Note on Technology and Critical Mass

Econ 570

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1 Introduction

These notes are inspired by Mokyr's book *The Gifts of Athena*.

The key to Modern economic growth is the transformation of negative into positive feedback. A phase transition occurs. But why? The Malthusian mechanism is one such negative feedback. We have argued that what is key in modern economic growth is that a threshold is achieved which leads to positive growth – a cumulative process. How?

Notice that before the modern period technological improvements occurred, but they did *not* amount to a key force for growth. Smithian factors were more important before the last couple of centuries.[1] Pre-industrial revolution growth was Smithian. But then technology took over, before the demographic revolution. Of course there was interaction – growth in trade, organization, property rights affected the returns to innovation. Also communication had a big impact.

Before 1750 knowledge was insufficient to make technological growth cumulative. An innovation occurs, but then the system stabilizes. Trial and error without mechanics. So innovations were not improved on. Technological change in this era is serendipitous, not causal. A critical point is that prior to 1750 even informed mechanics, chemists and farmers knew not enough about the fields of knowledge they sought to apply. Not enough was known to generate sustained economic growth based on technological change.

A similar problem occurs with institutions. For much of history, and perhaps for much of the world, institutions are a conservative force. Increases

[1] E.G., Imperial Rome, Venice, Genoa and Flemish cities fourished on the basis of commerical progress.

in wealth were dissipated through rent-seeking, and other predation that cooked the geese laying golden eggs. Often it was tax collectors and pirates or brigands. Or Mercantilism. The most insidious were institutions that resisted technological innovations.[2]

On this idea, the key to modern economic growth is the reversal of these processes. How does it happen?

One key element of this is what Mokyr calls the "Industrial Enlightenment." What is meant by this? It is a change in the culture and environment within which technology and science operate.

2 Knowledge

To understand the industrial enlightenment we need to distinguish two types of knowledge: propositional and prescriptive. The latter is invented, the former is discovered only (DNA existed before Crick-Watson). Propositional knowledge forms the *epistemic base* of society. It limits what can be done.

- Propositional knowledge need not be correct: the humoral theory of disease led to prescriptions that worked, such as the draining of swamps to cure malaria.
- The wider the epistemic base the lower the cost of research and development and the greater the likelihood of success.
- The wider the base the easier it is to improve an invention, primarily because more is known about why something works. It makes recombination with other techniques easier

3 Industrial Revolution

Some key points about the IR. First, it is wider than Britain. And it is application as much as invention. Britain had much greater success at applying inventions than in generating them. In France, for example, much talent was diverted to war and politics. Lavoisier was executed as a tax farmer.

[2] Not just the church but also medical establishments which resisted Jenner's discoveries with regard to smallpox.

Britain was also special in the willingness to adopt what was invented elsewhere (gas lighting, chlorine bleaching, Jacquard loom, Leblanc soda making process, for example).

Britain was also fortunate in that it had workers who could take advantage, and political institutions that were more adaptable to change. Continental countries had more medieval debris to remove. More rent-seeking and regulation, and more difficulty in removing it.

The key point about the IR was not just the clusters of inventions, but the persistence of technical change after the first wave. No petering out after 1800. It is really the second wave that starts the acceleration of per-capita income.

3.1 Why Did it Succeed?

Key was developments of useful knowledge before and around 1750. "What mattered was not so much scientific knowledge itself but the method and culture involving the generation and diffusion of propositional knowledge. The Industrial Revolution and its aftermath were based on a set of propositional knowledge that was not only increasing in size, but which was becoming increasingly accessible, and in which segments that were more effective were becoming tighter (Mokyr, 2003: 23)."

- scientific knowledge becomes public
- exogenous decline in access costs to propositional knowledge (including use of vernacular).

4 Technology

The limitations to the knowledge base cease to act as much of a constraint by the 18th century. Modern science helps to understand *why* things work. Blind alleys are forestalled.

It is important to recognize this interaction. Often we think of technology as the result of R&D input. If demand is great enough innovation will occur. But some innovations are beyond our current knowledge – there is a demand for AIDS cures or cheap 8-hour laptop batteries, but we don't know yet. What does knowing mean?

But the important point is that technology feeds back into science just as science advances technology

1. *focusing devices.* Technology poses well-defined problems for science to look at. It influences the research agenda, further enhancing the value of the science. As an example, the Newcomen steam engine induced research into the laws governing energy efficiency, which led to the laws of thermodynamics

2. *artificial revelation.* Technical advances in instruments overcomes the limitations of the senses. Think of microscopes and telescopes

3. *rhetoric of knowledge.* techniques are not true or false – they work or not. This is a much more open system. An important way to confirm knowledge – see if it works. Combats doctrinal authority and hierarchy. This helps science advance.

