change in components has a major discontinuity, specialization of system firms will take place if totally new capabilities are needed for developing new components and entry is relevant.
Proposition on the size of markets

An additional large external markets for components will support the growth and the specialization of component suppliers, which can therefore develop their capabilities and become quite innovative compared to vertically integrated system firms.

The absence of external markets, make components producers quite dependent on the decision to integrate or specialize by the existing system industry.
Vertical integration and specialization are co-determined by firms’ competences, the rate of technical change, and the size of markets.
THE MODEL
Computers have a mix of characteristics: cheapness and performance

Computers use semiconductor (SC) components

SC components are sold to computer firms and to an external market

At the beginning of the evolution of the computer industry: SC component technology (transistors) makes possible to have mainframes which are sold to big users (which are more interested in performance than in cheapness)

First technological discontinuity in SC components: integrated circuits (IC)
Entry of new SC firms producing IC

Mainframe producers adopt IC in mainframes

Second technological discontinuity in SC components: microprocessor (MP)
Entry of new SC firms producing MP

MP are used in mainframes and in the same time they open a new market: personal computers (PC). The new PC market appeals to a new set of consumers -individuals- who are more interested in cheapness than in performance.
SPECIALIZATION AND INTEGRATION DECISIONS

In the model

VERTICAL INTEGRATION decision is led by:

- the relative size of the computer firm compared to the largest SC component producer
- the age of the SC component technology

SPECIALIZATION decision is led by:

- Comparison between the quality of SC components produced in-house and the quality of SC components available on the market
COMPUTERS

Merit of design M of computers

\[ M_{i,t} = A \cdot \left[ \tau (M_{i,t}^C)^{-\rho} + (1 - \tau) \cdot (M_{i,t}^S)^{-\rho} \right]^{\left(\frac{-1}{\rho}\right)} \]

C= components
S= systems
DEMAND FOR COMPUTERS

\[ M_{i,t} = \alpha \cdot w_{i,t}^\delta \cdot z_{i,t}^{(1-\delta)} \]

\[ L_{i,t} = M^{\alpha_1} (1 + s_{i,t-1})^{\beta_1} \]

\[ \text{Pr}_{i,t} = \frac{L_{i,t}}{\sum_i L_{i,t}} \]

w = cheapness  z = performance  s = market share
DEMAND FOR COMPONENTS

\[ L_{i,t}^C = M_c^{\alpha^2} (1 + s_{i,t-1})^{\beta^2} \]

\[ \text{Pr}_{i,t}^C = \frac{L_{i,t}^C}{\sum L_{i,t}^C} \]
FIRMS’ BEHAVIOUR AND TECHNICAL PROGRESS

PROFITS: \[ \pi_{i,t} = M_{i,t} \cdot p_{i,t} - M_{i,t} \cdot o_{i,t} \quad O = \text{cost} \]

PRICE: \[ p_{i,t} = o_{i,t} \cdot (1 + m) \]

R&D OF INTEGRATED FIRMS: \[ R_{i,t}^C = m \cdot c_{i,t}^C + f \cdot R_{i,t} \]

FIRM DRAWS: \[ d_{i,t} = \frac{R_{i,t}}{\nu} \]

MEAN OF NORMAL DISTRIBUTION: \[ \mu_{i,t} = h \cdot M_{i,t-1} + (1 - h) \cdot K_t^K \]

PUBLIC KNOWLEDGE: \[ K_t^K = \lim_{K} \cdot \left[ e^{\phi_k \cdot t} \cdot \left( 1 - \frac{1}{n \cdot (t - t c_k)} \right) \right] \]
VERTICAL INTEGRATION

\[ V_{i,t} = \min \left( \frac{A_y}{g} ; 1 \right)^{g_1} \cdot \left( \frac{q_{i,t}}{q_t^c} \right)^{g_2} \]

\[ \text{Prob}(\text{Integrate})_{i,t} = \frac{b \cdot V_{i,t}}{1 + V_{i,t}} \]

A = time from each discontinuity \quad q = size
SPECIALIZATION

\[ Z_{i,t} = \max \left( \frac{\max M_t^C - M_{i,t}^C}{M_{i,t}^C} , 0 \right) \]

\[ \text{Prob}(\text{Specialize})_{i,t} = \frac{A \cdot Z_{i,t}}{1 + Z_{i,t}} \]
EXIT

\[ E_{i,t} = (1 - e) \cdot l + e \cdot s_{i,t} \]

Exit if \( E_{i,t} < E \)

L = inverse of the number of firms active in the market at the beginning of the simulation

E = constant
THE HISTORY-FRIENDLY SIMULATION

- Mainframes and the emergence of IBM
  IBM vertically integrates in SC components

- Invention of integrated circuits (IC):
  Entry of new SC firms
  IBM remains vertically integrated

- Invention of microprocessors MP:
  Entry of new MP firms and a large external market for MP
  A new computer market (PC) emerges for different users (individuals)
    PC producers remain specialized and buy MP
  A dominant microprocessor firm emerges in SC industry
  IBM dis-integrates
History Friendly Simulation

Figure 1a: Herfindahl index

Figure 1b: integration ratio
TESTING THE MODEL: COUNTERFACTUALS

1. Does lack of external markets lead to more vertical integration?

2. Do no demand lock-ins in mainframes lead to more specialization?

3. Do no demand lock-ins in semiconductors lead to more vertical integration?

4. Does a minor technological discontinuity in microprocessors lead to more vertical integration?
No external market for SC

Figure 2a: Herfindahl index

Figure 2b: Integration ratio
No lock-ins effects on Mainframes

Figure 3a: Herfindahl index

Figure 3b: integration ratio
No lock-ins effects on Microprocessors

**Figure 4a: Herfindahl index**

**Figure 4b: integration ratio**
MP is not a major discontinuity
CONCLUSIONS FROM THIS HFM

1. This ICC 2008 history-friendly model is able to reproduce the main stylized facts of competition and vertical integration in the computer and semiconductor industries.

2. Specialization and vertical integration are functions of competences, technological change and size of markets.

3. Dynamic processes are relevant.

4. Specific conditions affect the vertical scope of system firms:
   - Size of external markets
   - Magnitude of technological discontinuities