Annex B: R&D, innovation and productivity: the theoretical framework

Introduction

B1. This section outlines the theory behind R&D and innovation's role in increasing productivity. It briefly summarises the microeconomic foundations to the theoretical treatment of information to illustrate how views of information, and more widely knowledge, has developed. This has important implications for the new growth models explored later. It then outlines the neoclassical approach, to expose these models' weakness both in their treatment of information and of technology which is seen as essentially "manna from heaven" (Solow 1997).

B2. To answer these criticisms of the theoretical underpinnings of the neoclassical approach, new growth models (NGTs) attempt to endogenise fully technological progress into their theoretical models (see for example Aghion and Howitt(1992) and Jones (1995)). A short summary of their approach is given below. These models emphasise the central importance of the treatment of *information and more widely, knowledge,* in the models. This raises interesting - and crucial – questions about the role property rights have to play in R&D and innovation. It also serves to reveal the tensions between the *ex ante* incentives intellectual property rights provide for innovators to create knowledge by the promise of monopoly rents, and the *ex post* losses society faces of endowing monopoly rights to a private firm.

B3. A further important insights into the dynamics of growth theory comes from models that posit that knowledge should be treated as *embodied* in capital ie not as a specific, disembodied factor of production as implicated in the original neoclassical models (Kaldor 1989). This approach allows useful insights into the drivers behind innovation, and how it relates to productivity and growth. It also points to the importance of the role of institutional structures, both formal and informal, in determining the diffusion of knowledge and hence society's ability to use effectively new discoveries to raise productivity. The approach of *national innovation systems* (Nelson (1993); Lundvall (1993)) offer a useful way of identifying possible barriers to R&D and innovation, and where in the system incentives can most effectively be provided by government.

Neoclassical growth

B4. Following Keeley and Quah (1998), this section takes away the prominent emphasis on capital accumulation in Solow's (1956) analysis of economic growth in order to highlight its weakness in explaining the development of technological progress.

Let N(t) be the total number of workers, and Y(t) and K(t) the aggregate quantities of output and capital at time t.

Let output per worker, y(t) = Y(t)/N(t)
and

capital per worker, k(t) = K(t)/N(t)

Let A(t) be the state of technology at time t. The relation between output and capital can then be specified by the following production function:

$Y = F(K,NA)$? $y = F(k,A) = Af(k/A)$ (1)

with F homogenous degree 1 (constant returns to scale), $f'>0$, $f''<0$ (diminishing returns) (2)

Suppose N and K evolve as:

$\dot{N}/N = ? > 0$, $N(0) > 0$ $\Longrightarrow$ the rate of workforce growth (3)

$\dot{A}/A = ? > 0$, $A(0) > 0$ $\Longrightarrow$ the rate of TFP growth (4)

Let physical capital decay at rate d = 0. Assume savings are t of total income, and transforms into physical capital by the relationship:

$K = tY - dK$ t in (0,1)

$$\Longrightarrow \dot{k}/k - \dot{A}/A = \frac{t\, f(k/A)}{k/A} - (d + ? + ?)$$

ie balanced growth equilibrium $\dot{y}/y = \dot{k}/k = \dot{A}/A = ?$

B5. One of the shortcomings of Solow's initial model is that is does not afford insights into the dynamics influencing technical efficiency **?** (is it simply capital accumulation?), and how it might differ over time and between countries. Also, researchers have found it hard to reconcile the model with the empirical evidence. Dissatisfaction with the model focused on the specification technology (A_t), which is treated more or less as a factor of production alongside capital and labour ie not fully endogenised. More recent models attempt to answer this criticism and fully endogenise technology (Aghion and Hewitt (1992); Jones(1995)). These allow the growth rate of technology to be affected by both the incentives for capital accumulation and/or R&D. Importantly, in their microeconomic foundations allow for uncompetitive behaviour, by explicitly allowing for the non-rivalry but partial excludability of knowledge - such as permitted by society through the sanctioning of patents.

Microeconomic developments: the treatment of information

B6. Economic theory offers a number of views of how knowledge can be treated in terms of its private and social benefits and costs, and how knowledge can diffuse through an economy. The treatment of information and knowledge has been important in subsequent developments of growth models, with implications for policy in terms of its approach to protecting intellectual property rights.

B7. Neoclassical theory (Arrow 1962) viewed basic research (or ‘far from market’ research) as a public good, being both non-excludable and non-rival in nature. Because the use of information from basic research is non-excludable and indivisible, the argument is that private provision will be less than the socially optimum: private producers of new information will not be able to appropriate enough returns to cover the expense (and risk) of carrying out the basic research. Either public funding of basic research or a form of legal protection for new ideas (patents) are therefore necessary to address the market failure.

