TECHNOLOGY, POLICY, GROWTH -

THEORY, EVIDENCE AND INTERPRETATION

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ABSTRACT

In recent years the research on the relation between technology and economic growth has flourished. This paper presents a brief overview of different theoretical perspectives in this area; the old orthodox theory (that of Robert Solow and others), more heterodox approaches, and the new orthodox theory (commonly labelled new growth theory). Furthermore, we assess the relationship between these theoretical approaches and applied work on growth and policy.

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TECHNOLOGY, POLICY, GROWTH -

THEORY, EVIDENCE AND INTERPRETATION[1]

For many years economic growth was considered a quite boring theme. Some universities even stopped to offer courses in economic growth. However, now the interest has rebound, both among theorists and practitioners. This paper[2] reviews different theoretical perspectives in this area; the old orthodox theory (that of Robert Solow and others), more heterodox approaches, and the new orthodox theory (commonly labelled new growth theory). Furthermore, we will discuss the relation between these theoretical approaches and applied work on growth and policy. Finally we assess the available evidence; what is learnt, what we still need to know more about.

THE OLD ORTHODOX THEORY

The so-called old orthodox theory, advocated by Solow (1956) and others, was developed as a reaction to the contemporary Keynesian generalisations to the long run. These generalisations showed that growth with full employment was a possible but not at all necessary outcome of market forces. This left a large role to state intervention, in particular with respect to income distribution (see Luigi Pasinetti 1974).

The neo-classical growth theories developed by Solow and others in the 1950s showed that long-run growth with full employment was indeed no problem as long as

[1] For a more detailed discussion of many of the issues covered in this paper the reader is referred to

market forces were allowed to operate freely. However, this result rested on very strong assumptions. First, that of technology as a public good, freely available to everyone free of charge. Second, the assumption of so-called "perfect competition", which involves, among other things, no economies of scale and no market power of firms. Constant returns to scale were imposed, i.e., that a 1 % increase in all inputs yields exactly 1 % growth in output.

When applied to the global economy this theory led to an important prediction. Countries that differ in terms of initial productivity levels but not otherwise will converge towards the same level of productivity and the same rate of productivity growth. Thus, catch-up in productivity and income will take place, as long as market forces are allowed to operate freely. If countries differ also in other respects (population growth and savings propensities) convergence towards the same growth of productivity will still be achieved, but productivity levels will differ. The theory also predicts that in the absence of exogenous technological progress, this common rate of productivity growth (that all countries will converge towards) will be zero. Thus, what we have here is a theory that predicts that apart from exogenous sources there will be no productivity growth in the long run.

GROWTH ACCOUNTING

Armed with this theoretical perspective, economic practitioners started to analyse actual growth, weighting the growth of inputs with factor shares. For instance, the contribution of capital to economic growth was calculated as the growth of capital multiplied by the capitalists' share of national income. When the contributions from

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Fagerberg (1994).

factor growth are added together in this way a residual may occur. This unexplained part of actual growth was dubbed “total factor productivity growth”, that is, the part of actual growth that cannot be attributed to any single factor. This methodology, so-called growth accounting, was first applied to historical data for the USA by Moses Abramovitz (1956) and later to selected OECD countries by Edward Denison (1967). Over the years this methodology has also been applied to many individual countries and recently also to the Asian NICs .

The first exercises in this area showed that only a small part of actual growth could be attributed to growth of capital and labour. Up to 80 % remained unexplained and had to be classified as so-called total factor productivity growth. That the lion’s share of actual growth had to be explained by exogenous technological progress and other unidentified sources was something many were not willing to accept. Various remedies were invented to improve on this rather embarrassing result. The first was to adjust the factors themselves by taking into account the changes in quality and composition. For instance, new vintages of capital or labour were assumed to be more efficient than previous ones. To some extent this practice boiled down to no more than building the unexplained part of actual growth into the factors themselves. Second, it was suggested to take into account additional factors such as economies of scale, investments in R&D, possible differences in productivity levels across countries and sectors and a host of other factors (crime, for instance). For a good overview I refer to the paper by Angus Maddison (1987). When these additional factors were taken into account the growth accountants were able to explain a much larger part of actual growth. There was only one problem, that the very existence of some of these additional factors actually contradicts the assumption of the theory on which the analysis was based. For instance, the theory explicitly assumes no economies of scale.

