History friendly models as key tools in the Economics of Innovation research field

Mariangela Scorrano, PhD
mscorrano@units.it

UNIVERSITY OF TRIESTE
Department of Economics, Business, Mathematics and Statistics "Bruno de Finetti"

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Overview

1. Why history friendly models?

2. Features of these models

3. The model: evolution of computer technology and computer industry

Introduction

What are history friendly models?

By 'history-friendly' evolutionary economic modeling we mean formal models that aim to capture, in stylized form, qualitative and 'appreciative' theories about the mechanisms and factors affecting industry evolution, technological advance and institutional change put forth by empirical scholars of industrial economics, technological change, business organization and strategy, and other social scientists".

(Malerba, Nelson, Orsenigo, Winter, 1999)

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The steps in history friendly models

- 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.

A stylized history

The long-term evolution of the computer industry

The history of the computer shows continuous improvements in machines that serve particular groups of users, punctuated from time to time by the introduction of significant new component technologies which not only permit the needs of existing users to be met better, but also open up the possibility of designing machines that serve new classes of users whose needs could not be met using older technology.

A stylized history

The evolution of the industry divides rather naturally into four eras:

1. mainframe computer
2. introduction of integrated circuits and development of minicomputers
3. invention of the microprocessor and development of the personal computer
4. networked PCs and Internet

A stylized history

1) mainframe computer
   - Early 1950s: IMB and the rest of the 'Bunch' (Burrows, Univac Rand, NCR, Control Data, Honeywell), as well as GE and RCA.
   - 1954: with the introduction of the 650, IBM began to pull ahead of the Bunch
   - 1960: with the introduction of the 1401, IBM came to dominate the world market for accounting machines (not only the US market, but also Europe and Japan)
   - early 1960s: component technology improved greatly and transistors gradually replaced vacuum tubes as the basic circuit elements;
     IBM introduced its 360 family of models, and seized an even larger share of the market.

A stylized history

2) introduction of integrated circuits and development of minicomputers
   - possibility of designing very powerful computers that could be produced at a much lower cost than mainframes (stimulating the entry of new competitors to IBM);
   - in 1965 DEC's PDP8, the first minicomputer, was produced.

A stylized history

3) invention of the microprocessor and development of the personal computer
   - Personal computers opened up a new demand class: small firms and personal users.
     Established producers were slow in seeing the new market and the needs of users in that market.
   - Interestingly, when IBM did get into PCs, it did so with external alliances: Microsoft for operating systems software, and Intel for microprocessors. But it was never as dominant there as it had been in mainframes.

A stylized history

4) networked PCs and Internet
   - specialized firms compete in market layers (microprocessors, other components, printers, computer disks, operating software, application software, etc.) connected through open standards and interfaces. In this period we have a divided technological and market leadership among several firms, each of which may be a prominent actor in a specific market segment.

History friendly modeling's task

- explain the characteristics and the changes in the structure of the industry over time, in particular as new technologies were introduced and new markets emerged.
- explain progressive vertical disintegration of the computer industry, and in particular by the sharp increase in specialization that has marked the era of PCs
- explain the significant differences between the characteristics, changes and performance of the industry in the USA on the one hand, and Europe and Japan on the other, particularly with respect to the role of incumbents and the ability of new firms to take advantage of new technological and market opportunities.

The model

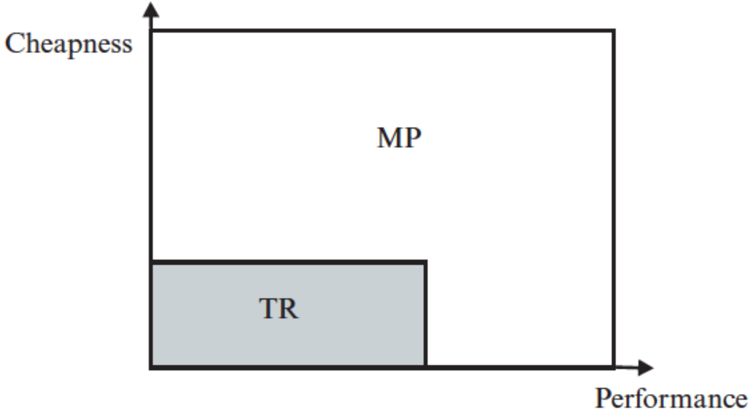
At the start of the episode, there is a single component technology (the '**transistor**' technology), which has the promise of enabling useful computers.

