Stylized facts about the economics of major inventions

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Abstract. This work lists similarities between historical episodes of adaptation to major inventions, and lists these statistical stylized facts characterizing the flow of minor inventions, wages, stock prices, and firm entry and exit flows. A useful mental model for the whole cluster of these similarities is to suppose that after the invention, relevant actors (investors, workers and firms) expect to see a future end-state in which well-defined production processes, products, and markets for the new technology will exist, but are qualitatively unknown at first. That is, there is uncertainty – and the players search to get to this end state first. If one takes this view it follows that many of these economic effects are predictable in advance, including: a wave of patents and freely shared information; a wave of new producers which are in one or two geographical regions, funded by equity, with low profits and low measured productivity; a rise in earnings inequality and asset price volatility; and a shakeout. The statistical stylized facts have mostly been established elsewhere, but the complete list of them and the link to technological uncertainty is more complete here than in previous work. The many statistical regularities can serve as tests for algebraic or simulated models of economies adapting to new technologies.

1.0 Introduction

What are the early economic effects of a great new invention? Some general answers to this are known and will be listed below as stylized facts, subject to disputes about magnitudes and interpretations. Instinctively one might think that the invention improves productivity, generates profits, raises some incomes and improves life chances for somebody if not almost everybody. Historically those effects usually take decades, however. Let us focus on the early effects.

The question needs some clarification. With rare exceptions, a new invention cannot be great (in terms of historical importance) and a great invention cannot be a new one.[1] Let us define a great invention as one that eventually makes possible some useful service that could not be accomplished before, or is made dramatically faster or cheaper and thus has a detectable effect on the productivity, income, profits, and life chances of large numbers of people. This is a definition that suggests time has passed and the invention diffused to many users.

A new invention is one that has not had time to diffuse into the population of natural users, which implies that it is not yet widely agreed upon how great it will be. Some people know the new invention exists, but many do not know it exists. Of those who know

[1] A dramatic exception is the atom bomb.

it exists, a few people believe they understand how the new invention works, at some level, but most probably do not. Of those who do not understand it, there are dramatic differences in how much they could understand it on the basis of a brief explanation. Of those who do understand it at some level, there are probably great variations of opinion about whether, when, and in what form it can bring about economic value (that is, greater freedom from some scarcity). This turn of the discussion about a new invention has taken us into subject of the economics of information, with variations in *knowledge*, *beliefs*, *opportunities,* and *abilities*. I will argue that most of the economic effects of a potentially great invention can be thought of and modeled as arising from these variations. There is uncertainty about the new technology, its value, and the products and processes it will lead to and how long it will take to get there.

In brief (and here, finally, there will be evidence): dramatic differences in ability or opportunity to adapt the new invention to some useful purpose lead to an increase in the dispersion of productivity in the population of workers and therefore their earnings and who immigrates or emigrates; differences in adaptations of the new technology and opinions about its value lead to volatility in the prices of equity assets and particular uses of equity financing versus debt financing; profits from investments in the new technology are negative at first; the measured productivity of firms investing in the new technology falls; diversity in strategies lead to many entrants into the relevant industry then a shakeout; quality adjusted prices of the outputs affected by the invention fall; ……….

Unrelated to uncertainty, the asset value of older production assets falls because they are anticipated to be made obsolete. Many people believe the useful life of these older assets has been shortened by the existence of the new invention.[2]

Taking a few cases as sources, we'll explore these generalizations and define them a little more sharply below. Relevant historical cases are, for example: steam engines; the first kind of mass-production steel, called Bessemer steel; [internal combustion engine?]; the transistor; the integrated circuit; the microprocessor and microcomputer; DNA duplication through the technology called PCR; ……

There is a useful distinction between technical progress that is exogenous to the large organizations, e.g. inventions made by a lone inventor, and that endogenous response we can call organized R&D. The first we can call exogenous technical change, and the second endogenous technical change, since we can usefully model it as profit-maximizing. This is similar to the distinction made by Mokyr between macro-inventions and micro-inventions. Uncertainty comes mainly from the exogenous technical change.

2.0. Some stylized facts

On the asset prices subject, note the first page of Laitner & Stoyarov (2001) in my files. In a US stock market aggregate, Tobin's q fell below 1 during 1974-1984, which they draw to be the arrival of the microprocessor lowering the value of old knowledge and physical capital.

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[2] Shown in one case by Laitner and Stolyarov 2001, in one example where tobin's q of the us stock market fell after 1973.

On the subject of special-types people, James Watt seems to have been a special person when it came to making steam engines. Mokyr, 2001, ch4, p140, says Watt personally supervised the production of engines, and (earlier) says that Watt had the bad experience when he was away that somebody would screw it up severely. Analogously, Alexander Holley as an information-sharing institution in the Bessemer-steel case.

3.0. Some disputed but possible stylized facts

4.0 Concluding comments

Why make a list of stylized facts of technological uncertainty? Knowing it can reduce the feeling of loss of control that happens when the environment is uncertain. The list can inform policy; if we know what's coming, we can control better what happens. The list can serve as a platform for economic theories about uncertainty that could apply to the historical cases I cited. If widely understood it can reduce the fears of those who might otherwise be Luddites, or back them up on factual grounds.

Consider an invention or discovery in a scientific laboratory, barely understood at the beginning, which evolves into widespread routine applications forty years later. Let us call this historical process a **technological takeoff**. The purpose of this chapter is to consider historical generalizations about technological takeoffs and evaluate their truth or falsehood. The process consists of both changes in process within a production organization (learning by doing) and changes in the products of production organizations (labeled here ease of use or design improvements). Technology changes of this kind are relevant since perhaps the Industrial Revolution, and the conjectures here are only meant to describe the free market West since 1750. In fact, they only describe technology changes which are in retrospect macroinventions in the sense of Mokyr (1990) and in particular, macroinventions that lead to the rise of new industries; a technological takeoff.

We want to create a list of stylized facts that abstract theories of technological change might fit. Stylized facts are useful to the construction and testing of dynamic theories. A structural theory is more useful if it applies more often. If it is designed around a particular historical example, it is unlikely to be portable to other countries or time periods. The theorist therefore wishes to extract from complicated histories some essential exogenous factors and endogenous outcomes that give a theory simplifying power overall. Formulation of stylized facts can alienate the historical perspective that recognizes explicitly what happened in each case. A good balance between these interests will avoid oversimplification, teleology, generalization of one-of-a-kind events, or prior commitment to any small class of theories.

Examples of such useful lists of stylized facts can be shown. Layard, Nickell, and Jackman (1991) have very successfully summarized critical stylized facts about national unemployment in industrial economies in the postwar era in a way that does not prejudge which theories might fit them. Cooley and Prescott (1995) have successfully summarized stylized facts of business cycles in the postwar U.S. Such lists of stylized facts are shown in Appendix A so the reader can see the form they take. Often a stylized fact is a fact about time series or cross-sectional observations on variables that relevant theories take as endogenous.

Do there exist such stylized facts of technological change? It is a presumption of this line of research that there are. The following stylized observations cannot be defended in detail here but will be taken as suggestive and believable for now. A detailed study of them is a necessary line of associated research before the argument here could be convincing. In a free market economy, technological change in an industry and a period is directly associated with waves of business births, alliances, and deaths. Technological takeoffs are associated with a period of lowered productivity and profits as measured in terms of current production, but not lowered production and profits in the long term. Technological takeoffs are associated with temporary increases in wage or income inequality. Technological takeoffs are associated with increases in immigration of persons with high levels of skill and talent in the relevant field. The wave of new businesses brought about by technological change is more likely to be funded by equity, rather than debt, than are contemporaneous businesses in technologically tranquil industries, or than in businesses in that same industry in technologically tranquil periods. A period of technological change in an industry is associated with a period when engineers and scientists are more likely to be running businesses than in other industries and other periods, when operations, sales, or financial experts are more likely to be in charge. If a patent system exists, a period of technological change is associated with an increase in the flow of patent applications and approved patents.