5 Industrial Enlightenment

This is the historical episode where it takes place. Like the general enlightenment but more concentrated on the application of ideas to industry and agriculture. It is a movement, the "Bacon Program". Bacon was the first to regard knowledge as something growing.

Mokyr sees it as a movement.

Three purposes

1. reduce access costs to technical knowledge[3]

2. understand why techniques worked

3. facilitate interaction between those who understood and those who did

We see this in scientific societies and societies of arts. Also catalogs, and definition of units and terms. Lowered barriers to diffusion of knowledge.

[3]The Industrial Enlightenment realized instinctively that one of the great sources of technological stagnation was a social divide between those who knew things (" savants") and those who made things (" fabricants"). To construct pipelines through which those two groups could communicate was at the very heart of the movement.

- Key institutional change made it possible: discoveries were no longer hidden but diffused to achieve priority
- notion of intellectual property came into being
- How to reward ingenuity?
  - first-mover advantage
  - secrecy (limited by reverse engineering possibilities)
  - subsidies and prizes
  - patents

Mokyr's point is that this is the way that "intellectual changes in the eighteenth century gradually transformed the way in which institutions affected technology." Other factors contributed by the key is the "positive feedback mechanisms *within* the sphere of useful knowledge and those *between* useful knowledge and institutions that changed the course of history [**?**, 28]."

This episode led to the breakout from concavity.

It was a peculiar historical episode in Europe that created this industrial enlightenment. The key economic question is why has it spread to some regions and not others? Why are some countries able to take advantage and in others not?

To summarize, then, the Industrial Revolution had intellectual roots that needed to be met if sustained economic growth could take place just as it had to satisfy economic and social conditions. The importance of property rights, incentives, factor markets, natural resources, law and order, market integration, and many other economic elements is not in question. But we need to realize that without understanding the growth of useful knowledge, the technological elements will remain inside a black box.

6 Technological Modernity

Why did the notion that knowledge is not stagnant arise? Why was there a phase transition where positive feedback arises? Evolutionary models predict explosions of change when conditions are ripe (as in the Cambrian explosion, or the post-KT event). Most growth models miss what happened. It is not

number of scientists,[4] or changing rates of return to human capital.[5] Britain was not the most literate place. How many inventors and truly technically able people were needed to generate sustained technological progress.[6]

Feedback between prescriptive and propositional knowledge is important

- steam engine and thermodynamics
- optics and batteries for chemical piles[7]
- Flight to aerodynamics

In addition to the positive feedback within the two types of knowledge, one might add the obvious observation that access costs were themselves a function of improving techniques, through better communications, storage, and travel techniques. Greater and greater combinations of known things are possible.

But obviously knowledge only creates opportunity. It does not guarantee action. Why the decline in negative institutional feedback.

7 Institutional Feedback

Why did the 18th century also see a slow (but uneven) decline in negative institutional feedback?

[4]It seems that only a small tail is responsible for the innovations, and some de-skilling actually took place initially.

[5]Fertility rates came down much later than the Industrial Revolution.

[6]Production techniques became more modular and standardized, meaning that labor might become more specialized and that each worker had to know less rather than more. If much of the new technology introduced after 1825 was like the self-actor— simpler to use if more complex to build— it may well be that the best model to explain technological progress (in the sense of inventing new techniques rather than implementing existing ones) is not the mean level of human capital (or, as model-builders have it, the level of human capital of a representative agent), but just the density in the upper tail of the distribution, that is, the level of education and sophistication of a small and pivotal elite of engineers, mechanics, and chemists, dexterous, motivated, imaginative, well-trained technically, with some understanding of some of the science involved.

[7]Without microscopes how would Pasteur have refuted the spontaneous generation theory to establish the germ theory? Indeed, the widespread use of glass in lenses and instruments in the West was itself something coincidental, a "giant accident," possibly a by-product of demand for wine and different construction technology.

