MOT1421
Economic Foundations
Week Four

TECHNOLOGICAL CHANGE

S. STORM

LECTURE NOTE MOT1421-W-4

The Lecture Note MOT1421-W-4 is part of the exam materials.
The required reading for Week 4 consists of:

- Lecture Note MOT1421 W-4.
- Chapter 16 "EVOLUTIONARY THEORIES OF TECHNOLOGICAL AND ECONOMIC CHANGE" (pp. 449-474) in S. Himmelweit, R. Simonetti and A. Trigg, Microeconomics. Neoclassical and Institutional Perspectives on Economic Behaviour (**posted on Brightspace**).

Supporting video:

- https://www.youtube.com/watch?v=p18Wtd-e66M explanation of growth accounting.

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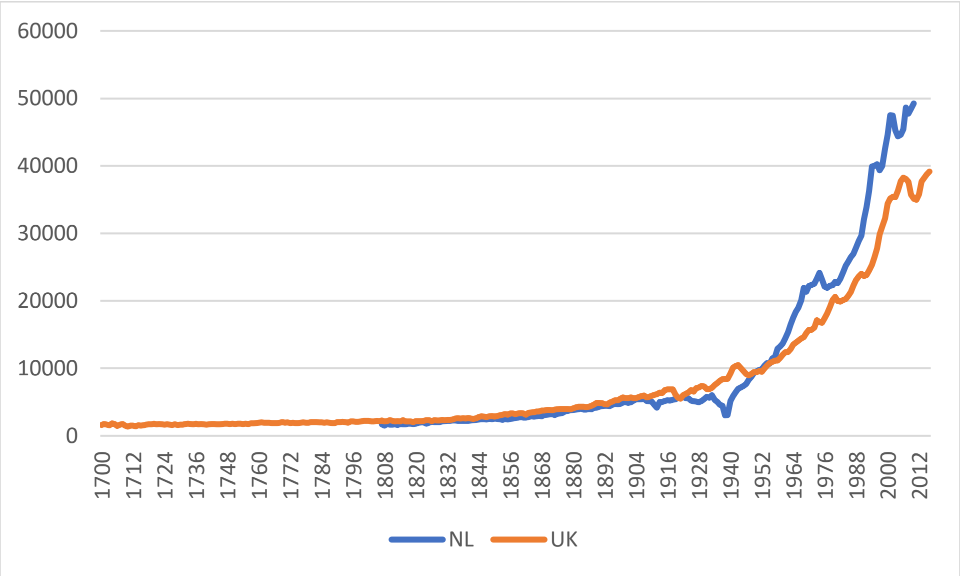
Introduction

Between 1700 and 2016, real income per person in Western Europe has increased by a factor of 25 – see Figure 1 which presents evidence on per person real income growth for the Netherlands and the U.K. This historically unprecedented era of high and sustained economic growth started with the **Industrial Revolution** in Britain, when (1) there was a substitution of mechanical devices for human activity and skills; (2) inanimate power – in particular, steam and later electricity – took the place of human, animal, and wind and water power; and (3) there were important innovations in the metallurgical and chemical industries. It was the **diffusion of (new) machines** – in the textile industry – which made the Industrial Revolution. The technological advance was a **cumulative process**: innovations in certain industries spilled over into improvements in other industries and the whole economy, especially innovations in energy generation and mechanisation. In sum, a key determinant of economic growth has been technological progress – and an unprecedented number of innovations.

Figure 1
Per capita real income
in the U.K. (1700-2016) and the Netherlands (1807-2016)



Source: Maddison Project Database 2018; link: https://www.rug.nl/ggdc/historicaldevelopment/maddison/releases/maddison-project-database-2018

Economists often use the Cobb-Douglas production function to evaluate the sources of per capita real income growth. Let us look at the following two-factor **Cobb-Douglas production function** and assume constant returns to scale:

(1) $x = a \times L^{\alpha} \times K^{1-\alpha}$ with $0 < \alpha < 1$

If we divide both sides of eq. (1) by the number of workers *L*, we get:

(2) $\frac{x}{L} = a \times (\frac{K}{L})^{1-\alpha}$

Eq. (2) states that real output per worker $\frac{x}{L}$ is a positive function of the capital-labour ratio (*K/L*) or capital intensity. According to this equation, increases in real income per person (or in real income per worker $\frac{x}{L}$) are caused by increases in capital intensity over time. But it is by now incontrovertible that increases in per capita income cannot be simply and fully explained by increases in the capital-labour ratio. As we shall see, **technological progress is a more important driver of economic growth than capital formation**.

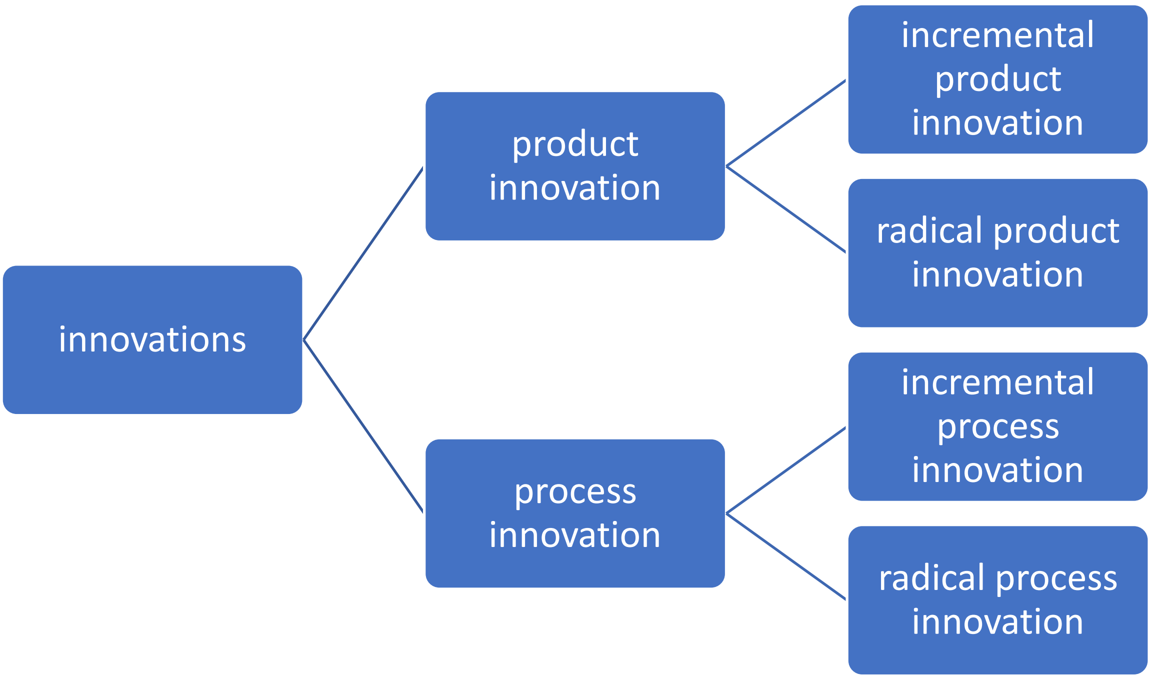
Motivated by a wish to explain the historically unprecedented rise in living standards and real incomes (Figure 1), economists turned to exploring the sources of technological progress. In the next section, we consider general approaches to technological progress, before we proceed to the more formal growth-accounting model of neutral technological progress.