B8. While introducing an element of market failure into the system and hence ex post welfare losses, property rights that protect information do provide the ex ante economic incentives to create and develop new ideas. Imperfect competition is therefore accepted as an essential element in any system that aims to encourage innovation. And as the more recent information economic literature contends (Stiglitz (1996)), information imperfections in any case pervade the economy. As a result, they create barriers to innovation which limit competition, and can give rise to oligopolies reinforced by large sunk costs and cumulative competitive advantages through learning-by-doing (pharmaceuticals for instance).

The development of growth models: endogenising technology

B9. Growth models reflected this change in the treatment of information in their microeconomic foundations by introducing an intermediate goods sector characterised by monopolistic competition and product variety (Chamberlain (1933); Dixit and Stiglitz (1977)). This allows interesting insights into the *demand* for intellectual property through its consumption by innovating firms who are then permitted to raise monopoly rents on their inventions, and its role in the dissemination of knowledge to other economic actors.

B10. More recent endogenous technology models replace technical progress as expressed in equation (4) in Solow’s model above with a specification that allows for the quantity of resources allocated to R&D effort, as well as the influence of ‘other factors’. This following version is provided by Griliches and Lichtenburg (1984):

$$A_t = f\,(B_t, G_t) \quad (6)$$

where A is the total factor productivity, B a set of residual influences, and G the stock of R&D knowledge. Taking logarithms and differentiating with respect to time, we get

$$\dot{A}_t/A_t = ?\,\dot{B}_t/B_t + ?\,\dot{G}_t/G_t$$

where ? = (dY/dG).G/Y, the elasticity of output to R&D effort and ? = (dY/dB).B/Y, the elasticity of output with respect to a set of residual influences.

Denote real R&D expenditure by R, and the rate of depreciation of the R&D stock by ?. Then G = R – ?G. Assuming ? is small, then

$$\dot{A}_t/A_t = ?\,\dot{B}_t/B_t + ?\,\dot{R}_t/Y_t$$

where ? = dY/dG, the marginal product of R&D.

B11. R&D activity can therefore directly influence on TFP growth, since it results in innovations that push out the technical frontier, with innovators able to appropriate the expected flow of profits from their inventions by the availability of patents. This in turn creates the incentive to invest and innovate further: knowledge accumulation and not physical capital accumulation becomes a decisive element in growth. Romer's (1990) alternative further underlines the recursive relationship by linking the rate of technical progress, A, and the resources devoted to 'ideas production'. He proposes a national ideas production function

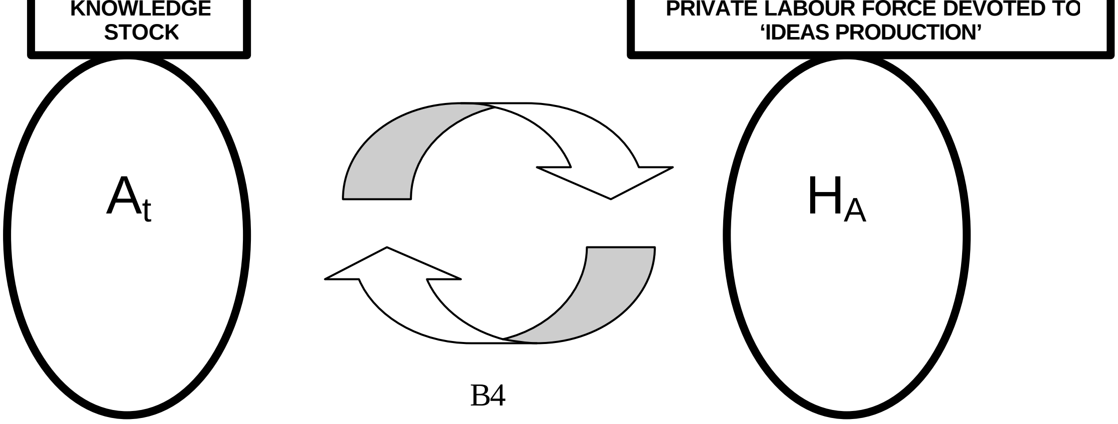
$$A_t = dH^{?}_{A,t}\, A^{F}_{t}$$

B12. 'Ideas production' is therefore determined by the number of workers devoted to 'ideas production' (H_A) and the existing stock of ideas that these workers can draw upon in their 'ideas production' work(A_t). This formulation makes technical change endogenous through two routes (see Figure A below):

a) The number of researchers working in 'ideas production'. This will be a function of conditions in the R&D labour market: the allocation of labour to the R&D sector depends on the productivity of the R&D sector, and the private returns to new ideas (determined in part by the existence of property rights)

b) The productivity of new 'ideas production'. This will be sensitive to both the existing stock of ideas, A_t, and the ability of the R&D labour force to use it effectively. So when F >0, prior research increases productivity and current researchers "stand on the shoulders" of past research efforts; and when F < 0, then new ideas are more difficult to find.

