An Evolutionary Interpretation of Technical Change

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Summary I

Summary II

- Means of appropriations
- Pavitt taxonomy
- Invention, innovation, diffusion
- Schumpeterian competition

Introduction I

What does it mean evolutionary?

- Since last 40 years, economists have started observing technical progress as an evolutionary process, closely linked to industrial dynamics and economic growth
- Not a new idea:

  "What a Noble as well as Beautiful, what a glorious Machine is a First-Rate Man of War... We often ascribe to the Excellency of Man's Genius, and the Depth of his Penetration, what is in reality owing to the length of Time, and the Experience of many Generations, all of them very little differing from one another in natural Parts of Scarcity"(Mandeville, 1714, pp. 141-142)

Introduction II

"Many improvements have been made by the ingenuity of the makers of the machine... and some by that of those who are called philosophers or men of speculation, whose trade it is, not to do anything by to observe everything; and who, upon that account are often capable of combining together the powers of the most distant and dissimilar objects" (Smith, 1776, p. 21)

- Authors like Mandeville reject the assumption of strong rationality, i.e. economic agents have neither perfect information nor perfect foresight
- Emphasis on disequilibrium dynamics: capitalism as a restless process in which innovation is associated with trails and errors, mistakes and unexpected successes

Introduction III

- Identification of the regularities in the process of technological and industrial change:
  - → any invariant pattern in the innovation process?
  - → how are innovations selected?
  - → how does history affect technical change?
  - → what is the role of institutions and policies?
- Dosi and Nelson (2010, p. 54): "An evolutionary perspective focuses upon the processes by which firms persistently search for and adopt new technologies as well as new organizational forms and new behavioral patterns as means of gaining advantages over their competitors, and upon the features of the competitive process driving the growth, the decline and possibly the disappearance of various firms"

Introduction IV

- The literature has developed across three main streams of research:
  - $\rightarrow$ theory of the firm;
  - $\rightarrow$ nature of competition in such industries;
  - $\rightarrow$ innovation-led economic growth

What is technology? I

- Definition: technology is a human designed means for achieving a particular end.
- Means require *knowledge*, *procedures* and *artifacts*
- Ex: Pythagoras' Theorem: *The area of the square whose side is the hypotenuse is equal to the sum of the areas of the squares on the other two sides*

Technology as Information I

1. Non-rivalry in use: two agents can use the Theorem at the same time
2. Indivisibility: half of the Theorem is not very useful
3. High up-generation cost but low cost of re-utilisation:
   - → Pythagoras did not conceive it in a day;
   - → once there is, anybody can use it;
   - → *scale-free* property, but at a first approximation only
4. Increasing returns: non-depreciation in use (technically)
   - → you can use the Theorem as much as you want at no cost, once developed

Deepening of the above:

- Non-rivalry implies *non-depletablity by reproduction*.

Technology as Information II

- Different from costless replication
- Tacitness: we know more than we can tell

  Most technology is specific, complex... [and] cumulative in its development... It is specific to firms where most technological activity is carried out, and it is specific to products and processes, since most of the expenditures is not on research, but on development and production engineering, after which knowledge is also accumulated through experience in production and use on what has come to be known as 'learning by doing' and 'learning by using' (Pavitt 1987, p. 9)

- Pragmatic nature of technological knowledge
- Technological knowledge is different from public goods

Technology as Information III

- Scaling-up is a challenge
- Additivity may stand
- Inability to explicity articulate the sequences of procedure by which "things are done"
- No clear distinction between "exogenous" and "endogenous" technical progress

Technology as Recipe I

- The production of any artifact requires *sequences of cognitive and physical acts*
- Technology as recipe: design of the product + set of procedures, e.g., Mandeville's warship
- Recipes specify the sequence of procedures that are technically feasible and apt to get the desired outcome: recipes as coded programs, e.g., make a cake
- No good artifact or service comes out of codified recipe alone: tacitness again
- When dealing with sophisticated technologies, skills and knowledge are distributed across many individuals

Technology as Recipe II

- Social technologies: intrinsic social elements nested in particular organisations that capture the ways of doing things

Technology as Routine

- The multi-person nature of the way organizations make or do things
- An executable *capability* for repeated performance in some *context* that has been *learned* by an organisation:
  - → memory of problem-solving repertoires
  - → mechanisms of governance
  - → meta-routines
- Routines involve multiple organisational members
- Difference between capability and competence:
  - → capability: high-level tasks, e.g., building an automobile
  - → competence: master a specific knowledge, e.g., organic chemistry