General concepts: technological change and innovation

Economists distinguish various types of technological change and innovation. Figure 2 presents a (rough-and-ready) classification of innovations. A first distinction is between **product innovations** (= the introduction of a new good or services) and **process innovation** (= the introduction of a new method of producing an existing good or services). A further distinction can be made between **incremental innovations** and **radical innovations**. The majority of innovation (> 90%) are incremental in nature.

Incremental product innovation concerns a series of small improvements made to a company's existing products or services. Generally, these low-cost improvements help further differentiate a company from the competition while building on current offerings. Consider the Apple iPhone: Since its debut in 2007, the phone's basic design has remained largely the same, and Apple has yet to release an entirely new type of phone. Instead, the tech giant has released a slightly upgraded version of the iPhone at regular intervals, with improved cameras, graphics, and other features that build off of the current model. A second example is Gillette razors, which started life with a single blade but their product has evolved, adding different features and more blades as the company has sought to better meet customer needs. And Cadbury Chocolates has innovated through introducing line extensions: as well as developing new flavours, the brand has also created new formats; for example, Cadbury made a popular chocolate bar available as a hot chocolate and a snacking bag.

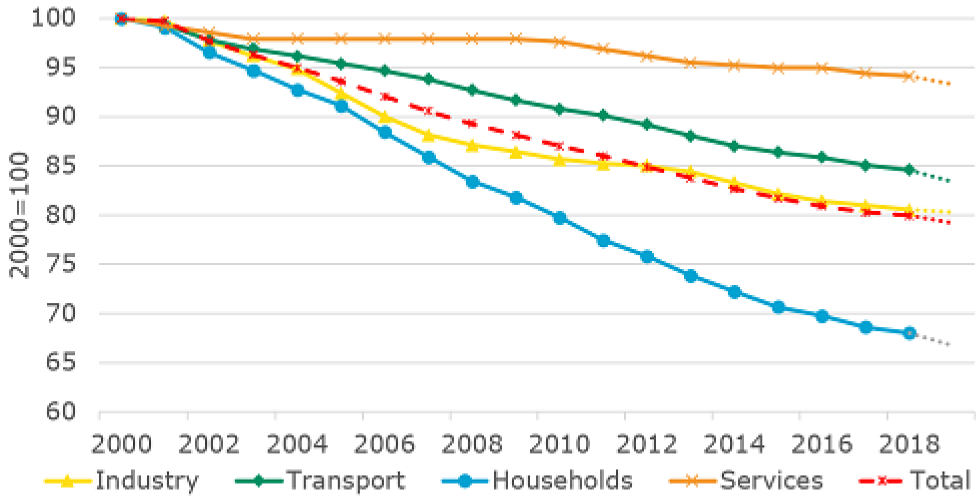
Figure 2
A typology of innovations



Radical product innovation refers to the introduction of a radically new product or service designed to replace an existing one. In the same way in which cars eventually replaced horse-drawn carriages, radical innovations dramatically alter the consumer landscape as well as the business model of firms. Transistors developed by Bell Labs uprooted the major players in the electronics industry who were all at the time focusing on vacuum tube technology. Farming equipment producer John Deere took notice of emergent sensory technology and added sensors to its tractors. Farmers could track and monitor their crops' yield via sensor, which revolutionized the farming industry. The flush closet, the vacuum cleaner, wooden shoes, digital cameras, the telephone, mobile phones, the wind turbine, electronic calculators, the TV, the PC, and word-processing software are all excellent examples of the role radical product innovation can play to disrupt an industry.

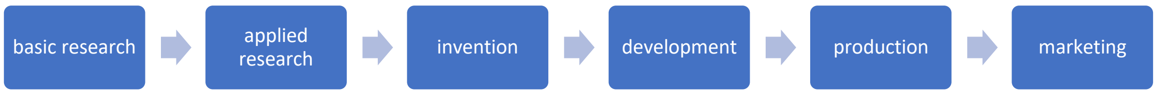
Incremental process innovation refers to the process of constantly implementing small improvements in an established production process of a good or service. established design. Improvement occurs in individual components of the production process, but the underlying core design concepts, and the links between them, remain the same. Incremental process innovation is a cumulative process that builds on existing knowledge and resources. Examples of incremental process innovations include improvements in the energy efficiency of production processes (see Figure 3); the reduction of waste (including carbon emissions), originating from production; improved logistics to reduce inventories and delivery times; and measures to improve the productivity of labour. Incremental process innovation includes changes across all the value-chain activities.

Figure 3
Energy efficiency trends in the E.U. (2000-2018)



Radical process innovation upsets and disrupts the established production process (of a good or service) and establishes a new dominant design of the production process. Radical process innovation requires new knowledge – and new skills and routines. Radical process innovation is risky – as it requires large-scale finance in a new, unproven technology. Radical process innovations may lead to the introduction of **general-purpose technologies** (GPTs): technologies that drastically change the way in which the economy is working. Examples include steam power, railroad, interchangeable parts, electricity, electronics, material handling, mechanization, control theory (automation), robotics, the automobile, the computer, the internet, and artificial intelligence (AI).

What are the **sources of innovation**? Economists have long recognised **scientific research** as one of the main sources of new technology. Scientific research is done in universities (stage 1: basic research) and in large industrial corporations (stage 2: applied research with direct commercial applications in mind; and stage 3: RD&D, directed toward incremental product and process innovation). These three stages of research have been seen as stages of a linear **technology-push process of innovation**:



Innovation is seen as process; only after the new product or process has been introduced into the market, can we talk about *innovation*. As Joseph Schumpeter (1926) argued: "As long as [the inventions] are not carried into practice, inventions are economically irrelevant. And to carry any improvement into effect is a task entirely different from the inventing of it, and a task, moreover, requiring entirely different kinds of aptitudes. Although entrepreneurs of course may be inventors just as they may be capitalists, they are inventors not by nature of their function but by coincidence and vice versa."

The **technology-push model of innovation** has been very influential in economic policy, witness the arguments in favour of government support for basic research and private-sector RD&D. However, in this model, market demand does not play a significant role in shaping the rate and direction of technological change.

This is different in the **demand-pull model of innovation**. In this model, economic activity influences innovative effort. Firms tend to put their innovative investment into areas where demand is growing, so that they can recoup their costs and reap greater returns on their investment. The demand-pull model of innovation was first proposed by Jacob Schmookler (1966) in his book *Invention and Economic Growth*. Schmookler's main contention, contrary to the prevailing emphasis on changes in scientific and technological knowledge, was that demand played a leading role in determining both the direction and magnitude of inventive activity. His basic underlying premises were two: (1) that the ability to make inventions is widespread, flexible, and responsive to profit-making opportunities; and (2) that the larger an actual or potential market is, the more inventive activity will be directed toward it, because the profitability of invention rises with market size, all else equal. In Schmookler's view, knowledge bases were highly adaptable, and so, the applications to which they were put depended upon relative profitability, which in turn depended upon demand.