Figure A (from Stern, Porter and Furman 2000)



National innovation systems

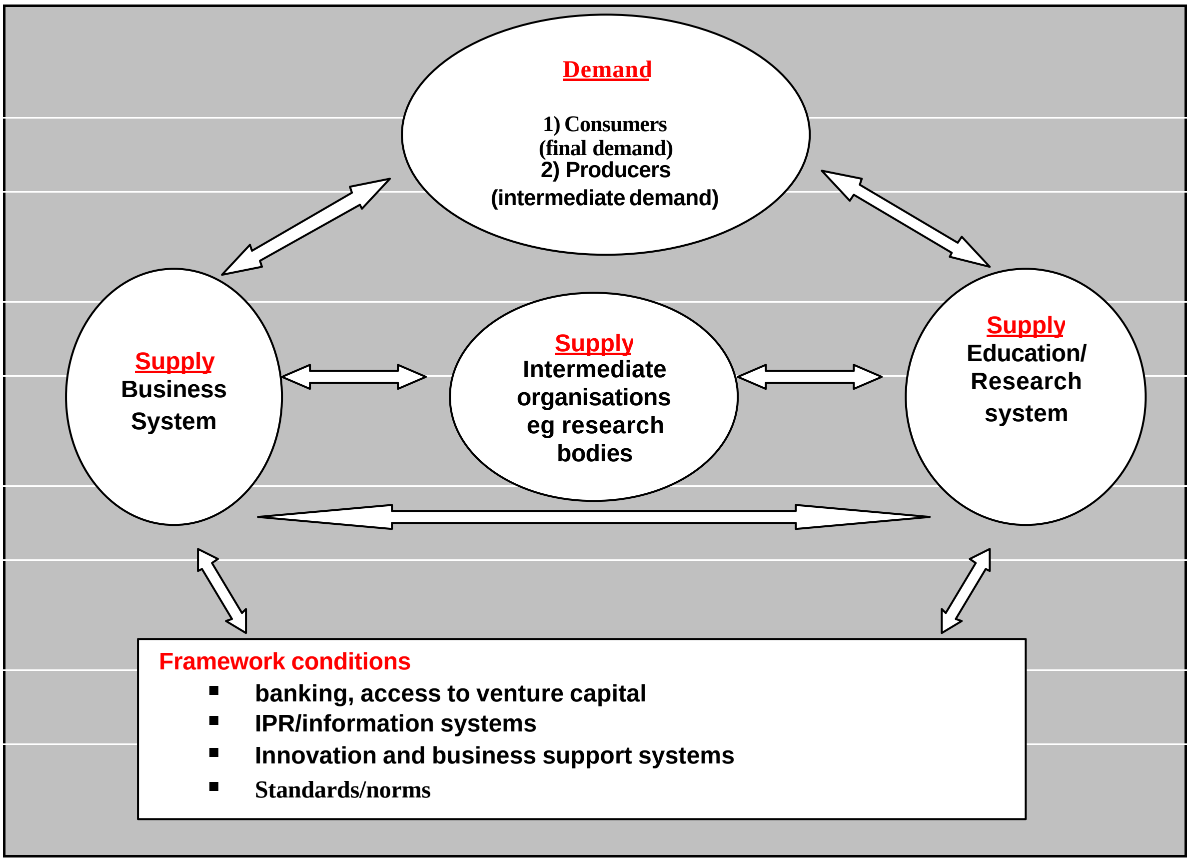
B13. The above theoretical developments throws light on the process of ‘supplying’ R&D to the economy. But this is only a small part of the overall process of innovation that leads to a finished product being placed on the market. More recent work has moved away from so-called ‘linear’ models of innovation, which regarded investment in basic R&D which, after a process of some development, fed directly into the output of firms. This advised government intervention on the basis of market failure – the private sector would not otherwise undertake certain ‘far from market’, basic R&D – leading to a focus on ‘supply side’ policies to boost R&D rather than considering how new knowledge and technology could diffuse through the economy to maximise their benefits. (This basically followed on from Arrow’s assumptions of ‘market failures’ and neo-classical assumptions of frictionless knowledge transfer and absorption.)

B14. Theories of innovation have subsequently recognised the complex web of relations that exist between the ‘ideas producing’ sector, the demand for R&D and innovation by firms (Porter(1990)), and the institutional context in which innovators work. This has shifted the focus away from the supply side of R&D ie where the technology frontier lies, onto the institutions and the practice of innovation within firms. On the latter (see for example Freeman and Soete 1997), theories of the firm that assume perfect knowledge or optimising behaviour have been challenged by the evidence that shows firms to be faced by ‘bounded rationality’, imperfect information, and market and technical uncertainties. Firm competences in R&D and innovation through their accumulated skills and knowledge are crucial to the outcomes of innovation. Finally, the evidence shows that behaviour is influenced according to industrial sectors, for example the role of science and learning by doing differ between specialised supplier firms and science-based firms.

