Transformative Technologies in the Past Present and Future: Implications for the U.S. Economy and U.S Economic Policy

ITIF Breakfast Forum

July 2007

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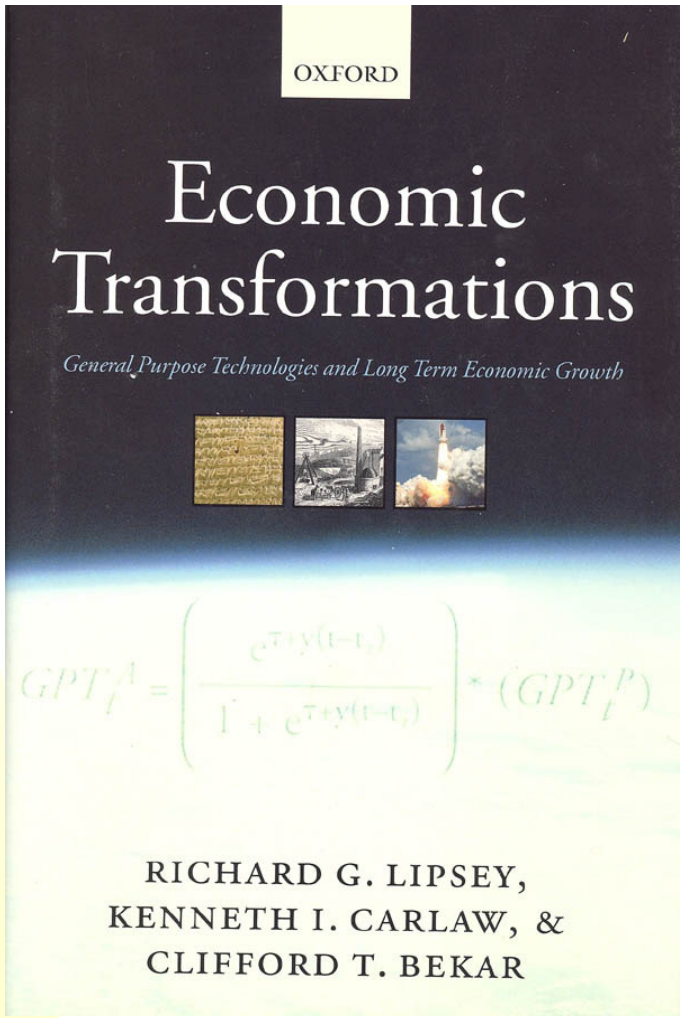
Most of the material I will discuss today is drawn from Richard Lipsey, Kenneth Carlaw, and Clifford Bekar,

ECONOMIC TRANSFORMATIONS: General Purpose Technologies and Long Term Economic Growth

Available through all good bookshops, or direct from Oxford University Press at:
URL: http://www.oup.co.uk/isbn/0-19-929089-X
URL: http://www.amazon.com


OXFORD
Economic Transformations
General Purpose Technologies and Long Term Economic Growth
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KENNETH I. CARLAW, &
CLIFFORD T. BEKAR

I. What Is The New Economy?

As I use the term, the New Economy refers to the social, economic and political changes bought about by the current revolution in information and communication technologies (ICTs).

- That revolution is being driven by the computer, lasers, satellites, fiber optics, the Internet and a few other related communication technologies (many of which were developed with the assistance of computers).
- It is an economy-wide ***process*** not located in just one hi-tech ***sector***, any more than the New Economy initiated by electricity was confined to the electricity-generating sector

II. GPTs

The electronic computer is an example of a transforming General Purpose Technology (GPT). Main GPT characteristics:

- typically start in a relatively crude form for a single or very few purposes
- increase in sophistication and efficiency as they diffuse through the economy,
- as mature GPTs they are used throughout most of the economy and for many different uses while having myriad spillovers in the form of externalities and technological complementarities.
- Evolution from crude beginnings to fully fledged GPT takes many decades, sometimes centuries.

- The responses to a new GPT cannot be modelled as the consequence of changes in the prices of flows of factor services produced by the previous GPT.
- Because most of the action is taking place in the technological structure of capital.
- The new possibilities depend on how one technology is related to another, not on how a given technology can respond to a change in price.