Schmookler's writing showed that technological change need not be treated as an exogenous variable. On the contrary, he showed that the changing direction of inventive activity could be accounted for by readily identifiable economic variables, most especially changes in the pattern of demand that determine the size of the prospective market, and hence potential profitability, for particular classes of inventions.

Both the technology-push and the demand-pull model of innovation are **linear models of innovation**. More recent research treats technology as a **system of innovation in which technological knowledge is accumulated by different actors and institutions** which are inter-related.

The system perspective on innovation goes back at least to the Friedrich List´s (1841) conception of "*The National System of Political Economy*" (**see box 1**). The (national) system of innovation can be defined as that set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artefacts which define new technologies. Figure 4 presents a schematic overview of such a (non-linear) system of innovation.

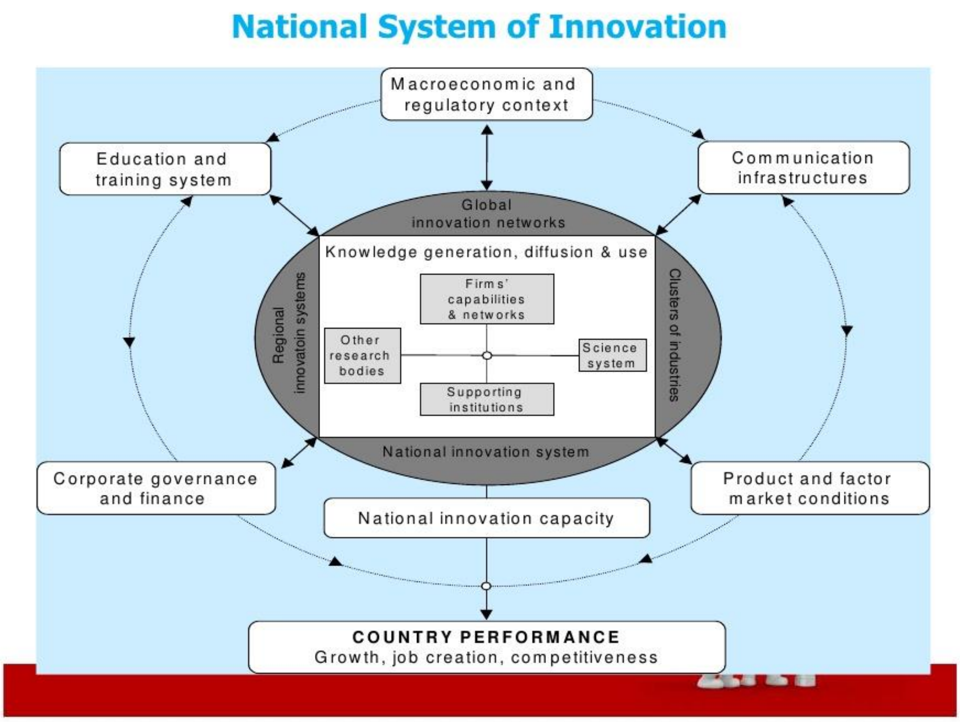
Box 1

Friedrich List (on a stamp)
(1789-1846), German-American economist

Friedrich List developed the "National System" of political economy. He was a forefather of the German historical school of economics and he advocated imposing tariffs on imported goods while supporting free trade of domestic goods, and stated the cost of a tariff should be seen as an investment in a nation's future productivity.

List's influence among developing nations has been considerable. Japan has followed his model. It has also been argued that Deng Xiaoping's post-Mao policies were inspired by List.

Figure 4



Technological change: the neoclassical approach

In Lecture Note W-3B, we reviewed the neoclassical approach to technological progress. Using isoquants and the production function, we discussed three forms of technological progress: (a) neutral; (b) labour-saving; and (c) capital-saving.

American economist Robert Solow (1957) used the production-function approach to measure the contribution of technological progress to economic growth (see **box 2**). Solow's study was an empirical investigation of the sources of economic growth in the U.S.A. during 1909-1949. Solow's aim was to measure the contributions to economic growth of (***a***) capital accumulation; and (***b***) neutral technological progress, using a new method, now known as the **growth-accounting model**. We will explore Solow's growth-accounting model below.

Box 2

Robert M. Solow
(b. 1924),
American macroeconomist,
Massachusetts Institute of Technology

Robert Solow is best known for his work on economic growth and his neoclassical growth model. Using his model, Solow (1957) calculated that about four-fifths of the growth in US output per worker was attributable to technical progress (measured as total-factor-productivity growth). "Any rapid technological change creates winners and losers amongst workers," Solow says. "There's no law of economics that says that it's impossible for the robots to do more and more, better and cheaper. Maybe in a hundred years, we'll all be taking care of each other rather than producing goods and services, the robots will be doing that. Let them." Solow believes that a well-functioning society will find ways of providing for people who lose their income due to technological change. In 1987 he was awarded the Nobel Prize in economics.

The growth-accounting model of Robert Solow

Solow began by postulating the following two-factor **Cobb-Douglas production function** and by assuming constant returns to scale:

(1) $$x = a \times L^{\alpha} \times K^{1-\alpha}$$

x = real output; L = the input of labour; K = the input of capital (= machines); a = the efficiency parameter (a scale factor). The two exponents (which add up to 1) are technical coefficients (which have to be empirically estimated using data). Dividing both sides of eq. (1) by the number of workers L, Solow obtained the following expression:

(2) $$\frac{x}{L} = a \times (\frac{K}{L})^{1-\alpha}$$

Eq. (2) states that real output per worker $\frac{x}{L}$ is a positive function of the capital-labour ratio (K/L) or capital intensity. Let us define $\frac{x}{L} = \lambda =$ labour productivity, and $\frac{K}{L} = \kappa =$ capital intensity (or the ratio of capital to labour). Eq. (2) then becomes:

(3) $$\lambda = a \times \kappa^{1-\alpha}$$

Totally differentiating eq. (3) gives:

(4) $$\Delta \lambda = \kappa^{1-\alpha} \times \Delta a + a \times (1-\alpha) \times \kappa^{-\alpha} \times \Delta\kappa$$

Dividing both sides of eq. (4) by $\lambda = a \times \kappa^{1-\alpha}$ and re-arranging yields:

(5) $$\frac{\Delta\lambda}{\lambda} = \frac{\kappa^{1-\alpha} \times \Delta a}{a \times \kappa^{1-\alpha}} + \frac{a \times (1-\alpha) \times \kappa^{-\alpha} \times \Delta\kappa}{a \times \kappa^{1-\alpha}} = \frac{\Delta a}{a} + (1-\alpha) \times \frac{\Delta\kappa}{\kappa}$$

Let $\frac{\Delta\lambda}{\lambda} = \hat{\lambda} =$ the growth of labour productivity; $\frac{\Delta a}{a} = \hat{a} =$ total-factor-productivity (TFP) growth; and $\frac{\Delta\kappa}{\kappa} = \hat{\kappa} =$ the growth of capital intensity. We can thus write down Solow's **growth accounting model**:

(6) $$\hat{\lambda} = \hat{a} + (1-\alpha) \times \hat{\kappa}$$

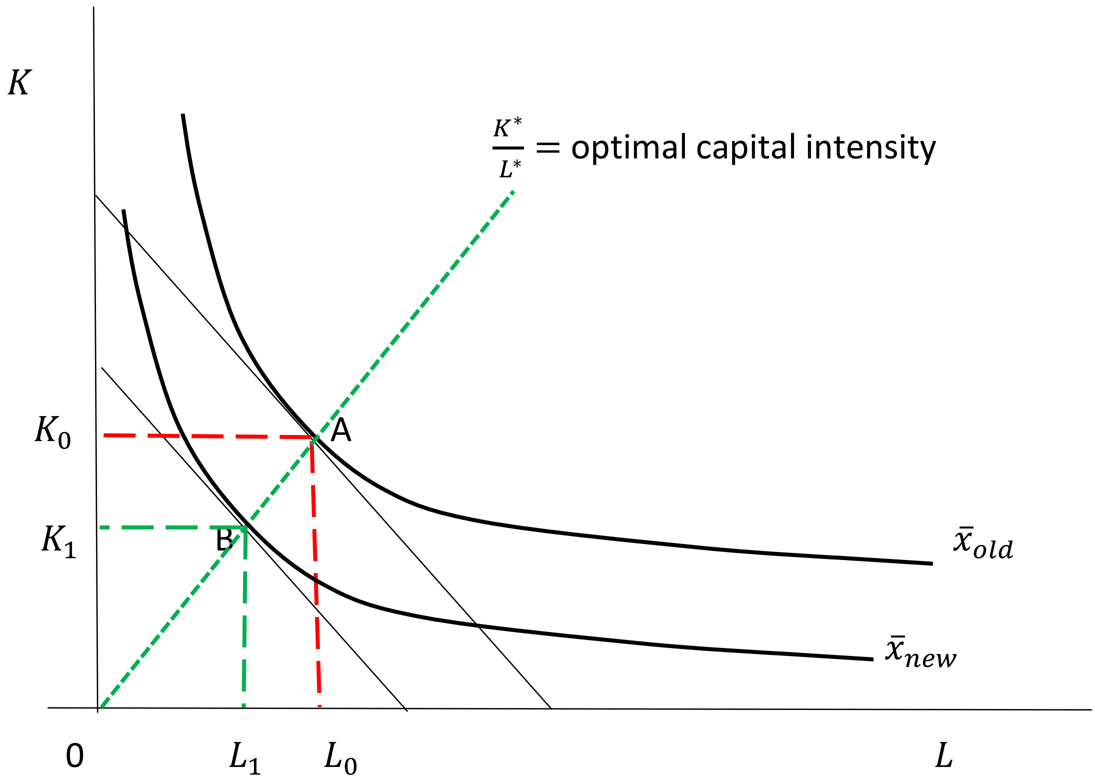
The growth rate of labour productivity can be decomposed into two terms:

- the term $(1-\alpha) \times \hat{\kappa}$, which expresses the contribution to labour productivity growth of capital intensity growth; and

- the term $\hat{a}$, which (in a production function framework) expresses the rate of neutral technological progress. The term is usually called **total-factor-productivity growth**.

In Lecture Note W-3B, we did see that an increase in the efficiency parameter a is defined as neutral technological progress (see Figure 5). The growth rate of a thus represents the rate of neutral technological progress over time.

Figure 5
Neutral technological progress



How does one use Solow's growth-accounting model? To use the model, one needs to have data on (i) the <u>growth of labour productivity</u> (for an industry or an economy) during a particular period of time, (ii) the <u>growth of capital intensity</u> (in an industry or an economy) during the same time-period, and (iii) the technical coefficient α. Data on labour productivity (growth) and capital intensity (growth) can be found in the national accounts statistics. We use data from the AMECO database of the European Union (see Table 1).

Let us suppose that we find that average labour productivity growth in Belgium equalled 2.43% per year during 1960-2008; hence $\hat{\lambda} = 2.43$; and that we find that the growth rate of capital intensity in Belgium is 2.10% per year during the same period; $\hat{\kappa} = 2.10$. Empirical estimation of coefficient α based on Belgian data gives us the following estimate for $\alpha = 0.68$. Using these numbers, we can now estimate the rate of neutral technological progress $\hat{a}$ as a **residual**, using eq. (6):

(7) $$\hat{a} = \hat{\lambda} - (1 - \alpha) \times \hat{\kappa} = 2.43 - (1 - 0.68) \times 2.10 = 1.75\%$$

Belgian total-factor-productivity (TFP) growth during 1960-2008 was 1.75% per year.

Table 1

Growth accounting (1960-2008): estimating TFP growth

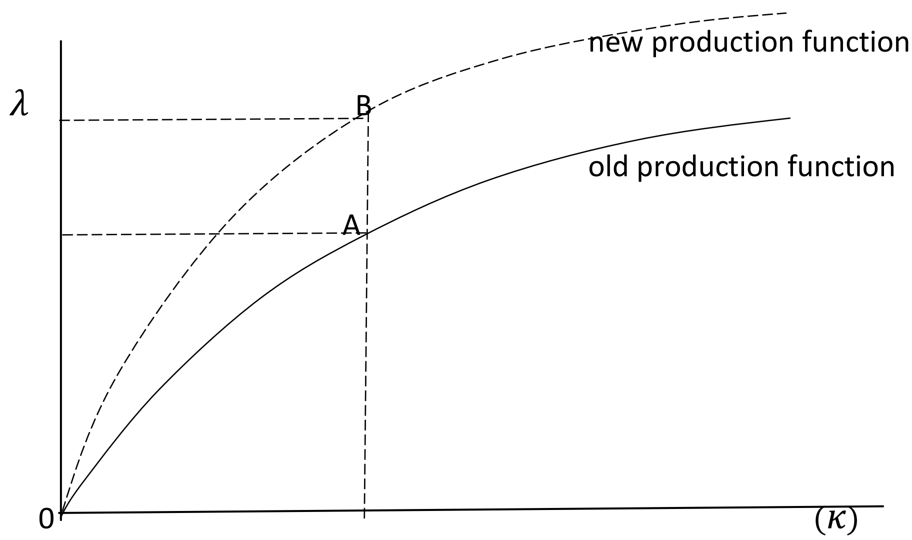
	$\hat{\lambda}$	$\hat{\kappa}$	α	$\hat{a} = \hat{\lambda} - (1-\alpha) \times \hat{\kappa}$	$\hat{a}$ as % of $\hat{\lambda}$
Belgium	2.43	2.10	0.68	1.75	72
Denmark	1.98	1.49	0.67	1.49	75
Germany	1.91	1.88	0.67	1.29	67
Greece	3.32	3.58	0.60	1.90	57
Spain	2.96	3.03	0.68	1.98	67
France	2.60	2.54	0.70	1.84	71
Italy	2.62	2.79	0.65	1.65	63
Netherlands	2.11	1.76	0.69	1.56	74
Austria	2.68	2.90	0.69	1.79	67
Portugal	3.50	3.41	0.70	2.49	71
Finland	3.11	2.86	0.68	2.21	71
Sweden	2.26	2.60	0.64	1.32	59
United Kingdom	2.13	1.54	0.64	1.57	74
Norway	2.40	2.20	0.61	1.53	64
Switzerland	1.21	1.15	0.65	0.81	67
Australia	1.58	1.23	0.65	1.15	73
Canada	1.36	0.72	0.66	1.11	82
Japan	3.67	3.70	0.68	2.51	68
United States	1.75	1.20	0.65	1.33	76
average	2.40	2.25	0.66	1.65	69

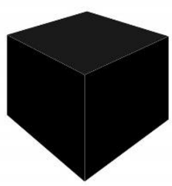
Source: calculated based on AMECO database.