Later, a new component technology, the '**microprocessor**', comes into existence.

The potential purchasers of computers value two attributes:

- the performance of the computer;
- its price or cheapness

The model



The model

The outer limits of what is feasible under the two technologies are '**potentials**'.
The potential is not achievable, however, without significant investment of resources in research and development, and requires learning from experience.
The first efforts of a new firm trying to design a computer using transistors, or (later) microprocessors, will only be able to achieve a design characterized by point Z (for zero experience).

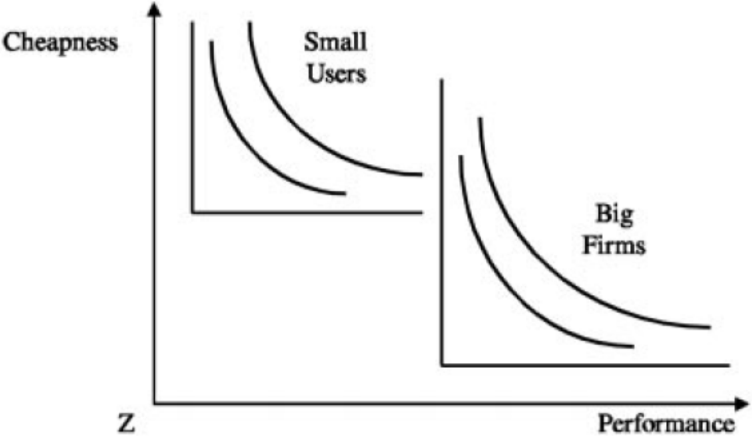
The model

On the demand side, there are two quite separate groups of potential customers:

- the 'large firms' → performance → mainframes
- the 'individuals' or 'small users' → cheapness → personal computers

A minimum level of performance and cheapness is required.
Once threshold characteristics are reached, the value that customers place on a computer design is an increasing function of its performance and its cheapness.
The indifference curves depict designs of equal value or 'merit' in the eyes of the two customer groups. We assume that higher computer merit translates into more computers bought by customers.

The model



The model

A considerable period may go by after a firm starts trying to operate in a new technology before it is able to sell any product, if it ever achieves that. At the start it must have **external financing** → venture capitalists → Z. Firms start off with different, randomly selected initial budgets, **IB** which they spend in equal amounts over a prespecified number of periods. Reflecting their bets regarding what is technologically easy and difficult, and what the market will buy, firms assign different fractions of their 'annual' R&D budget to efforts to improve on performance, and to reduce the production costs of a computer.

The model

From period to period, the quality of the design that a company is able to achieve in each relevant dimension improves according to the following equation:

$$\text{change } X_i = a_0(R_i)^{a1}(T_j)^{a2}(L_i - X_i)^{a3}e$$

R is the firm's R&D expenditure (i = 1 (performance) or 2 (cheapness)). After that initial loan is drawn down, a firm has either achieved a commercially viable design or is out of business.
T is the number of periods that the firm has been working with a particular technology.
$L_i - X_i$ is the distance of the achieved design to the frontier.
e is a random element to what a firm achieves.

The model

Designs will improve until ultimately they crack through the threshold requirements of the 'mainframe market'.
Then firms that have achieved threshold-meeting designs will begin to make sales. As computers improve, sales will grow.
Profits are calculated in each period t as:

$$\pi_t = M \cdot p - M \cdot k$$

M is the number of computers sold;
p is the computer price;
k is the production cost of a single computer.
Production costs, k, are determined by the technical progress function. All firms determine price by setting a constant 'markup' (the same for all firms) over production costs μ.

$$p = k(1 + \mu)$$

The gross margin over production costs is used:

- to repay its outstanding debt to venture capitalists
  Firms spend $\sigma = 15\%$ of their profits to pay back their debt D_t = the initial budget capitalized at the current interest rate, r, until the debt has been fully paid back (or the firm fails)
- on R&D

$$R_t = \phi \cdot \pi_t (1 - \sigma)$$

The variable ϕ is time-invariant and firm-specific.