Every one of these effects is temporary, and while patent, immigration, productivity, and other rates may not return to their previous values, they show a rise during the technological change and a decrease afterward. If they are part of the natural process of adapting to new inventions, it may be that the process is delayed or has other consequences in environments in which these side effects are repressed. Here are three suggestive examples: (1) it is possible that in an environment where government regulation or historical custom makes rapid increases in income inequality impossible, the adaptation process is delayed. This conjecture fits the relatively liberal British economy fostering the first Industrial Revolution of 1760-1830, and with the United States having more rapidly adopted uses of the microprocessor since 1973. (2) The same may be said of immigration, which is tightly regulated in many places but not in those economies. (3) It is observed historically that economies without reliable patent systems do not spawn industrial revolution; e.g. France in 1800.

A theory of technological takeoffs should predict not only where one will happen but also where it will not happen. It is useful to compare therefore the British takeoffs to the French or Irish situation of the same time. And similarly the takeoffs in the environments of the American takeoffs, which occur generally in the north, to the situation of the same time in Canada or the American South.

The evidence on technological takeoffs will come from a number of examples of invented technologies that began industries big enough to have macroeconomic effects. The list is not exhaustive but includes cases often cited as classics. All these cases are centered in the U.K. and U.S., which may impart a bias in the stylized facts below.

gunpowder in Europe!! Circa 1550-1700. See Burt (1991), in mining files which has at least bibliographically collapsing prices, pay dispersion (~p258); regulation (p263); the whole shebang.

the steam engine (Newcomen ~1712, Watt 1765-1775)

cotton textile improvements around 1760-1800

iron process improvements in Britain's Industrial Revolution (Darby; Huntsman; Cort; Neilson)

mass production steel (1856-1885) (Bessemer, Siemens-Martin)

the telephone (Bell 1876-1900?)

the automobile

mass electricity distribution ? Westinghouse? Edison?

the microprocessor and microcomputer (1971-1990)

the World Wide Web (1990-1997)

biotechnology findings enabling mass DNA reproduction in laboratories. (PCR 1985)

Network activities have somewhat different economics. (telephone, electricity, Web)

Software businesses do too (machine tools, microcomputer software)

Mining in the upper peninsula of Michigan in 1846-1890 included uncertainty about this part of the process: was it more efficient to ship the ore? Or as the firms all assumed at first, was it more efficient to set up forges on the upper peninsula, and make iron there? See Hatcher.doc. Harlan Hatcher, A Century of Iron and Men. This is product or process uncertainty. Speculators rushed in, in 1870s, to Menominee range for example. many failed. A few succeeded. (Hatcher, p 123-4)

Technology and science

Conjecture: New materials or tools are essential to the new industry.

TBIR/Landes, p 137, inspires this thought. We know it's true for the semiconductor industry by definition. Likewise, by definition, for the steel industry and the electrical power industry.

On manufacturing skill Landes TBIR p 162 footnote 26 is specific and cites others.

Cindy says births and deaths of SIC codes can show this.

Interest in practical problems at British universities cited in TBIR p 274, last line. This can be contrasted to abstraction at French universities and taxonomy at German ones, from other literature. Mitch/TBIR pgs 286-9 is good on this.

The reason this would be relevant to a theory of informational effects is that it tells us flows of information are not sufficient; flows of STUFF which did not exist before are essential to get the rise of a new technological industry. One way this is framed in some theories is the invention of a new intermediate good.

The rise of industries along with the new steel technology, e.g. Bessemer, in the late 1800s is a suitable example.

Steam engine: 1775 upgrade of best steam engine from Newcomen to Watt required new equipment, the early machine tool "boring machine" made by John Wilkinson.

Kemp on industrialization asserts that industrialization spread in Belgium, northern France, and western Germany out from coal fields. (see pg 10)

Conjecture: A technological takeoff includes a wave of patents citing the early macroinvention.

The patents are a measure of microinvention. See Polodny and Shepard (1997).

There is a kink upward in patents per year in the late 1750s, according to Richard J. Sullivan's article in EEH 1989 p 242-452. Maybe also his 1990 article in JEH. These patents should follow the critical inventions in iron and possibly in cotton/textiles; a study of their contents should verify the link.

TBIR cites Ashton, 1948 (*The Industrial Revolution*), p 63 on patent statistics of the Industrial Revolution. And Sokoloff, JEH 1988 p. 813.

A case study of the field of computed tomography equipment (Trajtenberg (1990)) shows that after the crucial invention in 1971 a wave of patents citing the first one are filed in the following years, peaking in 1977, then declining numbers of patents in the following years. The early ones are cited much more than the later ones, and a thin tail of patents in the same area continue to the end of the sample.

TBIR93, p 40-41, and 43 and 44 on importance of patent law and property rights in general. See North (1990) cited there. P 45: the case of Holland shows property rights were not sufficient for an IR.

The steam engine case: Flow includes Thomas Savery, 1968; Denis Papin; Thomas Newcomen, ~1705-1712; possibly John Wilkinson ~1769; and James Watt ~1765-1775.

Hall & Ham, 1999, in files, shows this for semiconductors. For a tech uncertainty argument one would have to demonstrate that collective invention or some other reason kept patent flow suppressed until 1984. Or that the explosion has this particular shape. Kim and Marscke (2001), in files, finds that industries with more turnover of scientists and engineers have more patenting since 1984, notably electrical components, office computing, and drugs. Kim and Marschke have a delicate, precise argument for why these variables would go together – that the firm protects its technology from job mobility by patenting fast. This doesn't seem stronger than the nearly-reverse argument that the firm could protects itself from job mobility by preventing the employees who generate patentable findings by delaying patenting. Substantively that's a wash. The real link, I'd argue, is that technological uncertainty and demand for specific tacit-type knowledge produces both patents and job mobility. See Cohen, Nelson, and Walsh 2000 too.

Conjecture: Collective invention occurs, and much technical information is freely shared at first.

Robert C. Allen (1983); both Nuvolari (2001) papers; my Bessemer Association sources.

Including Shane Greenstein's old paper. And Freiberger and Swaine, on the PC case. And Linux?

Take a look at Liebeskind et al (1996) in files, which focuses on superstar scientists and has a good definition of social networks which distinguishes them from hierarchies and markets. The definition would include the network of people not necessarily known to one another who share information through common bulletin boards, newsletters, and magazines. Information exchange is taken as crucial to their role. The many references in this paper could fill out much of what's needed in collective invention.

Conjecture: Old forms and technologies persist for decades along with the new.

Per Caselli 1997. TBIR, p 159 agrees explicitly.

This tells us something about the difficulty of adaptation to a macroinvention even if it will eventually have huge effects. Its really hard. And the properties of the new technology are not known (this phrasing from Rosenberg's essay in Mosaic of economic Growth). Even areas where it's clearly likely to predominate are not necessarily areas where new sales appear immediately; much microinventing has to happen.

Old inventions live long with the new one because improvements in the old one are stimulated. "[I]nnovations often appear to induce vigorous and imaginative responses on the part of firms which find themselves confronted with close substitutes for their traditional products." The competitive pressure from new technology induces accelerated improvement in the old one. Example: "Some of the greatest improvements in wooden sailing ships took place between 1850 and 1880, just after the introduction of of the iron-hull steamship and the compound steam engine, which were to displace sailing ships" by 1900. Similarly great improvements in gas lamps for interior lighting came shortly after the introduction of the incandescent electric light bulb. (p349-50) [rosenberg, in Mosaic]

Use and sales of the Newcomen steam engine thrived for twenty-five years after its successor steam engine was made by Boulton and Watt. (Charles Hyde, book review, JEH, Sept 1978 pp 813-814, reviewing an entire book on Newcomen's steam engine.) And at least one ran until 1834, according to www.technology.niagarac.on.ca/courses/tech238g/newcomen.htm.

According to Hyde, p. 814, Newcomen had to spend from ten to fourteen years on the invention before it was successful.

Conjecture: At some stages, enough standardization occurs in the technology that some improvements fail a market test because they would violate the standard.