We have done this not just for Belgium, but for 18 other OECD economies. The (unweighted) average rate of TFP growth in these 19 countries during 1960-2008 was 1.65%. These findings may look startling. <u>**About 70%**</u> of the growth in output per worker (= labour productivity growth) in these countries over the period 1960-2008 is accounted for by <u>**the Solow residual**</u> (i.e. TFP).

Figure 6 illustrates how a change in *a* (or TFP) shifts up the production function. The difference between productivity levels A and B is due to TFP growth.

Figure 6



Solow's growth-accounting finding confirmed the view that (neutral) <u>technological progress is more important for economic growth than capital accumulation</u> (= adding more machines per worker). At the same time, Solow does not clearly define his measure of technological progress, but just labels the residual (in the growth accounting model) TFP growth. TFP growth, or total factor productivity growth, is the change in labour productivity that we cannot attribute to changes in capital intensity. Solow's measure of technological progress is therefore rather **black-box**.  We don't know what is inside. There is also no analysis of the sources of new technology.

Solow's TFP measure can be criticised on the following grounds:

1. The production function analysis assumes that production is technically efficient – and firms choose a technique of production on the isoquant. The isoquant is based on the assumption that firms can choose out of a range of best-practice techniques, all known and accessible. This neglects the fact that in reality, the diffusion of new technology takes time and costs money. Firms may not (yet) be on the isoquant, and when they move toward the isoquant (see Figure 15.9 in the HST book), their productivity rises without any technological progress actually occurring.
2. Any mistake in measuring labour productivity and/or capital intensity will affect the residual and hence our estimate of TFP growth. Suppose we fail to account for improvements in the existing capital stock (= the machines in use), which have led to a higher productivity of labour. In our growth-accounting scheme, these improvements will incorrectly show up as extra TFP growth. (The improvement of existing machines does not constitute technological progress.)
3. The TFP estimate does not provide insight in the sources of technological progress, but only expresses the rate of advance.

The fact that TFP growth 'explains' 70% of labour productivity growth in the OECD countries can – perhaps better – be considered as a **<u>measure of our ignorance</u>**: economists can only attribute 30% of labour productivity growth to capital-intensity growth, but cannot explain the remaining 70%,

Technological change: evolutionary economics

The evolutionary-economics approach to technological progress goes back to the work of Austrian-American economist Joseph Alois Schumpeter (see **box 3**). The central point of Schumpeter's whole life work is that capitalism can only be understood as an evolutionary process of continuous **innovation** and '**creative destruction**'.

Schumpeter starts in his *The Theory of Economic Development* with a distinction between:

- the **circular flow** which, because these are periods without any radical innovations and innovative activities, leads to a stationary state; and
- **(long) growth cycles** which are caused by radical innovations, clustered in time. long cycles are caused by innovation, and are an incident of it. The longest such cycle is the Kondratiev cycle (which lasts 45-60 years). In Schumpeter's view, technological innovation is at the cause of both cyclical instability and economic growth. <u>Fluctuations in innovation cause fluctuation in investment and those cause cycles in economic growth</u>. Schumpeter sees innovations as clustering around certain points in time periods that he refers to as "neighbourhoods of equilibrium", when entrepreneurs perceive that risk and returns warrant innovative commitments. These clusters lead to long cycles by generating periods of acceleration in aggregate growth.

Schumpeter identified innovation as the main driver of economic progress. Innovation, in turn, was dependent upon the entrepreneur: the hero in Schumpeter's analysis of capitalism. Entrepreneurial activity upsets the (stationary) circular flow and leads to a structural transformation of the economy. Schumpeter called this '**creative destruction**'.

> "Capitalism ... is by nature a form or method of economic change and not only never is but never can be stationary. ... The fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers' goods, the new methods of production or transportation, the new markets, the new forms of industrial organization that capitalist enterprise creates. …… The opening up of new markets, foreign or domestic, and the organizational development from the craft shop and factory to such concerns as U.S. Steel illustrate the process of industrial mutation that incessantly revolutionizes the economic structure *from within*, incessantly destroying

> the old one, incessantly creating a new one. This process of Creative Destruction is the essential fact about capitalism. It is what capitalism consists in and what every capitalist concern has got to live in. [.....] Capitalism requires the perennial gale of Creative Destruction." (Schumpeter, Joseph A. (1994) [1942]. *Capitalism, Socialism and Democracy*. London: Routledge. pp. 82–83).

According to Schumpeter, the "gale of creative destruction" describes the "process of industrial mutation that continuously revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one." Emphasizing **dynamic efficiency**, Schumpeter sought to prove that innovation-originated market power can provide better results than the invisible hand and price competition. He argued that technological innovation often creates temporary monopolies, allowing abnormal profits that would soon be competed away by rivals and imitators. These temporary monopolies were necessary to provide the incentive for firms to develop new products and processes.

Box 3

Joseph Alois Schumpeter
(1883-1950),
Austrian-American macroeconomist,
Harvard University

Schumpeter was a professor of economics in Vienna and from March 1919 until 1921, he was the Minister of Finance in the Austrian government. In 1932 he migrated to the U.S. and became a professor at Harvard University. Schumpeter was probably the first scholar to theorize about entrepreneurship, and the field owed much to his contributions. He coined the term 'creative destruction'.

In 1942 published what became the most popular of all his works, *Capitalism, Socialism and Democracy*, reprinted many times and in many languages. Robert Solow (box 2) was Schumpeter's student.

The fact that Schumpeter stressed the importance for innovation of temporary monopolies, points to a more general issue: (perfectly competitive) markets tend to underinvest in innovative activity. Why is this the case?

- due to the **presence of indivisibilities**:
  - \# innovation is based on the production of new knowledge, which (generally) requires a large investment.
  - \# the bulk of the **costs of knowledge production are fixed**. As a result, the marginal cost of the new knowledge is much lower than the average cost.
  - \# To recoup the initial investment costs, the innovative firm has to set price > average cost (P > AC).
  - \# The more competitive the market is, the more difficult it is for the firm to obtain a price > marginal cost, and the more likely there will be underinvestment in knowledge production.

- due to the **in-appropriability of the returns from an innovative investment**.
  - \# Knowledge (information) is **non-rival and non-excludable** (public good). It creates positive externalities.
  - \# Knowing that it will not be able to recoup all the costs of innovation, the firm may not innovate in the first place.
  - \# Patents are meant to help the firm to appropriate the returns from an innovation. The monopoly is a reward for innovative effort.
  - \# The difficulty of appropriability is reduced when the innovation is based on tacit (rather than codified) knowledge.