The model

- on advertising
  It is assumed that the effect of advertising on sales follows a logistic curve.

$$A^*_t = \delta \cdot \pi_t (1 - \sigma)$$

The residual earnings are treated as 'reserves' and invested in an account, B_t, that yields the interest rate, r, in each period

Demand Side

The industry is composed of different types of users who have different needs regarding the characteristics of computers.
The market activity of each type is represented by independent purchasing decisions by a large number of 'submarkets' of that type.
Individual submarkets buy computers if they do not have one (either because they have never bought one before or because of breakdowns).

Computers have a finite life and surely break down after τ periods.
In each period, a fraction G/τ of the submarkets experiences computer breakdowns and becomes ready to buy new computers.
Moreover, submarkets buy computers if they 'see' the supply.

The model

The level of utility associated with a computer with particular attributes ($X_1 = cheapness = 1/p$; $X_2 = performance$) is defined as:

$$M = b_0(X_1 - X_1\text{min})^{b1}\,(X_2 - X_2\text{min})^{b2}$$

X_{1min} and X_{2min} are the threshold levels for cheapness and performance. This utility function is treated heuristically as a demand curve.

As the quality of computers increases and as more and more firms enter the market, total demand grows as a consequence of both an increase in the number of consumers and an increase in the number of computers purchased by individual groups of customers.

The model

Customers select different computer designs as a function of their relative utility, M_i, as it results from the specific mix of price and performance characteristics:

$$P_i = c_0(M_i)^{c1}(m_i + d_1)^{c2}(A_i + d_2)^{c3}$$

M: the 'merit' of a computer
m: the market share $\rightarrow$ bandwagon effects or brand loyalty (or lock-in)
d_1 assures that computers that have just broken into the market, and have no prior sales, can attract some sales
A: advertising expenditure of the firm producing the computer
d_2 assures that firms that have just broken into the market and have not yet invested in advertising, can attract some sales.

Microprocessors come into existence

A number of new firms start out at point Z, with funding provided by venture capitalists, just as earlier new firms had started out at that point using transistor technology.

The existence of established transistor firms in the mainframe market creates a significant barrier to entry

The model

Existing transistor-based mainframe firms are able to switch over to microprocessor technology for use in their mainframe designs, but this may be time consuming and costly for them.
It is new firms that do the initial work of advancing computer design using microprocessors.
The probability that an extant transistor firm will try to switch over is a function of two variables:

- how far microprocessor computer designs have been pushed
- the closeness of a transistor firm to the technological possibility frontier defined by transistor technology

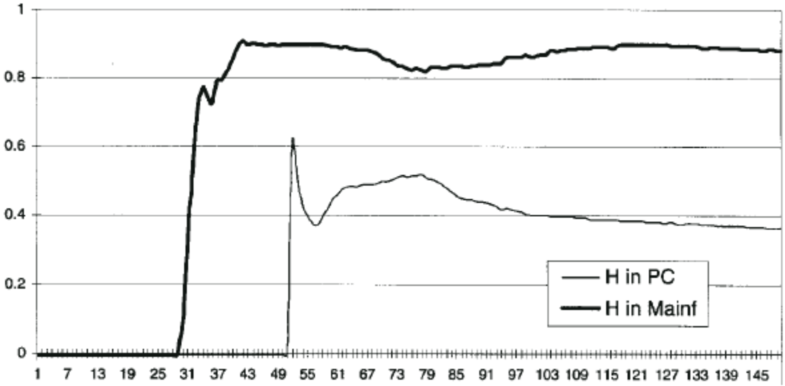
History-replicating and History-divergent Simulations

Model's aim:

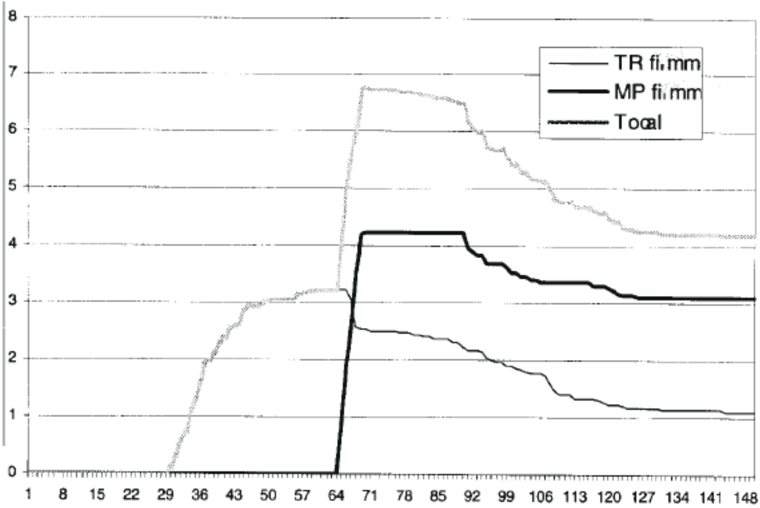
- try to get some runs that 'replicate', in a stylized manner, the actual industry history ('history-replicating' parameters)
- change the parameters that correspond to the key causal factors that analysts have put forth as behind the observed patterns, to see if, when these are changed, quite different patterns emerge.

The Basic Case: History Replication

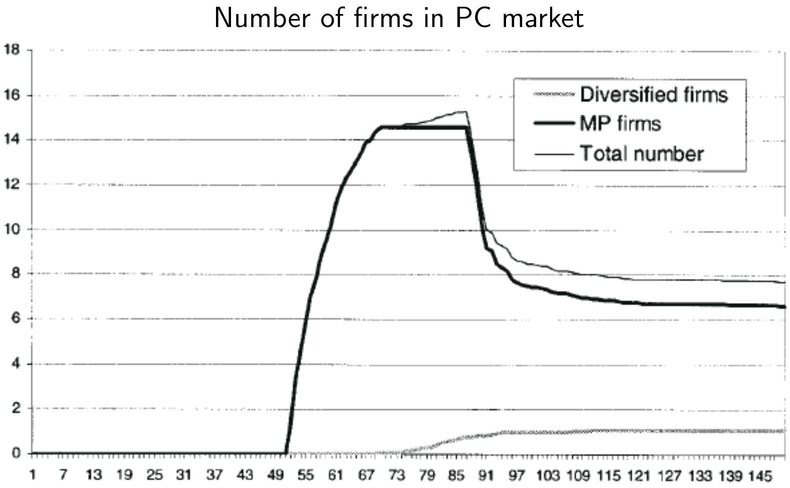
Herfindahl Index of concentration in PC and mainframe markets



Number of firms in mainframe market

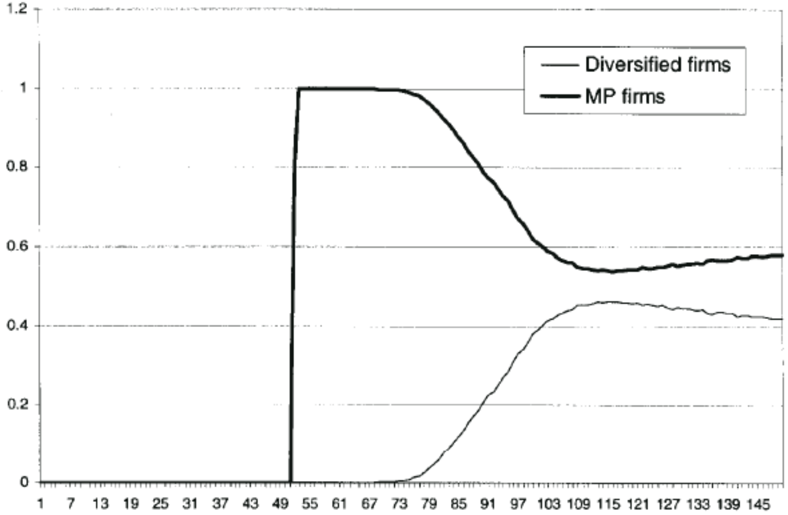


The Basic Case: History Replication



The Basic Case: History Replication

Market share in PC market



Conclusions

We have taken a body of verbal appreciative theorizing, developed a formal representation of that theory, and found that the formal version of that theory is consistent and capable of generating the stylized facts that the appreciative theory purports to explain.

Going through this analytic exercise has significantly sharpened our theoretical understanding of the key factors behind salient aspects of the evolution of the computer industry.

Thanks for the attention!