Cowan (1991) discusses inferior-technology lock-in, and has examples. Cites one in particular having to do with nuclear power.

PC vs Mac discussion.

Can I find where there is an 8086 example?

QWERTY (David ~1990, and Lie & Mark()).

This is not a permanent thing. There may be recurring waves of change where it becomes possible to change earlier decisions. An example is the QWERTY case, where plug-in keyboards could have a different design from today's standard.

Possibly relevant: after the printing press there was a dispute over alphabetization as a standard way of presenting encyclopedic information. See Headrick (1998). Alphabetization had existed before – it was not a new invention – but it became more important in the 1600s.

Likewise there is now a reevaluation of the academic journal – is it really an offline version of an online concept?

Industrial organization

Conjecture: In a technological takeoff, the key macroinvention is followed by a wave of business births, then a wave of business alliances, then a wave of business exits.

Examples: The early automobile business, the early telephone business, and the early computer industry. Chipmakers – expanding in number until recently, now declining in number. In the case of narrowly defined industries the evidence in Klepper and Graddy (1990) is convincing.

The facts in the case of cars or phones should also support this.

Exits here include exit by merger, plant shutdown, and bankruptcy.

Citing previous work, Nelson and Winter (1982) report "a tendency for concentration to grow in industries that start out initially unconcentrated."

Gort and Klepper (1982) and Klepper and Graddy (199) establish firmly that "the number of firms in new industries follows a distinctive path; first it growth, then declines sharply, and finally levels off". Their industries are narrowly defined – some as narrow as one seven-digit SIC code, but the regularities are striking in the post-World War II period. Essentially all of their 46 industries go through their stages of growth in number of firms, decline in number of firms, then a plateau in the number of firms. (Klepper and Graddy, 1990, pages 29-32.) They construct a formal model of this driven by cost reductions that occur over time for the firms in the industry.

On alliances, cite: Folta (1998); Steensma, Marino, Waver, and Dickson (2000); Robertson and Gatignon (1998); . (All abstracts in files.) Use also the term "joint ventures" and cite Olleros (1986, in files) who uses the term technological uncertainty and refers to market-oriented joint ventures, licensing, and subcontracting.

Conjecture: A technological takeoff is a period of increased investment, lowered productivity, and lowered profits relative to related industries and before and after the takeoff.

This case is made in Greenwood and Yorukoglu (1996).

The investment can be identified with learning-by-doing, which is the process that gradually results in productivity and profits rising back up to their previous level after the investment period. [Greenwood and Jovanovic (1998) cite Paul David, 1975,]. Learning by doing of this kind – investment in learning is documented more or less by Bahk and Gort (1993).

Note that this proposition does not say that macroeconomic growth is linked to the technology takeoff, nor does it reject that proposition. Historians do not find a link. A technological takeoff is localized. TBIR (1998 draft) page 7: "The point stressed by Crafts and Harley, as well as by students of other episodes of rapid technological change, is worth repeating: There is typically a long lag between the occurrence of changes in technology, even those of fundamental importance, and the time they start affecting aggregate statistics such as industrial production and national income per capita."

There is an effect of rising productivity (or should be) but it may diffuse slowly.

Conjecture: Just one or two geographic centers of the new industry appear.

Local knowledge spillovers are an important cause.

Examples: The cotton industry of the Industrial Revolution was concentrated in Lancashire. The iron industry of the Industrial Revolution was located in the upper Midlands and the Cleveland district of Britain. Bessemer moved to Sheffield to start his own firm using his new steel technology because that was the center of the steel world. The auto industry was centered on Detroit and the upper midwest. In the case of the telephone there may have been a takeoff centered on New Jersey and New England. Silicon Valley and Route 128 for the semiconductor and related industries. Saxenian (on shelf).

Mokyr, TBIR p 15, writes: "The Industrial Revolution was, above all, a regional affair, affecting Lancashire and parts of the adjoining counties and the Scottish Lowlands but leaving most of the country without visible marks. As late as 1851, only about 27 percent of the British labor force worked in the industries that were *directly* affected by the Industrial Revolution, although almost everyone had been touched by it indirectly as consumer, user, or spectator." Landes, TBIR, p 149 agrees and cites important relevant work. Harley, TBIR, p 210 may be relevant. "Cotton spinning was concentrated in a small part of Britain (Lancashire)." (TBIR, 1998 draft, p 15.) "The south of England remained largely unaffected by the Industrial Revolution because it specialized in agriculture." (p 21)

Zucker, Darby, and Brewer (1998) show strong evidence for a cause of geographical concentration in the use of biotechnology by new firms. By their definition of biotechnology there are almost no adopters as of 1975, but 700 in 1990. The number of firms using biotechnology in 1990, by region, was very strongly predicted by the number of highly prolific genetic scientists in the region several years previously and by federal government research grants to the region in the interim, but not by the presence of venture capital firms. This suggests that it was technological information, skills, or experience, not private financial backing, that was decisive in producing a large population of adopters of the technology. The authors refer to these as "intellectual human capital" variables. The intellectual human capital variables are stronger predictors in the early period of use of the technology than they are later, which the authors interpret to mean that the technology or critical skills diffused over time. They have some evidence that it is the actual presence of a scientist, not a spillover from the presence of numbers of scientists in the region, that makes an adopting firm appear. (That is, the knowledge in question seemed to be rivalrous or excludable, not a general externality.) "At least for this high-tech industry, the growth and location of intellectual human capital was the principal determinant of the growth and location of the industry itself." (p 302) (Mansfield, ReStat, Feb 1995 cited notably)

We partly know why the takeoff occurs in a concentrated region. It has to do with information / knowledge transmission. The AEA paper by Audretsch and Stephan says, on page 4: "The importance of geographic proximity for knowledge spillovers has been supported in a wave of recent empirical studies by Jaffe (1989), Jaffe, Trajtenberg, and Henderson (1993), Acs, Audretsch, and Feldman (1992 and 1994), Audretsch and Feldman (1996), and Audretsch and Stephan (1996)." <I must study these.> NBER Working paper 7064 by Jaffe and Lerner says on page 10: "Recent work has shown that knowledge spillovers tend to be geographically localized …" and cites Glaser et al JPE 1992 p. 1126-1152. And on that same page 10: "[v]enture capitalists tend to be highly localied in their investment patterns: over half the venture-backed firms have a venture investor who serves as a board member based within 60 miles of the firm. [Lerner 1995].

Lipsey, Bekar, and Carlaw (1998) use the example of mass-production printing of the 1500s-1700s. "The Netherlands were tolerant of both printing and the new knowledge that it represented. Thinkers, writers, and printers, exiled from other parts of Europe, moved there. The creation of the Dutch information networked based on low-cost reproduction of the printed word greatly increased productive efficiency and tax revenues. Although many factors contributed to their eventual victory over Spain, and their rivalry with Britain as a world trading power, research indicates that a key part of their success was owed to their liberal attitude toward the technology of printing and the learning that it embodied." (p 23). Many citations to back this up.

A partial cause for this could be that regions and countries might vary in their performance under tech uncertainty, e.g. TBIR. Market is perhaps wasteful but if confronts the problem of uncertainty with a diversity of approaches (p353) [rosenberg, in _Mosaic_]

This "regional strength and industrial-university linkage [in the Silicon Valley/Bay Area region of California, with its venture funding, universities, and can-do attitude] resembles the nineteenth-century situation in the German chemical industry along the Rhine, which permitted it to grow to world dominance by 1914." (p406) [landau, in _Mosaic_]

Review Almeida (1994), in files, on local knowledge diffusion by foreign multinationals, as evidenced by their patent citations. The multinationals don't mostly take the technology home to work on it; rather, they participate in the local technology exchanges.

Conjecture: Firms using earlier technologies in similar product markets are wiped out during a technological takeoff at a rate higher than in technologically tranquil times.

Examples: horse and buggy firms, dealing with the automobile. Presumably also teletype and telegraph firms confronting the phone. Mainframe and minicomputer makers confronting the microprocessor. And maybe adding machine and typewriter companies confronting the calculator and the computer.