Technology as Artifact

- Recipes usually involve the *design* of an *artifact*
- *Design space*: properties of the components that make up the final output
- By the way, we can study innovation in terms of modifications and improvements of the system
- Identification of techno-economic characteristics of outputs and inputs

Technology and Input-output Relations I

- The *procedural* view of technology concerns where the action is
- The production function (change in input-output relations) is an ex-post description and involves just *quantities*:
  - → ex: "90% eggs and 10% flour" does not give you a cake;
  - → this holds *irrespectively of relative prices*
- Substitution of inputs requires changes in production procedures
- Mapping between *procedures*-centered and *input/output*-centered representations: simular procedures that are far in the input-output space, and viceversa

Technology and Input-output Relations II

- Focussing on procedures allows to account for very different performances across firms:
  - → partial understanding of complex procedure;
  - → an organisation masters at most few of them;
  - → organisations master the same technique at different degree;
  - → firms are highly heterogeneous

How technology evolves I

- There is a convergence to the belief that technological advances should be understood as an evolutionary process
- Why evolutionary? At any time there is a wide variety of efforts to push the technology ahead, to fuel competition while the ex-post selection determines winners and losers
- Differences between selection in economics and in biology: the efforts at invention and innovation are not blind or random as assumed by biological mutation
- Part of the relevant variation and of the selection that characterises the evolution of technologies occurs *off-line*, in the human mind → R&D

How technology evolves II

- Yet, a great body understanding comes often from operating experience
- Ex-ante codified knowledge is not sufficient to detail properties of a production process or an artifact:
  - → a lot of know-how comes from practice;
  - → what works and what does not must be learned through experience;
  - → firms are heterogeneous in what they produce, how they produce, in their history etc.;
  - → idiosyncratic experience
- So, is there any regularity in the knowledge structure, or in the way technological knowledge accumulates? Any difference in the fields or in the periods of technological advance?

Technological paradigms I

- Technology understood as:
  - → specific body of practice;
  - → a design of the "desired" output;
  - → a body of understanding, some private but much shared
- These elements constitute the notion of technological paradigms

Definition: a technological paradigm is an *outlook*, a definition of the relevant problems to be addressed and the pattern of enquiry in order to address them:

- → scientific and technical principles to meet the tasks;
- → specific patterns of solution to selected techno-economic problems;
- → (imperfect) understanding of why prevailing practice works;
- → design concepts about the configuration of the artifacts or processes;

Technological paradigms II

- The emergence of a technological paradigm is often associated with the emergence of a dominant design:
  - → defined in the space of artifacts, embodied in the components and integrated in an architecture;
  - → exception is for instance the pharmaceutical industry;
- Technological paradigms also encompass:
  - → problem-solving heuristics: cognitive frames shared by professionals;
  - → heuristics of search: ability to combine basic knowledge to obtain a new product or knowledge with required characteristics;

Technological trajectories I

- Such features provide a focus to advance a technology along a technological trajectory, with improvements and refinements proceeding over time in a certain relatively invariant direction, in the space of characteristics of artifacts and production processes
- We can interpret technological trajectories as sequences of refinements in the supply responses to demands (needs) requirements

Technological trajectories II

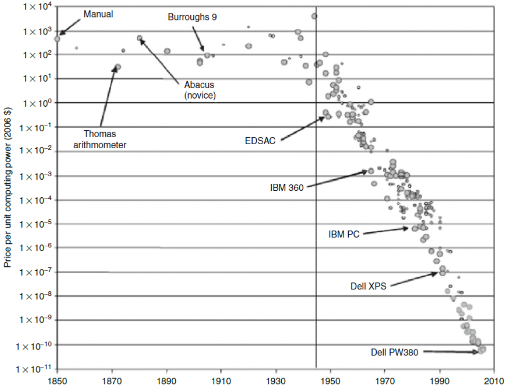

Figure: The progress of computing measured in cost per computation per second deflated by GDP price index

Technological trajectories III

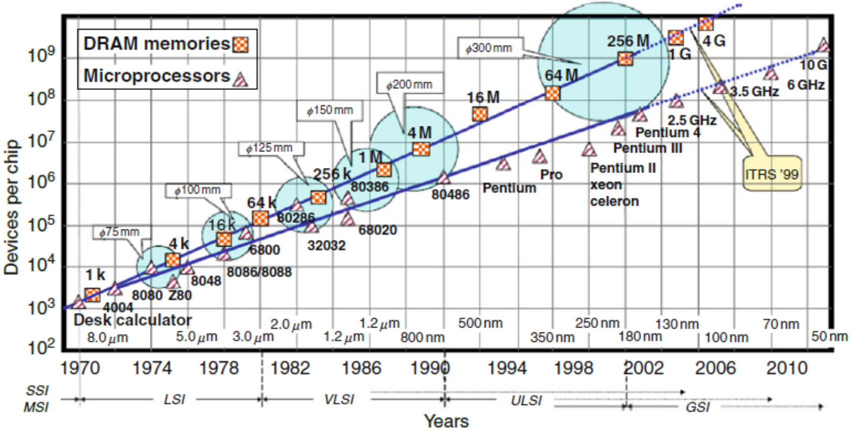

Figure: Moore's law and technology scaling

Technological trajectories IV

Properties of technological trajectories:

- Ordering and confinement, but not elimination, of the generation of variety in the product and process space:
  - → the paradigm defines the boundaries of technical feasibility and search;
  - → possible tradeoffs between output characteristics and performances;
- A trajectory reduces the uncertainty of what the future is likely to yield in terms of technological solutions, but it does remove neither *substantial* nor *procedural* uncertainty
- Trajectories suggest that technological advances are circumscribed within a limited subset of the techno-economic characteristics space
- Cumulative knowledge provides innovation avenues:

Technological trajectories V

$\rightarrow$ *normal* technical progress occurs along a given trajectories;

$\rightarrow$ major discontinuities result in paradigm changes

Any features shared by technological trajectories?

- Powerful trend toward mechanisation and automation of production, *regardless of relative prices*
- Learning curves $\rightarrow$ a power law distribution of the type:

$$p = \alpha X^{\beta}$$

- Moore's law: a double density of microprocessors every 2-3 years
- Learning is involved at any level of industries, firms, plants and over time $\rightarrow$ another source of heterogeneity

Technological trajectories VI

- Differences in technological paradigms and corresponding trajectories originate from different technological opportunities, appropriability conditions and process of knowledge accumulation

Technological opportunities and the accumulation of knowledge I

- Technological paradigms differ according to the knowledge base surrounding advancements
- Usually, the understanding advances quickly when there are fields of science dedicated to it:
  - → strong fields of applied science, engineering;
  - → high R&D intensity
- Since the Industrial Revolution, the science base has been largely a public research product, open source
- Rejection of any linear model, i.e., from pure science to technological applications:
  - → pure science is rarely enough;

Technological opportunities and the accumulation of knowledge II

- → technological advances make possible the scientific ones, e.g. microscope;
- → technologies sometimes work before we know why, e.g. steam engine;

- Different paradigms present different degrees of cumulativeness:
  - → measure to which innovations are made by dwarfs on the shoulders of (previous) giants;
  - → future probabilities of success conditional on past realizations;
  - → instance of knowledge-based dynamic increasing returns;
  - → cumulativeness applies both at paradigm and firm level;
  - → evidence of *anticumulativeness* and *organizational diseconomies of scope*, e.g., IBM, Microsoft

Socioeconomic factors shaping technical change I

- A widespread view suggests that the efforts to advance technology are generally triggered by new scientific knowledge and are directed to take advantage of it:
  - → however, several studies show this is not usually the case;
  - → firm-level search is influenced by users' value;
  - → technical feasibility
- Inducement hypothesis: the actual or perceived environment conditions affect the problem-solving activity which agents decide to undertake
- User markets differ greatly in needs, preferences, e.g., aircraft, operating systems, etc.

Socioeconomic factors shaping technical change II

Within the boundaries shaped by the technological paradigm, we find three sources of inducement:

- Changes in the microeconomic rules of search:
  - → *direction of exploration* within paradigms;
  - → Rosenberg's *focusing devices*: the case of 1800's machine tools;
  - → Marx's industrial relations and labour conflict as drivers of mechanisation;
  - → this allocation of search efforts does not depend on relative prices
- Schmookler's hypothesis:
  - → changes in the allocation of resources to search efforts *across paradigms*;
  - → *intensity of search*;

Socioeconomic factors shaping technical change III

- → cross-product differences in the rates of innovation may be explained by differences in the relative rates of growth of demand;
- → theoretical ambiguities in the definition of demand

- Changes in the relative prices: would be innovations are implemented only if they yield total costs lower than those associated with incumbent techniques
- Yet, the major step forward is the abandonment of whatever linear model and the acknowledgement of a coevolutionary view embodying persistent feedback loops between innovation, diffusion and endogenous generation of further opportunities for advancement
- In the very long run, changes in the patterns of innovation are associated with new technological paradigms that determine the *direction* and the *rate* of technological advance

Means of appropriation I

- In contemporary societies, most scientific knowledge has been generated as *open science*. Why?
  - $\rightarrow$ community based on self-governance and peer evaluation;
  - $\rightarrow$ motivational factors other than economic ones;
  - $\rightarrow$ "winner takes all" rules
- At the same time, profit-seeking organisations carry out a major share of inventive activity nowadays with the expectation of a reward
- Two general questions:
  - $\rightarrow$ is there any monotonic relation between returns to innovation and innovative efforts?
  - $\rightarrow$ how do inventors appropriate returns?