- due to **uncertainty** (which is not diversifiable through the stock market or banks, and not insurable).
- due to **increasing returns to scale** and **path dependence** (see below): any new technology serves as input for successive innovations.

Following the Schumpeterian approach, **evolutionary economics** places the firm and the entrepreneur at the centre of their theory. Evolutionary economics rejects the neoclassical assumption of instrumental rationality, and instead uses the concept of **bounded rationality**. Entrepreneurs may be over-optimistic and develop a new technology, because they lack reliable information about the future efficiency of the novel technology and about the possible spill-over effects of the technology.

Firms adopt **routines** – rules of thumb – to guide their decision-making. Such routines determine what firms do and don't do. Like individuals, firms are assumed to learn through experience and to update their routines (based on experience). Routines are the first building block of evolutionary models.

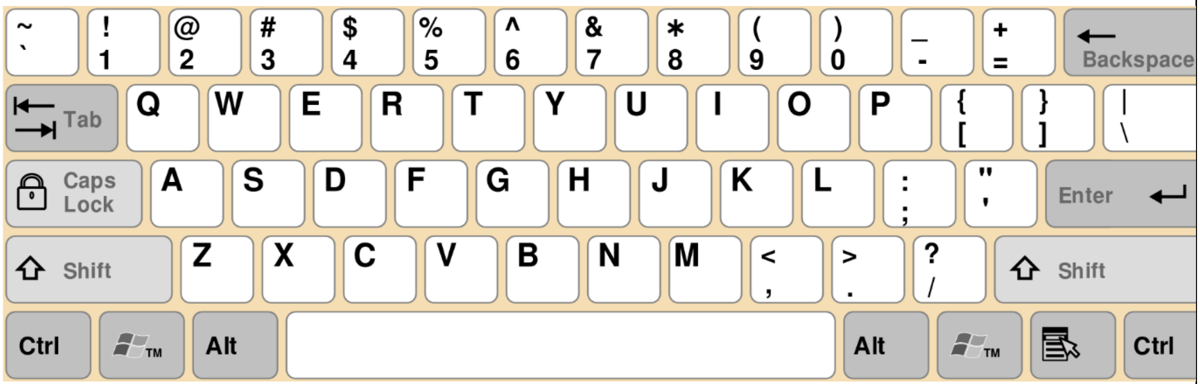
A second building block of evolutionary economics is **adaptation**: routines get updated based on learning from experience. Adaptation may involve firms learning from successfully innovative firms, and use their RD&D expenditure and other innovative activities to imitate the leading firm. However, imitative efforts are not necessarily successful, there is a risk of failure.

A third building block of evolutionary economics is **technological path dependency** (see **box 4**). Path dependency explains the continued use of a technology based on historical preference or use. A company or a whole economy may persist in the use of a product or practice even if newer, more efficient alternatives are available. Path dependency occurs because it is often easier or more cost-effective to continue along an already set path than to create an entirely new one. Studies of how technologies become path-dependent suggests that supplier and customer preferences lead to a dominant technology even if it might be inferior to an alternative. Or, alternatively, a system may become locked into an inferior technology if more people had adopted this technology earlier than the superior alternative. The dominant technology is called the paradigm and it may well have exhausted its potential for improvement. Nevertheless, it may be difficult for innovators to dethrone the paradigm technology; the case of renewable energy technologies versus the paradigm of fossil-fuel based technologies is a case in point.

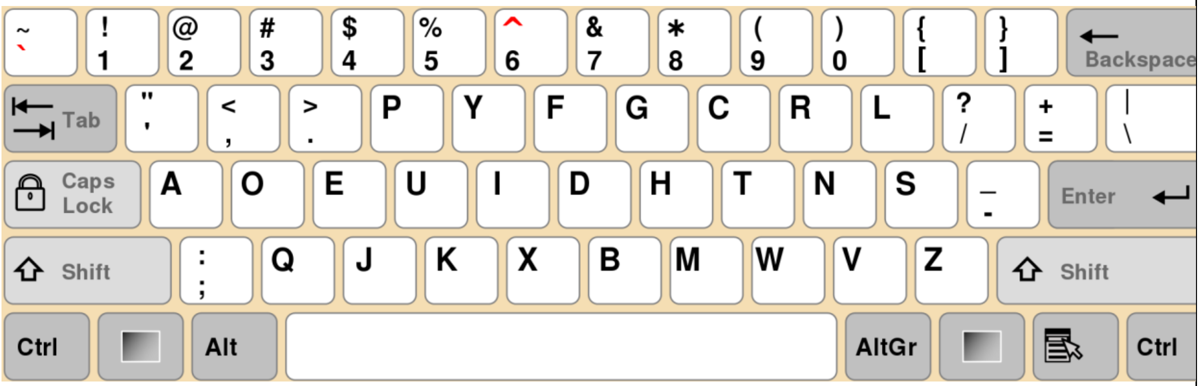
Evolutionary economics stresses the importance of **tacit knowledge** (= knowledge acquired by experience that cannot be codified in the how-to-do manual), **learning-by-doing**, and **search** by trial and error. Firms employ a set of procedures to search for profitable new routines (= innovation) and select promising new routines. This **selection mechanism** is located in a market environment within which firms compete with other firms. Selection increases economic efficiency by eliminating inefficient technologies – as an example of Schumpeterian creative destruction.

Box 4

The economics of QWERTY



A QWERTY Keyboard (above); a DVORAK keyboard below.



Paul David (1985) argued that a standard that is first-to-market can become entrenched, like the QWERTY layout in mechanical typewriters still used in computer keyboards, even if it is inferior in terms of efficiency. He called this "path dependence" and said that inferior standards can persist simply because of the legacy they have built up. The alternative Dvorak keyboard-layout uses about 63% of the finger motion required by QWERTY, which is claimed to make the keyboard more ergonomic and more efficient. Still, the QWERTY layout continues to dominate the market as the keyboard standard. QWERTY vs. Dvorak is an example of path dependence and technological lock-in. Economic debate continues on the significance of path dependence in determining how standards form.

Below we present a simple evolutionary model of market competition between three firms (see Chapter 16, Himmelweit, Simonetti and Trigg). The model has two (opposing) mechanism. First, the **selection mechanism** states that the market share of the “fittest” firm, defined as the firm having the biggest profit margin, will rise, while the other two firms will lose market share. The stronger is this selection mechanism, the more likely it is that this market will become a monopoly – captured by the “fittest” firm. Second, the **imitation mechanism** states that lagging firms will engage in imitating the leading firm, by copy-pasting the technology used by the leading; their unit costs will decline to the level of the unit costs of the leading firm. The stronger is this imitation mechanism, the more likely it is that this market will end up consisting of three equally large and equally efficient firms.

An Evolutionary Market Model

(1) $$\Pi_t^i = P_t - C_t^i$$

Profits per unit of output of Firm *i* =

Market Price – Unit Cost of Firm *i*

(2) $$\Pi_t^{AV} = \sum_{i=A}^{C} (\Pi_t^i * S_t^i)$$

Average profits per unit of Firms A, B and C

(3) $$G_t^i = \alpha(\Pi_t^i - \Pi_t^{AV})$$

Selection Mechanism: Growth of Market Share of Firm *i* depends on relative profitability (a “measure of “fitness””).