Conjecture: Early entrants, entrants with experience in related production, and entrants with a large amount of capital have better survival rates in the new industry. None of these advantages alone is sufficient, however, to guarantee survival.

Lane (1995) especially pages 1 and 23, documents that early entrants in the manufacture of automated teller machines did not always become dominant. Often larger manufacturers with experience in related production processes could enter later and outlive some of the early entrants. Among her sample of possible entrants, related production experience was a positive predictor of entry (p 23). Possibly this was because related production implied related experience with distribution networks, reputation, or customer contacts. (p 25). Large size and public equity lowered the probability of entry. (p 23) – possibly this is because entry was risky.

Conjecture: Each firm in rising technological industries experiences increasing returns to scale. The industry does to an even greater degree, because of demonstration effects and self-fulfilling expectations as well.

As in TBIR, p 29, and its cite of Crafts 1985b. Note the implied case for chaotic dynamics.

Product markets

Conjecture:

The price of the output product or service declines sharply.
Steam engine case satisfies this and of course microprocessor does too.

Conjecture: Prices of inputs and outputs of the technologically advancing sector are more volatile than previously, or than would be predicted by comparison to similar goods. There are supply and demand mismatches.

Carr and Taplin, p 153, says that one analyst thought the Americans would do better to replace their largest blast furnaces by two of them half the size, and that rivalry between firms had driven them to excessively high stacks, and records in output, rather than being economically efficient. Furnaces designed to output 1000 tons a day had never achieved 500. They revised them to be more like British ones making 400 tons a day.

The conjecture is testable in high tech markets. A standard PC's price is falling but predictably by say 1990. But new components have shortages, or gluts.

Finance

Conjecture: Asset prices in the relevant industries are volatile during a technological takeoff.

Probably because anticipated profits are so uncertain. In the CAPM, equilibrium expected returns from a security are high when the variance of possible returns are also high.
Examples: Biotech companies in the early 1980s (e.g. Genentech IPO); Internet-related businesses since 1995 (e.g. Netscape's IPO); Personal computer companies throughout.
The standard finance discussion about which stocks have high betas is relevant.

Conjecture: Assets associated with the new technology rise in value; those associated with the old technology fall.

Optimism bias appears. Optimism bias occurs because there are drastic differences in valuation from people with different information sets, or the slight differences are sufficient to keep one category of traders out since they do not know enough to have confidence in their decision. The second force is analogous to the home-bias in retail security purchases.
See evidence on this sort of thing in Hobijn & Jovanovic, AER Dec 2001, re the IT revolution.

Conjecture: Firms participating in the technological takeoff are ceteris paribus more likely to be funded by equity than by debt.

E.g. the celebrated role of venture capital and startup firms. The corporate finance type explanation for this is that there is a high level of uncertainty about anticipated profits.

Stock options contract with employees is an equity-like contract versus a salary which is a debt-type contract.

Debt funding generally takes the form of bank loans, private placements, or bond issues. Equity funding is through private placement, employee stock ownership and through issues to the public stock markets. Allen (1993) outlines the issues well regarding the natural role of banks and stock markets as sources of firm capital. Banks have a role as a monitor of the firm on behalf of the savers and investors who entrust their money to the bank. The monitoring role is done more efficiently by a single agent than many. Stock markets, by contrast, are better if efficient risk sharing is necessary, if it is useful to provide incentives for information gathering to get efficient prices, and if information makes efficient incentive schemes for managers feasible.

Allen (1993, page 102) explains further: "Banks will be a good way to provide financing in traditional industries such as agriculture where the technology is well known and there is a wide consensus on how things should be done. Here the bank can monitor firms effectively and take advantage of the scale economies in monitoring. In industries where there is little consensus on how the firms should be managed, an allocation of resources through a stock market is desirable. The theory predicts that stock market quotations will be observed among large corporations and in industries where there is continuous technological advance. Countries that have a significant stock market will be those with a significant amount of technological innovation in the sense of developing entirely new industries and those with industries with a significant amount of concentration."

The monitoring role of a bank is less useful in a situation of technological uncertainty. Allen, p 89: "[I]n industries where the optimal actions of management are widely agreed upon, banking will predominate; thus banking will be important in competitive industries such as agriculture. In industries where there is wide disagreement on optimal policies, however, stock markets will be important; these include industries dominated by large corporations and those with high technology."

"It was the UK that first underwent the Industrial Revolution in the nineteenth century with the development of the railways and other new industries, which were to a large extent financed through the London Stock Exchange. Similarly, in the US the New York Stock Exchange played a critical role in the development of the major twentieth-century industries such as the automobile, aircraft, electronics and computer industries. Among current emerging industries such as biotechnology, stock markets are again major sources of finance.

"In nineteenth-century Germany, in contrast, industrial development took place when the technologies were not as new and untried as in the UK. Similarly, in the twentieth century Japan's most important achievements have mainly been in existing industries rather than in entirely new ones. In both these cases, the factors that favour stock market finance are less prevalent and those that favour bank finance are more prevalent than in the US and the UK."

TBIR, pp 100-109, have many supporting facts and citations. It's essential to look at these materials more closely. Links between capital availability and information are also explicit. According to Harris (American Historical Review 83:3, pp 720 book review on Rolt's book on Newcomen and the steam engine), a "joint-stock company . . . took over the rights [to] Savery's engine . . . ." which apparently Newcomen ran, or had some leverage in running.

Another way to look at this question is to compare the categories of firms that try an initial public offering (IPO) versus those going private with a leveraged buyout (LBO). LBOs are conducted generally in industries where the cash flow is certain and a core issue for shareholders is keeping management constrained from perks or wild acquisitions.

Uncertainty is a driving force of the technological takeoff. To maximize the information they have in each deal, venture capitalist firms prefer to syndicate (share) investment deals so as to check out their thinking with one another and to diversify their risks. (Perez, p 53)

If natural forces drive high technology firms toward stock markets, and large scale businesses with stable technologies toward bank financing, then countries with financial systems with one or the other strength may develop orientations toward one or the other technology type. The following table is suggestive:

Country	**Number of firms covered by financial analysts**	**Firms covered by financial analysts per million population**
France	303	5.4

Germany	210	3.5
Japan	1152	9.3
UK	1183	20.9
US	>4600	18.6

Adapted from table 4.3 from Allen (1993) page 88, from original source *Nelson's Directory of Investment Research 1992*.

The correlation is important. Per capita, France and Germany have less investment in stock markets. Germany especially has had a strong investment banking system instead, and these Continental counties have been slower in the adoption of recent technologies as measured by computers per capita and biotechnology startups. New technology industries have arisen in the U.K. and in the U.S., which have stronger equity markets as is visible in the tables above and below.

Country	**Domestic bank credit to private sector as % of GDP**	**Bond market capitalization as % of GDP**	**Stock market capitalization as % of GDP**
France	80.03	5.63	19.54
Germany	86.58	0.13	25.79
Italy	33.04	0.68	21.17
Canada	44.21	7.42	50.56
Japan	104.22	4.74	85.31
UK	53.85	2.48	83.70
US	70.90	23.27	49.85

Adapted from Table VIII from Rajan and Zingales (1995) page 1448.

This paper, at its end, has an example of how a risky movie project was undertaken only when equity capital from Tom Hanks became available for risk-sharing. ("Bose-Einstein Dynamics and Adaptive Contracting in the Motion Picture Industry ", Arthur De Vany, W. David Walls *The Economic Journal*, Vol. 106, No. 439. (Nov., 1996), pp. 1493-1514.

More evidence: John Wilkinson took "a considerable share" of the firm of Watt & Boulton when it was "hard pressed financially." And he ordered the first "rotative engine", meaning Watt steam engine. (Roe, p. 13)

Relevant references cited in files but not yet dug up: Cameron (1967); Crouzet, in files; and especially Freedeman, in files. And Landes (1949), in files, on France and the absence of corporations in the industrial revolution period.

Business / political environment

Conjecture: Low tax rates are not essential to technological takeoffs; stable and predictable taxes, and government services, are chosen instead.