B15. These concepts are reflected new national innovation systems literature (notably Lundvall(1992) and Nelson (1993)) that argues that the key to innovation performance is not simply the creation and ownership of information from R&D (a ‘stocks’ approach), but the way that information is used by firms and disseminated through the wider economy ie how R&D knowledge flows through the economic infrastructure. Exactly defining a national innovation system is less easy but Metcalfe (1995) perhaps best captures its essence:

> *“A system of innovation is that set of distinct institutions which jointly and individually contributes 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 2 An example of a simplified national innovation system



B16. Since knowledge which enables the use of information is embedded in the fabric of institutions (von Tunzelmann (1995)), the effectiveness of the whole innovation process, from basic research to learning by imitation through to delivering the new product to the market, is bound to be effected by the quality of the organisational structures and networks in the economy. These will determine economies' ability to learn and interact with others; their capacity to absorb and use new ideas and technologies from within and without the economy; and to use to the full the different sources of knowledge embedded within networks and organisations.

B17. This approach therefore argues that a crucial element in the research and innovation process are effective institutions that smooth the flow of knowledge through the innovation system, and help match the 'supply' of R&D to innovators' 'demand'. As Nelson (1993) shows in his extensive survey of innovation systems, many different approaches produce equally good outcomes: the lesson is therefore that no one system is inherently superior. Nonetheless, there does appear to be consistent characteristics of successful research and innovation systems that appear to help maximise the positive spillover benefits: networks need to be flexible, to allow them to evolve as new technologies appear; policies that are integrated and co-ordinated; and policies that are constantly learning and adapting to new demands. This shift in thinking, away from a purely market failure approach which suggests areas for state intervention, towards one which recognises the long term dynamics of the research and innovation process - how economic agents learn and the spillovers between institutions.

B18. While intervention on the basis of market failures suggested by Arrow are not entirely invalidated – the importance of an economy's absorptive capacity for new technology and ability to generate ideas remain important – the new approaches indicate that intervention should focus far more on improving the network elements of the national research and innovation system. Some of the key areas are highlighted below (from contributions to Lundvall et al, 1997):

Smith's four types of 'failures'

1) Failures in infrastructure provision and investment. When there is problematic under-investment in the two types of infrastructure with which firms interact, namely, physical infrastructure (like communications and transport), and science-technology infrastructure (like universities, regulatory agencies, publicly supported laboratories). Public action should be directed towards setting up incentives for and controls on private provision, subsidies for private provision or direct public provision.

2)Transition failures. When firms are highly competent within their own technological area but not in other related areas. Public action generally aims to solve this problem implicitly, but public action should be more explicit and devise special measures for this type of failure.

3)Lock-in failures. When firms are not able to switch away from their existing technologies and get 'locked-in' to a particular technological paradigm or trajectory.

The rationale for public action is to generate incentives, develop technological alternatives and nurture emerging technological systems in order to make it easier for firms to move away from lock-ins.

4) Institutional failures. When the institutional and regulatory context is having an unexpected and negative impact on innovation in the system.

Public action here should concentrate on monitoring and assessing regulatory performance.

Malerba's evolutionary traps, trade-offs and failures.

1) Learning failures: Firms may not be able to learn rapidly and effectively. Public intervention has many different ways of tackling this kind of problem: human capital programmes, support for industrial R&D, public procurement, and dissemination policies.

2) Exploitation - exploration trade-off: Some industries may work on exploration, but not exploitation. Other industries may do the opposite, in both cases with negative effects. Public policy should try to ensure that the industrial system achieves a balance between the two. The author suggests three policy options:

- keeping technological rivalry open by supporting alternatives (i.e. by using public procurement and supporting universities)

- introducing diversity in the industry by supporting the entry and survival of new firms (SMEs)
- supporting variety through a common infrastructure (standardization and norms) and better dissemination of codified information.

3) Variety-selection trade-off: Industries may generate a lot of variety but have weak selection processes, or may have tough selection processes and little variety. Policy suggestion: antitrust and competition policies should be used in close relation to industrial and technology policy. This will affect the selection process allowing market competition to take place.

4) Appropriability traps: Too stringent appropriability may greatly limit the spread of advanced technological knowledge and eventually block the development of differentiated technological capabilities within an industry. The patent system is important for appropriability but not the only one, as secrecy, lead times, and complementary assets are also important. These latter fall outside the scope of public action.

5) Complementarities failures: The appropriate complementarities (required for sustained innovation) may not be present or the firm may not be connected to an innovation system. Public action should help by providing connections to trigger virtuous cycles. Examples could be supporting the formation of R&D networks, industry-university interfaces, and setting up bridging institutions.