Thus, if these additional factors are relevant, and the available evidence suggests that they are, what you need is a new theory!

It was pointed out by Richard Nelson (1964) that growth accounting is not a tested theory on growth. Rather it is an analysis - or description - of a growth process based on certain assumptions which are taken as given (i.e., not tested). It is clear, however, the validity of conclusions from such analyses depends crucially on whether the underlying assumptions are true or not. It is important to remember this when assessing some of the more recent applications of this methodology. I am referring here in particular to Alwyn Young's recent paper on the East Asian NICs (Young1995), where he claims that accumulation of capital and labour explains everything there is to explain. To assess this claim you have to find out whether the underlying assumptions, on which this conclusion is based, really hold. That means that you have to ask the following type of questions: Did perfect competition prevail? Were there no large firms with market power? No scale economics? Was technology freely available to everyone free of charge? Without answers to this these deeper questions growth accounting exercises cannot be used to draw conclusions about what drives growth. As pointed out by Robert Lucas (1993), commenting on Young's findings, just observing the fact that input and output growth tend to go hand in hand explains nothing. Arguably, any theory of growth would predict that!

THE HETERODOX CONTRIBUTIONS

Alternatives to the neo-classical interpretations of events have been formulated by a diverse group of historically oriented economists and economically oriented

historians. I will point to three main contributors: Joseph Schumpeter, Nicholas Kaldor and Alexander Gerschenkron.

Schumpeter (1934, 1939, 1943) focused on innovation activities in firms as the driving force behind economic growth. His concept of innovation is broad and goes beyond the mere invention of a new product or process. Essentially, he sees innovations as "new combinations" of existing pieces of knowledge, whether drawn from science, engineering, market research, organisational experience or other sources, but with a view to commercial application. Successful innovating firms will benefit economically due to the temporary monopoly they get on the innovations they make. Eventually, the knowledge embodied in new innovations will diffuse to other firms and industries, and this will fuel growth further. It follows from this perspective that without innovation there will be no growth.

While Schumpeter focused on deliberate innovation activities by firms, Kaldor (1957, 1967) emphasised yet another aspect of this process by pointing to learning, either through investments and the subsequent application of new machinery, or as a result of cumulative production (so-called learning by doing) as the source of technological progress and growth.

Gerschenkron (1962) emphasised the national aspects of this process. Some countries are at the technological frontier, while others lag behind. Although the technological gap between a frontier country at a laggard represents as "a great promise" for the latter (a potential for high growth through imitating frontier technologies), there are also various problems that may prevent backward countries from reaping the potential benefits to the full extent. Gerschenkron argued that if one country succeeds in embarking on an innovation-driven growth path others may find it increasingly difficult to catch up. He explained this partly as a result of cumulative

learning as emphasised by Kaldor, but also as a result of the dynamics of the technological process itself, particularly increasing economies of scale as a function of time (as pointed out later by Raymond Vernon (1966) in his product cycle theory). Because of such factors, Gerschenkron argued, technologically backward countries have to develop new institutional instruments for overcoming these obstacles, above all in the financial sector, "instruments for which there was little or no counterpart in an established industrial country" (op.cit., p. 7). Abramovitz (1994) uses the concepts "technological congruence" and "social capability" to characterise the situation for latecomers. The first concept refers to the degree to which leader and follower country characteristics are congruent in areas such as market size, factor supply etc. The second points to the various efforts and capabilities that backward countries have to develop in order to catch up (education etc.).

In a sense these more heterodox contributions paint a much bleaker picture of the prospects for catch-up than the old orthodox theory. Catch-up is not something that can be expected to occur only by market forces left to themselves, but requires a lot of effort and institution-building on the part of backward country. An important reason for this is that technology is not regarded as a public good but something that to a large extent is organisationally embedded and intertwined with other factors of production.

Applied work on technology gaps and catch-up inspired by the heterodox approach took several different routes. Gerschenkron and others provided illuminating case-studies based on material from specific countries. Quantitatively oriented economic historians such as Abramovitz and Maddison made detailed investigations into the changes in relative productivity across countries in the long run and various efforts that countries made to impact on this process. Applying an econometric technique,

John Cornwall (1976) regressed variables assumed to reflect the scope for catch-up, investment and endogenous technological progress (the so-called Verdoorn law) on GDP growth for a sample of OECD countries. Later, in the 1980s, Keith Pavitt and Luc Soete (1982) and Jan Fagerberg (1987) presented regression models that also included variables reflecting resources devoted to (or output from) innovation (patents/R&D). Inspired by the work by Abramovitz and others on technology gaps and growth William Baumol et al. (1989) applied regression models of the type just discussed to cross-country samples including up to 100 countries or more. Variables taken into account in that study included the scope for catch-up, measured, as in the other studies, by GDP per capita, investment, educational attainment and growth of population/labour force. Thus, in contrast to studies just discussed, Baumol et al. did not include an independent variable reflecting the level of innovation in the country.