(4) $$S_{t+1}^i = S_t^i(1 + G_t^i)$$

Definition: Growth of market shares.

(5) $$C_{t+1}^{i} = C_t^i - \beta(C_t^i - C_t^{MIN})$$

Imitation Mechanism: Unit Cost of Firm i are made to converge to the (given) unit cost level of the market's most efficient firm – at speed *β.*

(6) $$C_t^{AV} = \sum_{i=A}^{C} (C_t^i * S_t^i)$$

Definition: Average unit cost of Firms A, B and C.

MODEL-EXPERIMENTS:

Case 1: Only Selection, No Imitation

- $\alpha =$ selection parameter = 0.5
- $\beta =$ imitation/adaptation parameter = 0.0

See Table 16.2 and Figures 16.1 and 16.2 in Himmelweit et al.

Conclusion: there arises a tendency towards monopoly (of Firm A, the most cost-efficient firm). Firm A (the most profitable firm) gains market share and by period 13 it has driven firms B and C from the market. Average (market) unit cost decline (obviously) to the level of unit cost of A.

The higher is α, the more rapid will Firm A gain market share. If α = 0.75, Firm A becomes a monopolist by period 10. If α = 0.90, Firm A becomes a monopolist by period 5.

Case 2: No Selection, Only Imitation

- $\alpha =$ selection parameter = 0.0
- $\beta =$ imitation/adaptation parameter = 0.5

See Figure 16.5

Time	Π_t^A	Π_t^B	Π_t^C	S_t^A	S_t^B	S_t^C	Π_t^{AV}	G_t^A	G_t^B	G_t^C	C_t^A	C_t^B	C_t^C	C_t^{AV}	C_t^{MIN}
1	6	5.0	4	0.33	0.33	0.33	5	0	0	0	9	10	11	10	9
2	6	5.5	5	0.33	0.33	0.33	5.5	0	0	0	9	9.5	10	9.5	9
3	6	5.8	5.5	0.33	0.33	0.33	5.8	0	0	0	9	9.3	9.5	9.3	9
4	6	5.9	5.8	0.33	0.33	0.33	5.9	0	0	0	9	9.1	9.3	9.1	9
5	6	5.9	5.9	0.33	0.33	0.33	5.9	0	0	0	9	9.1	9.1	9.1	9
6	6	6	5.9	0.33	0.33	0.33	6	0	0	0	9	9	9.1	9	9
7	6	6	6	0.33	0.33	0.33	6	0	0	0	9	9	9	9	9
8	6	6	6	0.33	0.33	0.33	6	0	0	0	9	9	9	9	9
9	6	6	6	0.33	0.33	0.33	6	0	0	0	9	9	9	9	9
10	6	6	6	0.33	0.33	0.33	6	0	0	0	9	9	9	9	9
11	6	6	6	0.33	0.33	0.33	6	0	0	0	9	9	9	9	9
12	6	6	6	0.33	0.33	0.33	6	0	0	0	9	9	9	9	9
13	6	6	6	0.33	0.33	0.33	6	0	0	0	9	9	9	9	9
14	6	6	6	0.33	0.33	0.33	6	0	0	0	9	9	9	9	9
15	6	6	6	0.33	0.33	0.33	6	0	0	0	9	9	9	9	9

→ Because there is no selection, market shares remain unchanged.

→ Imitation by Firms B and C leads to a decline in their unit cost, they become more efficient. Average (market) unit cost decline to 9 by period 10.

→ Strong imitation (and weak selection) thus leads to a rise in average efficiency and entails no market concentration.

Case 3: Selection and Imitation

- $\alpha =$ selection parameter = 0.5
- $\beta =$ imitation/adaptation parameter = 0.5

See Figures 16.6 and 16.7

	Π_t^A	Π_t^B	Π_t^C	S_t^A	S_t^B	S_t^C	Π_t^{AV}	G_t^A	G_t^B	G_t^C	C_t^A	C_t^B	C_t^C	C_t^{AV}	C_t^{MIN}
1	6	5.0	4	0.33	0.33	0.33	5	0.6	0.0	-0.5	9	10	11	10	9
2	6	5.5	5	0.50	0.33	0.17	5.7	0.2	-0.1	-0.3	9	9.5	10	9.3	9
3	6	5.8	5.5	0.58	0.31	0.11	5.9	0.1	-0.1	-0.2	9	9.3	9.5	9.2	9
4	6	5.9	5.8	0.62	0.29	0.10	5.9	0.0	-0.0	-0.1	9	9.1	9.3	9.1	9
5	6	5.9	5.9	0.64	0.28	0.08	6	0.0	-0.0	-0.0	9	9.1	9.1	9	9
6	6	6	5.9	0.65	0.27	0.08	6	0	-0.0	-0.0	9	9	9.1	9	9
7	6	6	6	0.65	0.27	0.08	6	0	-0.0	-0.0	9	9	9	9	9
8	6	6	6	0.66	0.27	0.08	6	0	-0.0	-0.0	9	9	9	9	9
9	6	6	6	0.66	0.27	0.07	6	0	-0.0	-0.0	9	9	9	9	9
10	6	6	6	0.66	0.27	0.07	6	0	-0.0	-0.0	9	9	9	9	9
11	6	6	6	0.66	0.27	0.07	6	0	-0.0	-0.0	9	9	9	9	9
12	6	6	6	0.66	0.27	0.07	6	0	-0.0	-0.0	9	9	9	9	9
13	6	6	6	0.66	0.27	0.07	6	0	-0.0	-0.0	9	9	9	9	9
14	6	6	6	0.66	0.27	0.07	6	0	0	-0.0	9	9	9	9	9
15	6	6	6	0.66	0.27	0.07	6	0	0	0	9	9	9	9	9

→ Firm A has a “first-mover” advantage: because of superior efficiency, it initially has the highest unit profits, which it invests; the result is a rise in its market share from 33% to 66%.

→ Firms B and C imitate: their efficiency rises and unit costs decline. But they lose market share: B from 33% to 27% and C from 33% to 7%.

→ Market structure stabilises in period 10. Firm A has become dominant; overall efficiency has improved.

Competition between technologies

- If there are increasing returns (if learning is fast and early adoption generates high efficiency advantages), pioneers gain a substantial lead on competitors, who will not be able to catch up. In contrast, if appropriability is weak and there are significant spill-over effects (competitors benefit without spending), pioneers will lose market share.
- a potentially superior technology might not be developed without the presence of over-optimistic pioneers, who:
  - lack information about the future efficiency of new technology and about the extent of learning and spill-overs;
  - are heterogeneous and therefore make different guesses.
- **network externalities**: more resources are devoted to the improvement of widely-adopted technology, and the uncertainty that surrounds its effectiveness declines as its familiarity increases (benefits of standardisation).