What happened to make the view that knowledge will be socially useful, even though it can be socially disruptive and politically dangerous? The Luddites did rebel but they were not successful (everywhere). Why? Resistance was also important in the medical industry. Jenner's discovery was resisted. He was told "not to risk his reputation by presenting to this learned body anything which appeared so much at variance with established knowledge and withal so incredible."[8]

Key process hard to understand. Clearly uneven across countries

The key event is a change in cultural beliefs that made possible the industrial enlightenment. Not just cultural beliefs, though, but also the metaphysical beliefs that people held about their environment and nature, and their attitudes toward the relationship between production and useful knowledge. It should also include their cultural beliefs about the possibility and desirability of progress and their notions of economic freedom, property, and novelty.

It is interesting to note that this cultural change occurs after many other institutional innovations in Europe, such as corporations, formal law, individualism, self-governance, property rights. These elements did not trigger modern growth because they occurred prior to the industrial enlightenment.

Useful knowledge grows because in each society there are people who are creative and original, and motivated by some combination of greed, ambition, curiosity, and altruism. Yet in order to be translated from personal predilections to facts on the ground and from there to economic growth, an environment that produced the correct incentives and the proper access to knowledge had to be there. The uniqueness of the European Enlightenment was that it created that kind of environment.

[8] Jenner's famous discovery of the smallpox vaccine ran into the opposition of the inoculators concerned about losing their lucrative trade (Hopkins, 1983, p. 83). The source of the vaccine, infected animals, was a novelty and led to resistance in and of itself: Clergy objected to the technique because of the "iniquity of transferring disease from the beasts of the field to Man" (Cartwright, 1977, p. 86). Cartoonists depicted people acquiring bovine traits, and one woman complained that after he daughter was vaccinated she coughed like a cow and grew hairy (Hopkins, 1983, p. 84). Despite all this, of course, the smallpox vaccine was one of the most successful macroinventions of the period of the Industrial Revolution and its inventor became an international celebrity.

8 Interaction between Institutions and Technology

There are interactions and feedbacks between I and T.

8.1 From $T \rightarrow I$

- T creates markets
  - think of reduction in transportation costs
  - improvements in communications
  - military advances created the nation state which helped make rule of law feasible
- T creates forms of business appropriate to its needs
  - factory system
  - business corporation, with separation of ownership and control, with ability to raise capital and large fixed investments
    - clearly related to the rise of the railroad (Chandler)
- Rise to technical universities needed due to advances in technology

8.2 From $I \rightarrow T$

- Institutions can frame the agenda
  - With the wrong institutional setup the brains in society are devoted to economically unproductive ideas. Think of Confucian and Talmudic scholars.
- Institutions affect how we choose between competing theories. What is an acceptable proof?[9] If commercial success is rewarded this leads to the *rhetoric of knowledge* effect mentioned above.

[9] Interesting to ponder the link between open societies and scientific discovery, ala Popper.

- Institutions affect how knowledge is shared and communicated, if at all
  - accessible or secret[10]
  - do the informed interact with those who can productively use knowledge, from the *savants* to the *fabricants*. In technologically advanced societies "intellectuals get dirt under their fingernails."
- Institutions affect whether knowledge will create "techniques"
  - sets up incentives and payoffs for discoveries and applications
  - patents are an obvious notion here
- Diffusion
  - institutions can block diffusion – act as barriers – via vested interests, and governments worried about political instability and unemployment
  - fear of technology – the EU and genetically modified crops
  - hierarchy can impede diffusion, ala my paper – it exacerbates incentive problems that arise from incomplete information. Hierarchy implies greater costs to reveal hidden information, hence it is costlier to induce adoption of innovations in a hierarchy
- coordination
  - for innovations to be successful coordination may be required. A firm may allow for this, allowing capital and labor to collaborate to make the innovation work. Lack of such institutional arrangements may defeat it

remark Innovations open doors, and institutions invite or prohibit the economy to walk through

- think of the holy inquisition versus current US rewards to innovators

[10] numbered copies of economics texts in USSR.

9 Institutions and Income Differences

If technology or know-how was the only thing that explained differences in income it would be easy to teach Zimbabwe to be rich. Knowledge can diffuse, but educated labor goes the wrong way. The key problem is that technology diffuses easier than institutions that are amenable to economic growth

- note that Iraq and Pakistan are better at importing western technology than efficient institutions
  - This suggests that institutions are critical to *cross-country* differences
- but over time, Germany is richer now than in 1815 due to differences in knowledge, so that is the key for time series differences.
- Notice that because of success we now *demand* that technology solve problems, from AIDS to pollution. The industrial enlightenment caused optimism to replace fatalism

References

[1] Mokyr, Joel, "Thinking About Technology and Institutions," October 2002.