At first this may seem surprising, so it would be especially informative to establish it firmly on an empirical basis.

Tax rates were lower in France than in Britain during the IR. (and possibly also in Ireland?)

Were tax rates also low in the American South at the time technological takeoffs were occurring in the North and the West? I bet they were. Were tax rates low or high in Michigan at the time of the automobile takeoff?

I can establish that California was a high tax state over the period of semiconductor development relative to other states. (I have to think about how broadly framed that should be. Since 1943? Since 1958? Or just since 1968?) I believe I can establish that only once the technology is understood do semiconductor fabs get built in, for example, Texas, New Mexico, Oregon, and the Far East. The Thibeault principle of tax and location choice should tell us then why the entrepreneurs vote with their feet for manufacturing, but not with R&D. It suggests that the expected benefits of being in a low tax environment are significantly positive for manufacturing but low or negative for early R&D.

TBIR93 Note on p. 45-46 that taxes are not central to where the industry arises.

A reasonable theory exists of why this should be – that is, why variations in tax rates (often thought to be critical by those who theorize about physical capital accumulation) would not be critical in a technological takeoff. The technological takeoff is driven by extremely broad distribution of returns from enterprise. Since the variance of returns is so high, the effect of a tax rate on whether the entrepreneur becomes rich is not very great. That is, the probability that the tax rate differences are decisive in whether the entrepreneur achieve wealth level x is small. Far more important determinants of whether the entrepreneur becomes rich are success at product development, product design, hiring appropriate employees, adapting to the product market environment, and appropriate technology adoption. Generally therefore variations in tax rates will not be decisive in the choice of a location.

Carroll, Holtz-Eakin, Rider, and Rosen (1997) show evidence that the reduction in income tax rates in 1986 U.S. tax legislation did increase investments by sole proprietors in their businesses as measured by their tax returns. Is it the case, then, that the entrepreneurs in a technological takeoff respond very differently to tax changes than do the sole proprietors in the study? It may well be, and if so would be worth establishing empirically. Entrepreneurs in a technological takeoff are rarely sole proprietors, since they are attempting to found fast-growing firms, and in general face much greater risk than most sole proprietors which according to the theory above would make them much less sensitive to marginal tax rates. Carroll et al suggest however that the results in their paper would apply to entrepreneurs in general. So there is a difference of opinion which calls for evidence.

Conjecture: Technological takeoffs happen in common-law environments, not civil-law ones, or sharia ones, or totalitarian ones.

Could it be that simple? Is there more to say?
Yes – need some clear statement of how these are different at a micro business level.

Employment relationships and the labor market

Conjecture: During a technological takeoff there is a temporary increase in income inequality among the kinds of workers in the industry who can make relevant microinventions.

Studied in Greenwood-Yorukoglu (1996) and in my other dissertation papers.

The temporary increase is not far from the proposition of the Kuznets curve (Kuznets (1955)). That proposition is that during the early phases of the transition from an agricultural economy to an economy, income inequality increases because the expanding urban industrial sector is more unequal than the agricultural sector. Later, "once the early turbulent phases of industrialization and urbanization had passed, a variety of forces converged to bolster the economic position of the lower-income groups within the urban population. The very fact that after a while, an increasing proportion of the urban population was 'native,' i.e., born in cities rather than in the rural areas, and hence more able to take advantage of the possibilities of city life in preparation for the economic struggle, meant a better chance for organization and adaptation, a better basis for securing greater income shares than was possible for the newly 'immigrant' population coming from the countryside or from abroad. . . . Furthermore, in democratic societies the growing political power of the urban lower-income groups led to a variety of protective and supporting legislation, much of it aimed to counteract the worst effects of rapid industrialization and urbanization and to support the claims of the broad masses for more adequate shares of the growing income of the country." (Kuznets (1955), p 17). This is phrased partly as an information story itself.

In defense of the proposition that the same is found for other technologies:

(1) Goldin and Katz (1996) reports that over the period 1909-1919 at least, and probably generally, high-education industries were also more capital-intensive than the others, and grew faster through 1940. That was a period when new technology was highly capital intensive, so if the education is linked to skill and capital-intensiveness to new technology, the finding may be interpretable as a statement about wage and skill inequality and new technology. (Goldin and Katz (1997) reports some similar finding in regard to industries using electricity in 1900 [cited by Greenwood and Jovanovic (1998)].)
(2) Autor, Katz, and Krueger (1997) can account for 30-50% of the changes in demand for 'skilled' workers in the past 25 or so years to the spread of computers, and within industries not from industry composition suggesting a production process change not a demand change.
(3) Autor, Katz, and Krueger (1997) and Krueger (1993) find that a growing wage differential associated with the use of computers on the job in the U.S. since 1970.

(4) G&J cite a couple of papers that link capital-intensiveness in an industry to its rise in wage inequality since the 1970s, which suggests a technological link.
(5) Murnane and Levy (1996) discuss an example of a bank offering information management services. Over the 1980s its business expanded, as demand rose and technology changed. The bank hired more college graduates than it had before, because it had (a) reduced the routine work and caused job redesign and expansion so that employees took on more work and focused on more difficult problems, and (b) had expanded the range of business opportunities.
(6) North and Thomas (1973) make the case that medieval guilds put restrictions on technologies and workers to such an extent in France and Spain from 1500-1700 that it partly explains why the Netherlands and Britain outperformed France and Spain so much in that period.

[Greenwood and Jovanovic (1998) categorize theories of this phenomenon – income dispersion as a function of technology change -- into capital-skill complementarity types and skill-in-adoption types.]

Related, not particularly supportive evidence: Goldin and Katz (1996a,b as cited in AAK) find that demand for nonproduction worker and educated workers rose in U.S. manufacturing from 1909 to 1929, associated with "capital-deepening", diffusion of purchased electricity, and the introduction of continuous-process and batch methods of production, but wage differentials did not. They offer a labor-supply-side explanation. Notice that if the labor supply side characteristically responds quickly to technological change, the demand side explanations stop being convincing unless they model the supply side too.

TBIR discusses this with respect to the first British Industrial Revolution. Williamson (1985) makes a case from the evidence for a broad temporary dispersion of wages at that time. Feinstein (1988) convincingly disputes that case, and argues that there is no evidence for either dispersion or contraction of the wage distribution. Neither makes a case that focuses on the industries in flux. Harley, TBIR, pp 209-216 does not buy into Williamson's conclusions but adds useful evidence.

As countries develop economists examine them for signs of a Kuznets curve. Takayama and Miyazawa (sp? Date?) report that the Japanese experience of redevelopment after World War II did show a gentle Kuznets curve. Taiwan appears to have been an exception (Fei, Ranis, and Kuo 1979) where the family income distribution had a Gini coefficient that was generally steady or falling (meaning inequality was declining) during its process of industrialization from 1949 through at least 1972. The explanation offered by those authors is that Taiwanese industrialization involved early land reform (1948-58) and investment principally in labor-intensive technologies in rural areas. The investments began in agriculture, food processing, and textiles. Industrialization and increasing use of machinery in these sectors were the stepping stone to others. This suggests that (a) urbanization is associated with the inequality process driving the Kuznets curve, and (b) that the technology evolution in these industries was different from the technology process driving industrialization in other industries and countries. It may be, for example, that Taiwan was adopting well-understood technologies that required relatively little adaptation and learning. If so perhaps it was not necessary to invest in bidding for sophisticated workers or retraining outside the regular work environment. A theory of relationships between technological adoption, labor markets, and inequality should have explanatory power over exceptions like this.

If increases in compensation inequality are intrinsic to the process of technological takeoff, it could help to explain why new technologies are so slowly adopted in certain environments. Consider slavery in particular. The slave contract, so to speak, is like a perpetual debt contract, not the sort of flexible wage or equity contract that seems to be necessary. Perhaps it is just not feasible for the master to give a slave the kind of ownership of a problem that is necessary for technological exploration. In any case we observe that even the well-understood technologies of textile mills were not set up in the American South until after the Civil War. And in Cuba the general adoption of high-throughput continuous-process sugar milling technology followed by a few years the abolition of slavery in 1886. (Alan Dye, various papers, 1993-98)

Conjecture: Wages in the new sector rise faster than in other sectors in the technological takeoff. Working hours extend in the new sector relative to the old sector.