For example, the most profound effects of electricity came not from a fall in the price of power, but in making possible new products and new process that were technically unavailable with steam, such as assembly line production, refrigerators, vacuum cleaners and microwave ovens, to mention just a few .

Any technological change requires alterations in the structure of the economy, changes that often proceed incrementally, more or less unnoticed.

Some major new GPTs cause extensive structural changes to such things as the organisation of work, the management of firms, skill requirements, the location and concentration of industry, and supporting infrastructure—***all of which we call the economy's facilitating structure.***

"Transforming GPTs," lead to massive changes in many, sometimes most, characteristics of the economic, social, and political structures. ***Other GPTs do not***. Electricity is a good example of the former; the laser of the latter.

III. New Economies Throughout History

Our list for transforming GPTs from 10,000 BC to 1900 AD is as follows:

1) The domestication of plants. *10000 BC*
2) The domestication of animals *8000 BC*
3) the smelting of ore 7000-6000
4) Pottery *6000 BC*
5) The wheel *5000 BC*
6) Writing *3400 BC*
7) Bronze *2800 BC*
8) Iron *1200 BC*

- The water wheel *Early medieval period*

9) The heavy plough *Early Medieval period*
10) The three masted sailing ship *13th century AD*
11) Printing *14th century*
12) The steam engine *18th century*
13) The factory system *18th century*
14) The railway *19th century*
15) The internal combustion engine *19th century*
16) Electricity *19th century*
17) Mass production late 19th early 20th century

This list shows three things:

- That the kind of ICT induced economic-social-political transformation that we are living through today s *not* unique in history.
- That those transformations are relatively rare in history.
- That the interval between them has been diminishing over the last couple of centuries.

  - Note that new transforming technologies induce massive changes but do not determine precisely what these will be, since they are also influenced by the social, political, and economic structure into which they are introduced. New technologies strongly influence, but do not fully determine, what happens in these adjustments.

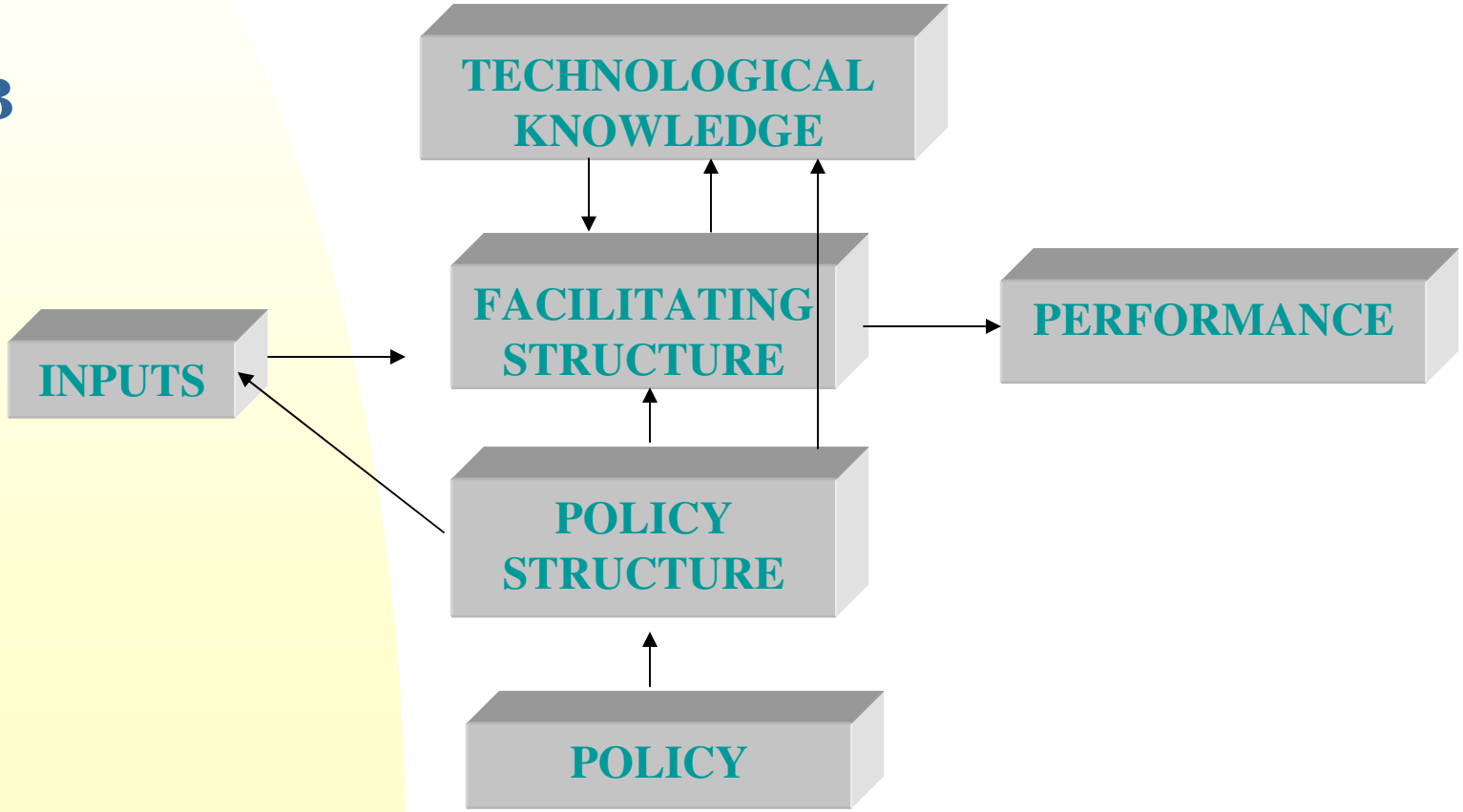
Can New GPTs be identified by accelerations in productivity growth?