Means of appropriation II

Any positive relationship between returns to innovation and innovative efforts?

- The empirical evidence shows the view that the key to increasing technological progress is in strengthening appropriability conditions (patents) is misconceived
- No evidence that stronger patents significantly increase the rate of technological progress
- Strong patent protection might have detrimental effect on the rate of technological change, since it could preclude the exploration of alternative applications of the patented inventions

Means of appropriation III

- It is rather likely that the reasons for the highly uneven rates of progress among industries depend on the different strength and richness on the underlying technological opportunities
- The anticommons tragedy: excessive fragmentation of IPRs slows down research because owner can block each other

How do inventors appropriate returns?

Levin et al. (1985, p. 33): "lead time and learning curve advantages, combined with complementary marketing efforts, appear to be the principal mechanisms of appropriating returns to product innovations"

For process innovations, secrecy is often important

Means of appropriation IV

General finding: building organisational capabilities to implement the new technology, along with complementary assets, enables returns to R&D to be high, *even when patents are weak*

Technological regimes: Pavitt taxonomy I

- Regimes: distinct ensembles of technological paradigms with their specific learning modes and equally specific sources of technological knowledge
- Pavitt (1984) taxonomy divides sectors in four groups:
  1. Supplier-dominated sectors:
     - → innovative opportunities come through the acquisition of new machines from other sectors;
     - → Example: textile, clothing, agriculture
  2. Specialized suppliers: producers of industrial machinery and equipment
  3. Scale-intensive sectors:
     - → the scale of production affects the ability to exploit innovative opportunities endogenously generated from science-based inputs;
     - → Example: automotive, oil refining, steel making

Technological regimes: Pavitt taxonomy II

4. Science-based industries:
   - → innovative opportunities coevolve with advances in pure and applied sciences;
   - → Example: microelectronics, informatics, bioengineering

- Schumpeter Mark I:
  - → innovation carried out by new entrants;
  - → low degree of cumulativeness of knowledge accumulation;
  - → creative destruction
- Schumpeter Mark II:
  - → innovative activity undertaken by few giant firms;
  - → high cumulativeness in knowledge;
  - → serial innovators

Stylised facts on invention, innovation, diffusion

- Invention: original conception/development of a novel would be process of production or product
- Innovation: actual introduction of the novelty and tentative economic development
- Diffusion: introduction of the novelty by buyers and competitors
- Four stylised facts:
  - → diffusion is a time-consuming process;
  - → the speed varies across technologies and countries;
  - → S-shaped (logistic) process;
  - → many innovations never diffuse and fail

Example: steel casting

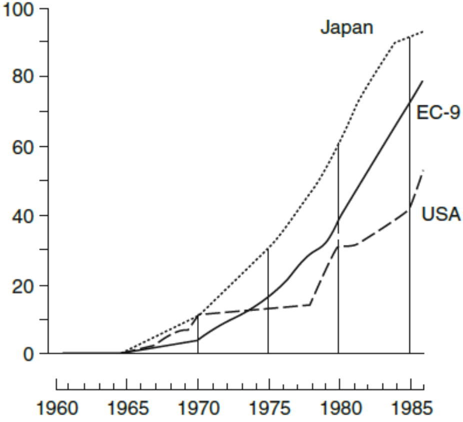

Figure: The diffusion of continuous casting of steel, as a percentage of total crude steel production.

Firm's heterogeneity

- Due to different *absorptive capacities* and abilities to use new techniques, pieces of equipment and consumption goods
- On the supply side, heterogeneity is endogenous to the dynamics of learning, innovation, imitation, selection among producers
- On the demand side. *learning by using* is a powerful driver of diffusion

Schumpeterian competition I

- Process through which heterogeneous firms compete on the basis of the products they offer and get selected
- Some firms grow, some decline, other exit the market, new ones enter
- Competition is fuelled by innovation, adaptation, imitation by incumbents and entrants
- Selection operates:
  - → across firms;
  - → within firms, among techniques
- Creative destruction:
  - → rapid technological advance associated with new paradigms;
  - → incumbents do not seize opportunities;

Schumpeterian competition II

→ innovations introduced/exploited by new entrants

- General properties:
  - → what drives the process is firm's efforts to get economic advantages over competitors;
  - → competition may be fragile: tendency to concentration;
  - → competition still benefits final users;
  - → competition keeps prices moving in line with total costs