TBIR p 93, and to be shown in my other thesis papers. For the statement on working hours see TBIR p 97. Voth (1998) has also shown unique evidence that the working hours of London workers expanded during the Industrial Revolution.

There is a general observation that Silicon Valley workers have been expected to work long hours; perhaps this can be documented.

[Hours in U.S. blast furnaces were longer than in other work places during the time when blast furnace practice in the U.S. took the world lead. But in Britain, per Carr and Taplin, p146, iron and steelworker hours were still incredibly long – 84 hours a week or more. One report says 12 hours a day, with a 24-hour weekend day once every two weeks. Incredible.]

The reason I expect this conjecture to be true is that certain talents and skills are in short supply during the takeoff and it is therefore more effective for the employer to press a skilled, experienced, or talented worker for more hours than to find comparable workers in the labor market. There is intertemporal and interpersonal labor substitution.

On not hours but strain (not far from "effort") see Mullarkey, Jackson, Wall, Willson, and Grey-Taylor (1997). (Abstract in files)

Conjecture: A technological takeoff includes a wave of immigration of workers who are skilled in the area of the macroinvention, and often of emigration of workers who understand it.

The immigrants want to learn about it or they want high wages because they can contribute to microinventions, or, most realistically, both. These are ability and energy carriers. The emigrants are knowledge carriers.

TBIR p 95 discusses this although not sympathetically.

The point is not that large numbers immigrate but that informed workers do. I believe this is not true in every case, but it may be true generally if the valuable talents and skills are in short supply.

Examples:

(1) from the microprocessor technology: Philippe Kahn, founder of Borland International; the founders of Sun Microsystems; Andrew Grove, cofounder of Intel.

(2) <Need to cite from Duncan Burn's book the particular Germans noteworthy to him, in the Industrial Revolution.>

(3) After the invention of the hot blast technique for iron blast furnaces in 1828, and the discovery of great iron ore beds in the northeast of England, immigrants came. Notable among them were Bolckow, from Germany, one of the founder of Bolckow, Vaughan in 1840, and John Gjers, a Swedish expert in blast furnace design who made important inventions. These innovators were responding to opportunities.

(4) The Siemens brothers (C. William and Frederick) came to Britain to work on advanced blast furnaces from 1840 to 1870.

(5) England under Elizabeth I invited in many foreigners with useful innovations, and this really helped England get its economy going. "Of the fifty-five grants of monopoly privilege made under Elizabeth, twenty-one were issues to aliens or naturalized subjects." (North and Thomas, p. 153). Note that the immigrants are not just bringing abilities here, but information.

Exchange of personnel from Britain to Belgium in the iron business (Carr and Taplin, p40)

Conjecture: Workers move between employers more during a technological takeoff than at other times and places. Technical consultants moving between employers play a key role and may appear more after a great new invention than at other times.

As in Ljungqvist and Sargent (1996). Evidence: High turnover rates in Silicon Valley. Possibly also evidence from the panel data sets in my other dissertation papers.

Some of these breakoffs are important – that's where startups come from. Fairchild Semiconductor spawned many, notably Intel. Also the U.S. Bessemer consulting firm at the time of Bessemer adoption.

Why? Because of the general ferment of talents, mismatches of workers and jobs, instability of new firms, uncertainty about the future, and the heterogeneous information, skill, and talent contributions of workers.

On the subject of technical consultants, Mokyr "the factory system", 2001, ch4, p.143 lists a bunch of them in the British industrial revolution.

See Almeida (1996, esp page 197), for more on this.

Kim &Marschke (2001, page 21, in files) find that scientists and engineers changed employers at a 13%/year clip in 1975 rising slowly to 15.6%/year in 1997. The data came from the March CPS. Jay Stewart (1998) found that overall annual job turnover rate fell from 28.8% to 27.3% over about the same period. Scientists and engineers show the opposite direction of change! Can probably narrow this down by occ & ind.

Conjecture: In a technological takeoff there is an inflow of people to the key industry from many other fields of specialization. Conventional education is not held by all. There is a rise in demand for education reform.

Partly because the industry's own skills aren't what's needed to run with the new technology; some cross-fertilization is natural for the new golden egg.

Plainly true in computer software. Not clear where to start, in saying so.

Bessemer's Autobiography says that as he began to explore making steel or wrought iron in a fluid state, his "knowledge of iron metallurgy was very limited, and consisted only of such facts as an engineer must necessarily observe in the foundry or smith's shop." He adapted a device he had invented for glassmaking.

The British Iron and Steel Institute (started when?? About 1870?) was devoted partly to sharing research but partly to improving metallurgical training once it became clear this area would be important. Industry expert John Jones argued around 1876 that because of the lack of "a highly intelligent class of workmen to carry out the practical details", many valuable inventions had had to be abandoned. Metallurgical expert Bernhard Samuelson decided from experience that it was "next to useless to attempt to give technical education to workmen until their general education had been more thoroughly attended to." (Carr and Taplin, pp 48-49).

Sidney Thomas, inventor of the basic lining, was new to the field but very devoted to it when he made his important discoveries of the basic lining for steel production. The experts in the field did not pay attention to his claims of success in this, in the 1876-78 time period, because they had tried and failed and apparently did not believe him. (Carr and Taplin, p 99).

Roe: "Like most of the early mechanics, he had little or not education" (p. 59, referring to Richard Roberts). Useful to show that skill-bias misses a bunch of the story. Roe details a number of others who were not conventionally educated. Joseph Clement is distinctive insofar as he was only ambiguously literate.

Superb summary of this regarding the machine tools builders on p. 107 of Roe. See notes. These were not particularly men of education, nor did most have a conventional apprenticeship. Few of these early tool builders "were men of education. All were men of powerful minds, many of them with broad intellectual interests. . . . Only three of all these men, Matthew Murray and the two Fairbairns, served a regular apprenticeship. Bentham and Brunel were naval officers; Bramah, a farmer's boy and cabinetmaker; Maudslay, a blacksmith; Clement, a slater; Roberts, a quarry laborer; Nasmyth, a clever school boy; and Whitworth, an office clerk." (Roe, p.107)

Macleod (1986, p. 596-7 footnote 62, in files) makes a list of British industrialists who didn't have university educations. Pre-1840, look for William George Armstrong, Richard

Longdon Hattersley, Henry Lee, William Menelaus, Anthony John Mundella – but these were all born after 1800 and thus late in the IR period.

Conjecture: Adoption of new technology is slower in highly regulated labor markets, and technological change is more likely to bring about a rise in unemployment in a highly regulated labor market.

As in Mortensen and Pissarides (1997) and Ljungqvist and Sargent (1996). These papers compare continental Europe in the 1980s to the U.S. in the 1980s.

Rajan and Zingales papers on Law and Finance make some similar statement.

This statement would follow from the previous ones about turnover and working hours. It should be possible to establish it independently on the basis of direct historical evidence.

Conjecture: A technological takeoff is followed by an increase in demand for worker retraining.

This is not direct evidence, but it's related: Black and Lynch (1996) find that of training programs employers used in the early 1990s, those related to computer-skills development had a positive impact on the organization's productivity, holding constant the industry` the organization was in. The direction of causality here has not been established.

Nelson and Phelps (1966), page 70, cite evidence that the presence of education increases the rate of technological diffusion in agriculture. And their models are designed to produce the finding that "the payoff to increased educational attainment is greater the more technologically progressive is the economy." (p. 74).

TBIR discusses the importance of scientific societies. This is not retraining, however.

This proposition can aid development of a theory if it gives us a handle on the presence of information content in the use of the new technology, e.g. the need for new skills. It is my sense that the demand for worker retraining does not become visible in the general labor market until the late in the takeoff, after the new product or process has evolved a lot towards its final form. Retraining of workers in the takeoff sector itself does not seem to occur early, although a theory might predict it. I believe general early retraining is absent because the takeoff sector is seen as specialized and uncertain in the early period.