- Common erroneous beliefs: new GPTs lead sooner or later to a “productivity bonus”.
- The expectations of a productivity bonus necessary accompanying the introduction of every new transforming GPT is ill founded.
- Growth economists typically have these expectations because in any model based on an aggregate production function there can be no technological change without productivity growth.
- This is shown in Part A of the figure.
- In part B we go inside the black box of the neo classical production function.

Part A


INPUTS
PRODUCTION FUNCTION
PERFORMANCE

Part B


TECHNOLOGICAL KNOWLEDGE
FACILITATING STRUCTURE
INPUTS
PERFORMANCE
POLICY STRUCTURE
POLICY

1) Although a new technology will be instituted whenever it promises to be profitable, there is no guarantee that each new GPT will have larger, or even the same, life-time effects on productivity as the ones that preceded it (however this is measured).
2) Even if one GPT has a larger impact than its predecessor, it may take longer to work through the economy and thus show smaller gains in each year***.***
3) the extent to which the new technology comes to pervade the economy and the extent of the induced changes in the facilitating and policy structures bear no necessary relation to the induced changes in productivity or real wages.
4) ***It is true that*** if no further GPTs were invented to provide new research programs, the number of derivative technological developments would eventually diminish. ***But it does not follow that*** each successive GPT will increase the average rate of productivity growth over all previous GPTs. ***GPTs sustain the growth process; they do not necessarily accelerate it.***

5) Fifth, there are reasons why a new GPT may slow the growth of productivity during the first stages of its introduction below what it will be on average over its lifetime followed by an acceleration to its average rate after the facilitating structure has been fully adopted.

- Not a real productivity bonus in the sense that the GPT has brought more productivity growth than previous new technologies.
- Only a return to whatever underlying rate of growth the particular GPT in question will produce.

- Neither is it a phenomenon that is necessarily associated with all new GPTs. The possibility of a slow down is problematic because (1) at any one time there are likely to be several GPTs, at least one in each of the categories listed above and each at various stages of its development and (2) typically, the existing GPT in any one category has not been fully exploited when another challenges it.

6) Traditional measures of productivity, including total factor productivity, emphatically do not measure technological change, in spite of the common opinion to the contrary.