Questions

1. What is meant by incremental innovation? And by radical innovation?
2. What is product innovation and what is process innovation?
3. Give a definition of technology-push innovation.
4. What is meant by demand-pull innovation?
5. Why are the technology-push and demand-pull models of innovation called linear models?
6. What is a general-purpose technology? Give an example.
7. What is a national system of innovation?
8. What is TFP growth?
9. How does one measure TFP growth?
10. What is the role of the entrepreneur in Schumpeter's theory of economic development? How does the entrepreneur upset the stationary circular flow?
11. What does Schumpeter mean by the term "creative destruction"?
12. Why did Schumpeter argue that technological progress requires temporary monopolies? (Explain in detail).

13. Why do perfectly competitive markets tend to under-invest in research, knowledge generation and innovation? Give three reasons.
14. What is bounded rationality? How is it different from neoclassical instrumental rationality? How does bounded rationality lead to "routines"?
15. What is path dependency? Give an example.
16. What is tacit knowledge? Why is it important according to evolutionary economics?
17. What is the selection mechanism in an evolutionary market model? What is the imitation or adaptation mechanism?
18. What are network externalities?

Exercises

Exercise 1

1. It is argued that "Innovation is thus just a case in which perfect competition does not yield the best outcome." Explain why this is so.
2. "Economic selection entails the survival of the "fittest" firm, which means that the most efficient firms will compete less efficient firms out of the market." Based on the evolutionary market model of Himmelweit, Simonetti and Trigg (HST) Chapter 16, do you agree?

Exercise 2

Consider the following data:

	Income (X)	Hours Worked (L)	Capital Stock (K)
1970	€3000 million	50 million	€6000 million
2020	€ 10311.3 million	67.34 million	€25778 million

1. What is the level of labour productivity (per hour worked) in 1970? And in 2020? What is the (annual compound) rate of growth of labour productivity (in percentages) during 1970-2020?

2. Assume that the generation of income X can be described by a constant-returns-to-scale production function. Assume that α = 0.6. Calculate the rate of total factor productivity (TFP) growth (in percentages) during 1970-2020.
3. How do you interpret TFP growth? What does it stand for? Why?
4. According to some authors, TFP growth is basically a measure of “our ignorance” about the sources of productivity growth. Do you agree? (motivate your answer).

Exercise 3

In this exercise we use the growth accounting model to account for the contribution of ICT-capital stock to labour productivity growth. Consider the following Cobb-Douglas (constant-returns-to-scale) production function:

$$x = a \times L^{\alpha} \times ICT^{\beta} \times K^{1-\alpha-\beta}$$

where ICT = the stock of ICT capital (computers). Dividing both sides of this equation by *L* (= the number of workers), we get:

$$\frac{x}{L} = a \times (\frac{ICT}{L})^{\beta} \times (\frac{K}{L})^{1-\alpha-\beta}$$

and in growth rates, this gives:

$$\hat{\lambda} = \hat{a} + \beta \times \widehat{ict} + (1 - \alpha - \beta) \times \hat{\kappa}$$

Labour productivity growth depends on the growth of ICT capital stock per worker and the growth of non-ICT capital stock per worker.

Let us assume that $\alpha = 0.6$ and $\beta = 0.15$.

1. Suppose that labour productivity growth $\hat{\lambda} = 2.3\%$ per year during 1980-2018; the growth of ICT capital stock per worker $\widehat{ict} = 3.4\%$ per year and the growth of non-ICT capital stock per worker $\hat{\kappa} = 2.8\%$ per year. Calculate the annual rate of TFP growth.
2. What is the contribution of the growth of ICT capital per worker to labour productivity growth?

3. We know that not only the quantity, but also the quality of ICT capital has increased over time. We are not “accounting” for the quality increase in ICT capital stock per worker in our growth-accounting model. How does this neglect bias our estimate of TFP growth?

Answers to the exercises

Exercise 1

1. In PERFECT COMPETITION, equilibrium means that P = MC = AC; there are no supernormal profits for firms. However, to innovate, firms need to invest (in R&D); innovations are lumpy (indivisible) and large, and risky. When P = AC, firms are unlikely to earn enough profits to internally finance the required investment effort.

   In addition, if the PERFECT market is transparent and information is free (a public good), then investing in innovation (= new knowledge) is not rational for firms, since they will not be able to recoup the investment. They cannot exclude competing firms from imitating, and using the innovative knowledge. PERFECT Competition may be good for achieving static efficiency, but it fails in generating dynamic efficiency.

2. According to Chapter 16, <u>“fittest” does not necessarily mean the most efficient firm</u> (= the firm which has the lowest AC of production). “Fitness” is defined in terms of the profit margin (P – AC). If a firm manages to differentiate it product and hence to obtain a price higher than the other firms, its (P – AC) margin may be the largest. This would then be the fittest firm then, and it would gain market share. It is NOT however the most efficient firm (with the lowest average cost) – in this evolutionary market model of HST Chapter 16.

Exercise 2

1. The level of labour productivity (X/L) in 1970 is € 60 per hour. The level of labour productivity (X/L) in 2020 is € 153 per hour. The annual (compound) growth rate of labour productivity *g* is 1.89%.

$$g = 100\% \times \left(\left(\frac{153}{60} \right)^{\frac{1}{50}} - 1 \right) = 1.89\%$$

2. First, we have to calculate the compound growth rates of (X/L) and K/L). See the table:

	X	L	K	X/L	K/L
1970	3000	50	6000	60	120
2020	10311.33	67.43	25778	153	382
Compound growth rate	2.50	0.60	2.96	1.89	2.34

Solow's **growth accounting model**: $\hat{\lambda} = \hat{a} + (1-\alpha) \times \hat{\kappa}$. With the above numbers this gives: $1.89 = \hat{a} + (1-0.6) \times 2.34$. TFP growth is 0.95% per year during 1970-2020.

3. TFP growth is that part of labour productivity growth that cannot be attributed to capital-intensity growth. It is basically an unexplained residual. It is often argued that TFP growth is a reflection of process innovations and/or organisational improvements, which raise the productivity of both labour and capital.

4. This statement reflects the fact that TFP growth is an unexplained residual. It is not explained within the growth-accounting model. Hence, one can "speculate" about what TFP growth represents, but such inferences are basically unfounded. Hence, the higher is the proportion of TFP growth to productivity growth, the smaller is the explanatory power of the growth accounting model. In this sense, TFP growth is indeed a measure of our ignorance.

Exercise 3

1. The growth-accounting equation is;
   $\hat{\lambda} = \hat{a} + \beta \times \widehat{ict} + (1 - \alpha - \beta) \times \hat{\kappa}$
   $2.3 = \hat{a} + 0.15 \times 3.4 + 0.25 \times 2.8$ → TFP growth = 1.09% per year during 1980-2018.
2. The contribution of the growth in ICT capital per worker to labour productivity growth is $\frac{0.15 \times 3.4}{2.3} = \frac{0.51}{2.3}$ x 100% = 22%. (More than one-fifth of labour productivity growth during 1980-2018 must be attributed to the growth in ICT capital per worker).
3. If we would account for the improved quality of ICT capital, the contribution of ICT capital growth to labour productivity growth would be higher – and the residual (= TFP growth) would have become smaller. The neglect of this quality improvement leads to an over-estimation of TFP growth.