Bartel and Sicherman, NBER working paper #5107, May 1975, in OPUB office, discuss this regarding IT revolution.

Carr and Taplin, pp 48-49 are good with the specific example of the iron business in Britain in the 1860s. A big quote from my notes from that book:

> I.L. Bell noted in "his 1873 address to the Institute [ISI] that 'the cultivation of metallurgical science has been much more industriously pursued abroad than has hitherto been the case in this country'." (p48) "As a nation, Britain did indeed show up badly in the organization of scientific training." (A detailed list of Continental schools follows.) "By the 1870s there were relatively fewer highly-qualified scientists in Britain than in the advancing Continental countries, and certainly far fewer concerning themselves directly with industrial production. There was an even bigger disparity in the supply of scientifically-trained technicians. In 1875 there were only three colleges outside London teaching science to an advanced level. For elementary instruction a national system of part-time education had functioned under the auspices of the Science and Art Department of the Board of Trade since the early 1850s, but in 1872, although great progress had been made, less than 37,000 pupils were examined in scientific subjects -- only a fraction of the number of trained operatives needed by industry. The fact that until 1871 the [British] state assumed no responsibility for free elementary education was, as John Jones pointed out to the Iron and Steel Institute in 1876, a major hindrance to the advocates of more widespread technical training for artisans, and constituted a lasting source of weakness in the late nineteenth century industrial race. Jones, in fact, thought that because of the lack of 'a highly intelligent
> class of workmen to carry out the practical details', many really valuable inventions had had to be abandoned. Bernhard Samuelson -- who, of all those in the industry could speak with the most authority upon the subject -- added that experience had proved it was 'next to useless to attempt to give technical education to workmen until their general education had been more thoroughly attended to'." (p48-49)

Conjecture: Collective bargaining never precedes a technological takeoff but often follows it.

Possibly because the uncertainty blocks a common understanding of common interests. Examples:

The automobile business took off in a competitive labor market but became established as a central location of collective bargaining.

Silicon Valley has never been a home of collective bargaining.

The British iron industry began in an environment where the worker had no leverage, then evolved to become the canonical location of recalcitrant organized labor. This is largely a function of the kind of management culture cultivated there, I assume, which may follow from the ‘types’ of managers in a technological takeoff – brash, risk-tolerant, and focused on technology not smooth human relations.

The first strong unions in the British iron business were of puddlers in the 1860s, a time when the decline of that way of doing business was forecastable. (Carr and Taplin, p 56).

Unions form at the rear of technology, among mature technologies staffed by the skilled and educated.

See Lewchuk, 1987, a book reviewed in my files. It apparently shows that British carmakers were constrained by labor in a way that US carmakers were not.

A book by Yellowitz looks like it will be good on this subject.

What does David Montgomery say?

Management and Strategy

Conjecture: In a technological takeoff younger and more technical people, especially engineers, are more likely to run firms than in other times and places.

E.g. the presence of programmers as CEOs now: Bill Gates, Larry Ellison, Gordon Eubanks. Similarly the early steel businesses and car manufacturers had technologists in charge. Thomas Edison was a manager in the early days of lighting (Edison's company became GE.) Utterly true of early machine tools.

It is well established that entrepreneurs have different personal histories than corporate executives generally do; they are more risk-tolerant. (Perez, p 88-89) They got lower grades in school.

High technology startups often have founders in charge for a while, then must have a transition to another chief executive. Venture capital firms have a sense of how this should work and now discuss the situation explicitly with the (usually technical) founder.

The value of establishing this is again that it gives us a measure of the information content needed in the executive at various stages of the takeoff.

Bessemer was an inventor and ran his own firm.
Boulton and Watt may be a counterexample since Watt was the engineer and Boulton the financier.

Take a look at Liebeskind et al (1996) in files, which focuses on superstar scientists; not focused on whether they run the firm or not. Information exchange is crucial to their role.
In Liebeskind et al (1996), page 431, it is stated that Herbert Boyer, of one of the key discoveries/patents, was a founder of Genentech.

In the transistor case, Shockley founded a firm. Then techies founded Fairchild. And then techies founded Intel. And there are partnerships between the techie and a financier, e.g. the founders of Netscape, and Boulton and Watt. One doesn't see pure corporations, however.

Maudslay was made general foreman at Bramah's at age 19, and started his own shop at 27. (Roe, p 34)

Conjecture: Regarding strategies, managers plan less and experiment more.

Bahrami & Evanst 91989) in files; possibly also Campbell-Aspray (2001?) on software biz. Likewise, Ghemawat (1985). Writing in HBR.

Conjecture: Practices diffuse from the new sector.

Stock options in the 1970s in the U.S.. Use of information technology for internal business practices. (Need some evidence on that.)

Scientific training from iron and steel in UK and maybe also in US.

Open-source practices? From hobbyists to IBM.

Venture capital?

The factory, from textiles and/or steam engines.

Diffusion is aided by seeing the practice have some good effect in the earlier sector, but must be adapted to work in later sectors. These are like microinventions.

Earnings inequality may diffuse too, perhaps through practices one could identify. Piece rates? That's not obvious.

Notice that the government is a very visible adopter of new practices, in the sense that it has to come slowly to an explicit decision to adopt, sometimes. The CIA is now backing a venture firm.

It's possible that open sharing of tech information as practiced in the iron and steel industries on both sides of the Atlantic after 1860, and in the machine tools industry in the U.S. in the mid-1800s, etc., had diffused from the steam engine practice in Cornwall of Lean's Reporter.

McGaw, Judith, as cited on Mackenzie p.60, may guide us to a diffusion of labor-saving machinery and corrections in accounting practices for overestimating the costs of labor.

Concluding remarks

Industries using completely new technology appear not necessarily where the first invention occurs but where adaptation is easiest institutionally and socially. This statement can have empirical content with appropriate study. An informational theory of technological adaptation can help to frame the proper roles and importance of employment regulation, taxes, retraining, and other institutions in adaptation. This paper defines some of the facts that an ideal such theory should fit.

The United States and other industrialized countries are now (1998) going permanently into a world competitive environment in which capital, technology, and information moves quickly and flexibly. The U.S. workforce competes against workers paid far less in other countries. As technologies are well understood in any country they can be made available in other countries. The U.S. has de facto committed to finding new technological opportunities and creating new industries in order to maintain a higher standard of living than other countries and low unemployment rates, although this is not always explicitly acknowledged in the political process. Industrialized countries cannot monopolize such high paying opportunities through constraints on capital, nor through better infrastructure which can eventually be imitated. A possible strategy is for them to specialize in the adoption of new technologies and thus maintain higher productivity.

An explicit understanding of the history and theory of technological takeoff and rising industries will be useful for the U.S. to avoid policy mistakes and recognize opportunities of this kind in the future. It is partly for this reason that the present work attempts to systematize this understanding. And more generally, technology advance is required to make drastic improvements in human welfare.

Appendix A. Examples of lists of stylized facts

Dynamic theorists often construct stylized facts for their theories to fit. Examples are below

Layard, Nickell, and Jackman (1991, pp 1-7) have summarized "the key facts to be explained" about national unemployment in industrial economies in the postwar era in a way that does not prejudge which theories might fit them:

1. Unemployment fluctuates over time.
2. Unemployment varies much more between business cycles than within business cycles.
3. The rise in European unemployment has been associated with a massive increase in long-term unemployment.
4. In many countries the level of unemployment has risen sharply relative to the level of vacancies.
5. Unemployment is untrended over the very long term.
6. Unemployment differs greatly between countries.
7. Few unemployed people have deliberately chosen to become unemployed.
8. Unemployment differs greatly between age-groups, occupations, regions, and races.