IV. Some Key Characteristics of the New ICT Driven Economy

Process technologies

- Computerized robots and related technologies have transformed the modern factory and eliminated most of the high-paying, low-skilled jobs that existed in the old Fordist assembly line factories. (G)
- Computer assisted design (G)
- Surgery by computers, which will soon facilitate distant surgery permitting specialists working in major urban hospitals to operate on patients in remote parts of the world. (S)

- Instead of flying to Ottawa, lawyers make teleconferencing submissions to the Supreme Court of Canada, turning a two day slog into a two hour effort. (S)
- Research changed dramatically by the ability to do complex calculations that were either impossible or prohibitively time consuming without computers. (S)
- Computer age crime detection in which the biological and the ICT revolutions complement each other as is so often the case with co-existing GPTs (S)
- Traffic control in the air and on the ground and at sea has been revolutionized (S)

Organizational technologies

- In management the direct lines of communication opened up by computers eliminated the need for the old pyramidal structure in which middle managers processed and communicated information leading to today's horizontally organized loose structures (G&S)
- Firms are increasingly disintegrating their operations. (G)
- The e-lance economy, groups of independent contractors who come together for a single job then disperse, is growing. (S)
- Just as the First Industrial Revolution took work out of the home, the ICT revolution is putting much of it back. (S)
- ICTs have been central to the globalization of trade in manufactured goods, and of the market for unskilled workers, shifting the location of much manufacturing and allowed poorer countries to industrialize. (G&S)
- Digitalized special effects have changed the movie industry in many ways. (S)

Product technologies

(G = goods; S = services)

- Many goods now contain chips that allow them to do new things or old things more efficiently. (G)
- Computer and satellite linked ATMs allow access to one's bank account and obtaining funds in any currency in almost any part of the world. (S)
- Email has largely replaced conventional mail with a large increase in volume and speed of transmission. (S)
- The ability to download music into computers that burn CDs is welcomed by many users while threatening the music recording industry. (G)
- Computerized translation is a now reality. (S)
- Children do school work by consulting the Internet. (S)

Product technologies

- Distant education allows many to be enrolled in education courses where they never (or only rarely) set foot inside the institution that they are “attending”. (S)
- Cars can now receive real time information on traffic conditions at all points in their projected journey. (S)
- Smart buildings and factories already exist and will grow rapidly in number. (G&S)
- The electronic book with blank pages fill up on demand with any one of a hundred or more books stored in a chip that is housed in its cover. (G)

Political and social

- The computer-enabled Internet is revolutionizing everything from interpersonal relations to political activity.
- Driven by the Internet, English is becoming a lingua franca for the world and, unlike Latin in the Middle Ages, its use is not limited to the intelligentsia.
- With computers, email links and a host of other ICTs, the age-old link between physical presence and service provision has been broken in many lines with profound social and political effects.

I cannot help but marvel over how many observers can assert, first, that all of these rich events can be adequately summarized in one series for productivity (usually total factor productivity) and, second, that the existence or non existence of this entire ICT revolution depends on how this number is now behaving in comparison with how it behaved over the past couple of decades!

V. Structuralist-Evolutionary (S-E)

Two views of the economy

Neoclassical

- Tastes and technology are the two exogenous variables.
- Maximizing agents equate the expected returns from a marginal unit of expenditure everywhere in the economy, ***including all lines of R&D***.
- Given all the other standard assumptions, an income or a welfare-maximizing equilibrium exists.
- Departures from this equilibrium are caused by market failures

Endogeneity: Because R&D is an expensive activity which is often undertaken by firms in search of profit, innovation is partly endogenous to the economic system, altering in response to changes in perceived profit opportunities.

Uncertainty: Uncertain events have neither well-defined probability distributions nor well-defined expected values. Because innovation means doing something not done before, it always involves an element of Knightian uncertainty.

- When major technological advances are attempted, it is typically impossible even to enumerate in advance the possible outcomes of a particular line of research.
- Furthermore, the search for one objective often produces results of value for quite different objectives.
- There is also enormous uncertainty with respect to the range of applications that some new technology may have.
- No one knows how long their new technologies will go on being useful.

- *The basic uncertainty surrounding invention, innovation and diffusion does not arise from a lack of information that one might feasibly obtain given enough time and money.*
- *It arises from the nature of knowledge.*

A key characteristic of risky situations is that two agents possessed of the same information set, and presented with the same set of alternative actions, will make the same choice—the one that maximises the expected value of the outcome.

A key characteristic of uncertain situations, however, is that two equally well-informed agents presented with the same set of alternatives actions may make different choices. If the choice concerns R&D, one may back one line of attack while the other backs a second line, even though both know the same things and both are searching for the same technological breakthrough.

Non-maximization and non-optimality

- *Because firms are making R&D choices under uncertainty, there is no unique line of behaviour that maximises their expected profits—if there were, all equally well-informed firms would be seeking the same breakthrough made in the same way.*

- *Because of the absence of a unique best line of behaviour, firms are better seen as groping into an uncertain future in a purposeful and profit-seeking manner (instead of maximizing the expected value of future profits).*

- *This approach to the behaviour of firms has a long lineage going back at least to the work of Herbert Simon. Later it was pioneered in relation to growth and technical change in a seminal book by Richard Nelson and Sidney Winter (1982).*

Contrast in desirable characteristics.

Neoclassical desirable market characteristics include:

- *the absence of market power so that price taking is the typical situation*
- *prices are equal to opportunity costs and do not, therefore, allow for any pure profits*
- *rents associated with market power of oligopolies and monopolies or other forms of market power are eliminated*
- *sources of non convexities such as scale effects and high entry costs are minimal or non-existent.*

S-E characteristics that drive the economy towards desirable results ***are the very characteristics that are undesirable sources of market imperfections in neoclassical economics.***

- *Although the special case of an entrenched monopoly that does not innovate is regarded as undesirable, most other market "imperfections" are the very stuff of economic development.*
- *In the past it was oligopolies that did most. They still do much today but smaller enterprises, enabled by the ICT revolution, now do much more than in the recent past.*
- *Market power gives firms the opportunity to exploit temporary advantages brought about by their own or other's research.*
- *Profits drive the system and really large ones are the carrot that pushes agents to attempt **leaps into the unknown** and to make many more modest decisions under conditions of uncertainty.*

- *Path dependent evolutions brought about by new technologies are preferable to static equilibriums.*
- *Non convexities are a key part of the desirable growth process. Scale effects, rather than being imperfections to be offset, are some of the most desirable results of new technologies.*
- *Entry costs for new products and new firms are the accepted costs of innovation and the source of some of the rents that drive such behavior.*

Neoclassical policy implications

Neoclassical policy advice is quite general applying to all times and places and is not context specific" remove market imperfections wherever possible.
Policy with respect to technical change: the basic analysis is Arrow's:

- *The return to society from a new technology greatly exceeds the private return to the entrepreneur who introduces it. (The difference is what economists call an externality.) Thus the entrepreneur will do less R&D than is socially desirable. In technical terms, if private benefits are equated at the margin in all lines of economic activity, and there is a large externality in R&D but not elsewhere, too few resources will be allocated to R&D compared to all other lines of activity.)*

- *Encouraging these activities through public policy may, therefore, be welfare enhancing.*
- *If the only source of externalities is the non rivalrous aspect of new knowledge, R&D will be below its optimal rate, giving policies to encourage the potential to increase welfare.*
- *If the externalities are uniform across all lines of R&D, a generalized R&D subsidy is appropriate and, in principle, can restore a first-best optimum.*
- *In contrast, more focused policies are judged to be non-optimal. The reason is that such policies* ***selectively distort the price and profit signals*** *that are generated by perfectly competitive markets. Although such policies may sometimes yield a positive net benefit, more benefit can always be achieved by devoting the same expenditure under a non-distorting framework policy*

S-E Theory Policy Implications

- Profit seeking in the presence of uncertainty, rather than profit maximizing in the presence of risk,
- => no unique optimum allocation of resources.
- => there does not exist a unique set of scientifically determined, optimum public policies with respect to technological change in general and R&D or human capital in particular. .

IF THERE ARE NO UNIQUE OPTIMUM RATES OF R&D, INNOVATION OR TECHNOLOGICAL CHANGE, POLICY WITH RESPECT TO THESE MATTERS MUST BE BASED ON A MIXTURE OF THEORY, MEASUREMENT AND SUBJECTIVE JUDGMENT.