Cooley and Prescott (1995, p. 32) have summarized stylized facts of business cycles in the postwar U.S.:

1. Magnitudes of fluctuations in output and aggregate hours of work are nearly equal.
2. Employment fluctuates almost as much as output; average weekly hours fluctuate considerably less.
3. Consumption of nondurables and services fluctuates much less than output.
4. Investment in both producers' and consumers' durables fluctuates much more than output.
5. The capital stock fluctuates much less than output and is largely uncorrelated to output.
6. Productivity is slightly procyclical and varies considerably less than output.
7. Wages vary less than productivity.
8. The correlation between average hourly compensation and output is essentially zero.
9. Government expenditures are essentially uncorrelated with output.
10. Imports are more strongly procyclical than exports.

Mortensen and Pissarides (1997), page 3, on unemployment incidence, duration and participation:

1. Participation rates have fallen in Europe but risen substantially in the U.S. from 1960 to 1995.
2. Unemployment in Europe has longer duration and lower incidence than in the U.S.
3. Changes in unemployment rates from the late 1970s to the late 1980s are positively correlated across countries with generosity of unemployment benefits and employment protection policies.
4. Changes in earnings inequality are negatively correlated to changes in unemployment rates between those periods.

Barro and Salai-i-Martin (1995), p 5 on economic growth, citing Kaldor (1963):

1. Per capita output grows over time, and its growth rate does not tend to diminish.
2. Physical capital per worker grows over time.
3. The rate of return to capital is nearly constant.
4. The ratio of physical capital to output is nearly constant.
5. The shares of labor and physical capital in national income are nearly constant.
6. The growth rate of output per worker differs substantially across countries.

Appendix B. On policy; a later section of the book

The arguments here about how a government, economy, and society can prepare to adapt to great new inventions are institutional. That is they have the form not of changing culture but of changing rules and constraints. But it is common to say some cultures adapt to new technologies quickly and others don't because they are culturally different. The French, it has been argued (Landes 1949) are culturally conservative, and inclined to social prestige not to business, and so forth. So it would be unreasonably to expect them to act like the English.

I take this to be true, but nevertheless the institutional steps are good ones, and are likely to help regardless of the general culture, because there are usually exceptions. There are ethnic minorities or immigrants who have different cultural precepts and there are inventive people everywhere who might try their hands in business. If the institutions are encouraging, someone will try. And this can make a real difference. After all, in no country are most people entrepreneurs, inventors, or financiers. But just a few of them can make a great difference. Consider what the growth rate of a country with zero innovators is likely to be, compared to one where there are at least a few. And once there are a few innovative companies, the excitement will eventually spread, as their employees learn the game.

References

Allen, Franklin. 1993. "Stock markets and resource allocation" in C. Mayer and X. Vives (eds.), *Capital Markets and Financial Intermediation*. Cambridge University Press, Cambridge. Pages 81-108.

Autor, David H., Lawrence F. Katz and Alan B. Krueger. 1997 "Computing inequality: have computers changed the labor market?" NBER Working Paper 5956. NBER, March 1997.

Bahk, Byong-Hyong and Michael Gort, "Decomposing learning by doing in plants", *Journal of Political Economy*, 101 (August 1993): 561-583.

Barro, Robert J. and Xavier Salai-i-Martin. 1995. *Economic Growth*. McGraw-Hill, Inc.

Bartel, Ann P. and Frank R. Lichtenberg, "The comparative advantage of educated workers in implementing new technology", *The Review of Economics and Statistics* LXIX (February 1987): 1-11.

Black, Sandra E., and Lisa M. Lynch. "Human-capital investments and productivity" ***American Economic Review*** 86:2 (May 1996): 263-267.

Carroll, Robert, Douglas Holtz-Eakin, Mark Rider, and Harvey S. Rosen. "Entrepreneurs, income taxes, and invetment." Paper prepared for the conference *Does Atlas Shrug? The Economic Consequences of Taxing the Rich* held at University of Michigan. September, 1997.

Cooley, Thomas F. and Edward C. Prescott. 1995. "Economic Growth and Business Cycles" in *Frontiers of Business Cycle Research*. Princeton University Press.

Fei, John C.H., Gustav Ranis, and Shirley W.Y. Kuo. 1979. *Growth with equity: the Taiwan case*. Oxford University Press, for the World Bank.

Goldin, Claudia, and Lawrence F. Katz. "Technology, skill, and the wage structure: insights from the past." *American Economic Review*, 82:2 (May 1996), 252-257.

Goldin, Claudia, and Lawrence F. Katz. 1997. "The origins of technology-skill complementarity." *Quarterly Journal of Economics*, forthcoming [as of Greenwood & Jovanovic time]

Gort, Michael and Steven Klepper. "Time paths in the diffusion of product innovations." *Economic Journal* 92 (1982) 630-653.

Greenwood, Jeremy and Mehmet Yorukoglu. "1974." Carnegie-Rochester Conference Series on Public Policy 46 (June 1997): 49-95.

Klepper, Steven and Elizabeth Graddy. "The evolution of new industries and the determinants of market structure." *RAND Journal of Economics* 21: 1 (Spring 1990), 27-44.

Krueger, Alan B. "How Computers Have Changed the Wage Structure? Evidence from Micro Data." *Quarterly Journal of Economics*. (February 1993): 33:60. [This title may not be quite right; double check.]

Kuznets, 1955, *American Economic Review*.

Landes, David S. 1993. "The fable of the dead horse; or, the Industrial Revolution revisited." In *The British Industrial Revolution: an economic perspective*. Joel Mokyr, editor. Westview Press, Inc.

Lane, Sarah J. "Entry and industry evolution: the ATM manufacturers market." Boston University School of Management, working paper. July, 1995.

Landau, Ralph. 1996. "Strategy for Economic Growth: Lessons from the Chemical Industry." In *The Mosaic of Economic Growth*, edited by Ralph Landau, Timothy Taylor, and Gavin Wright. Stanford University Press.

Layard, Richard, Stephen Nickell, and Richard Jackman. 1991,1994. *Unemployment: Macroeconomic Performance and the Labour Market*. Oxford University Press.

Levy, Frank and Richard J. Murnane. "With what skills are computers a complement?" *American Economic Review* 86:2 (May 1996): 258-262.

Lipsey, Richard G., Cliff Bekar, and Kenneth Carlaw. 1998. "What requires explanation?" Chapter 2 of *General purpose technologies and economic growth*, edited by Elhanan Helpman. MIT Press.

Mokyr, Joel. 1990. *Lever of Riches: Technological Creativity and Economic Progress*. Oxford University Press.

Mokyr, Joel, editor. 1993. *The British Industrial Revolution: an economic perspective*. Westview Press, Inc.

Mokyr, Joel, editor. 1998. *The British Industrial Revolution: an economic perspective*, second edition. Draft.

Mortensen, Dale, and Christopher A. Pissarides. "Unemployment Responses to 'Skill-Biased' Technology Shocks: The Role of Labor Market Policy" CEP/CEPR Workshop on Growth, Trade, and the Labour Market." London, UK. July 1997.

Nelson, Richard R., and Edmund S. Phelps. "Investment in humans, technological diffusion, and economic growth." *American Economic Review*". 1966. 69-75.

Nelson, Richard R., and Sidney G. Winter. "The Schumpeterian tradeoff revisited." *American Economic Review*. 1982. 114-132.

Perez, Robert C. *Inside Venture Capital*.

Rajan, Raghuram G., and Luigi Zingales. 1995. "What do we know about capital structure? Some evidence from international data" *Journal of Finance L:5* (December 1995), p 1421-1460.

Rosenberg, Nathan. 1996. "Uncertainty and Technological Change." In *The Mosaic of Economic Growth*, edited by Ralph Landau, Timothy Taylor, and Gavin Wright. Stanford University Press.

Trajtenberg, Manuel. "A penny for your quotes: patent citations and the value of innovations." *RAND Journal of Economics* 21:1 (Spring, 1990), 172-187.

Zucker, Lynne G., Michael R. Darby, and Marilynn B. Brewer. "Intellectual human capital and the birth of U.S. biotechnology enterprises." *American Economic Review* 88:1 (March 1998), 290-306.