Thus good policies are context specific.

Technologies can be singled out

Neoclassical theory calls for a generalized subsidy to all R&D as *the* optimal policy. It is opposed to policies that focus on specific sectors or technologies.

S-E theorists stress that, given endogenous technological change taking place under uncertainty, there is no theoretical justification for the neoclassical condemnation of focused policies. They then argue that the debate should be settled on grounds of evidence. Here there is voluminous evidence that focused policies can be successful.

- Many countries, including the US, went through the early stages of industrialisation with substantial tariff protection for its infant industries.
- Publicly funded US land grant colleges have done important agricultural research from their inception in the 19th century.
- The 20th century "green revolution" was to a great extent researched by public funds. In its early stages.

- the US commercial aircraft industry received substantial assistance from the National Advisory Committee on Aeronautics (NACA) which, among other things, pioneered the development of large wind tunnels, and demonstrated the superiority of the retractable landing gear.
- The airframe for the Boeing 707 and the engines for the 747 were both developed in publicly funded military versions before being transferred to successful civilian aircraft.
- Electronic computers and atomic energy were largely created in response to military needs and military funding.
- For many years, support for the US semiconductor industry came mainly from military procurement whose rigid standards and quality controls helped to standardise practices and to diffuse technical knowledge.
- The US government's heavy involvement in the early stages of the US software industry produced two major spin-offs to the commercial sector. One was an infrastructure of academic experts, built largely with government funding; the other was the establishment of high and uniform industry standards.
- The post war Japanese automobile industry
- The Taiwanese government literally created its electronics industry from scratch using government owned firms that once they became successful were hived of to private owners.

- Given that governments can and have picked many winners (usually in cooperation with private sector agents and;
- Given that governments can and have picked many "turkeys";

- It follows that the time has come when ideological extreme positions need to be abandoned and the following questions addressed

  - What are the conditions that increase the chance of "picking" of winners and reduce the chances of picking turkeys.

Ken Carlaw and I have studied over 30 cases of government policies designed to encourage specific winners around the world and developed over 20 “lessons” of *do’s and don'ts* that deal with this key question.

These lessons are discussed in some detail in Chapter 17 of Lipsey, Carlaw and Bekar.

Those are only meant as a beginning and I urge further research to refine and add to our list.

Is market orientation enough?

- *Many neoclassical economists argue that creating a market oriented environment is a sufficient goal for public policy.*
- *Others argue that, although necessary, instituting the measures of the market-oriented consensus is not sufficient. They argue the need for more focussed policies—always understood that these are in addition to, not substitutes for, the market-orienting policies.*

- *Accepting that new technological knowledge, has major positive externalities provides a reason to encourage technological advance with public funds.*

- *Accepting that technology changes endogenously provides a reason why present comparative advantage can be changed by public policy as well as by the private sector.*

- *Accepting that technological change is highly dependent on local contexts implies that the best policies are context specific rather than being the same for all countries at all times.*

- *Accepting the conclusion that there is no unique optimum rates of R&D, of innovation, and of diffusion, implies policy with respect to these matters must be based, as we have already argued, on a mixture of theory, measurement and subjective judgement.*

These ideas are both powerful and dangerous. They are powerful because they suggest ways to go beyond neoclassical generic policy advice to more context-specific advice. They are dangerous because they can easily be used to justify ignoring the market-oriented consensus, accepting only the interventionist part of the S-E policy advice (forgetting that this is meant to supplement the advice of the consensus, not to replace it).

VI. CONCLUSION

"Economic analysis will no doubt be used in the future to analyse many dismal economic events. But the days when the underlying basis of the subject justified the title "dismal science" are over. The modern title should become "the optimistic science"—not because economics predicts inevitable growth or the arrival of universal bliss, but because its underlying structure, altered to incorporate the economics of knowledge, implies no limit to real-income-creating, sustainable growth, operating in a basically market-organized society. If we cannot achieve sustained and sustainable economic growth, the fault dear Brutus must lie with ourselves not with some iron-clad economic law that dictates failure before we start."