The results from these regression analyses led to a quite vivid debate about how the results should be interpreted (see Baumol 1986, Bradford DeLong 1988 and Baumol et al. 1989). The conclusion of this debate was that while unconditional convergence could perhaps be established for the OECD countries in the post war period, and probably extending to some other countries as well, it does not hold for the world as a whole. However, when other variables were introduced, such as investment, education, etc., the scope for catch-up (approximated with the gap in productivity – or GDP per capita - between the country in question and the frontier) regained its role as an important explanatory factor behind differences in growth in the world economy, so-called "conditional convergence". These results should not be regarded as very surprising except, perhaps, for some very firm believers of the old orthodox theory. Heterodox writers, on the other hand, had never predicted global convergence. On the contrary, these writers stressed that catch-up was possible but difficult and that

countries wanting to succeed in catch-up processes had to undertake a series of efforts to succeed.

THE NEW ORTHODOX THEORY

The problems that traditional neoclassical growth theory and empirical applications faced in explaining the "stylised facts" of long run growth, and the emergence of other, competing approaches, led eventually to a search among neoclassical theorists for new models of growth that could be made consistent with what could actually be observed, without having to abandon the neoclassical framework altogether. The central contributor here is Paul Romer. More specifically, he wished to design a model that could explain both long-run growth of productivity (without having to revert to the assumption of exogenous technological progress) and why convergence in the world economy did not occur. In so doing he first followed a route which we may label the Kaldor route (Romer 1986). The idea was that capital accumulation leads to learning which, however, cannot be appropriated by the firms within which the learning takes place. Learning is assumed to be external to firms, hence the assumption of constant returns to factor accumulation at the level of the firm can be sustained (perfect competition). However, although learning cannot be appropriated by any single firm, all firms in a country are assumed to benefit collectively from it. Thus, there are increasing returns to accumulation of all factors at the country level. This checks the tendency towards decreasing returns to capital accumulation that would otherwise have led long-run productivity growth to cease (in the absence of exogenous technological progress). Hence, long-run productivity growth may occur,

and rich countries may grow as fast as the poor ones, consistent with the lack of convergence in the global economy.

For various reasons Romer himself was not very satisfied with this first version of the theory and therefore in a later work (Romer 1990) suggested an alternative framework based on Schumpeterian ideas. Models along similar lines were also suggested by a number of other authors such as Gene Grossman and Elhanan Helpman (1991) and Philippe Aghion and Peter Howitt (1992). In contrast to the previous model, in which technological progress was considered as a pure externality, this new approach models innovation as the outcome of deliberate efforts by firms. The assumption of imperfect competition secures that the fixed costs necessary to develop new products and processes can be covered. However, although new technology in these models is a private good, there is also a public good component that feeds back on the capability to produce new innovations in the future. This feedback prevents decreasing returns to innovative activity in the economy. Hence, innovation and growth may go on. The main difference between this framework and the previous one is that in this case it is factors such as resources devoted to R&D the degree of appropriability that determine economic growth, not capital accumulation in the traditional sense.

New growth theories may have interesting implication for policy. In the old framework, where productivity growth in the long run depended only on exogenous technological progress, policy by definition could not have a long-run impact. In these new models this is not longer so. Policies that impact on the propensities to invest in physical capital (the first type of model) or R&D/innovation (the second one) may raise growth permanently.

THE EVIDENCE

These theoretical advances led to a surge of empirical work. As the new theory differs from the old one in important respects one might perhaps have expected that a new type of empirical work would have developed, focusing on new issues, using new data and applying new methods. This, however, has not been the case, or at least not until very recently.

What most applied researchers in this area have done is to follow the tradition from Cornwall, Baumol and others, applying single equation regression models to cross-country data sets. This type of work has later been dubbed "Barro regressions" after Robert Barro (1991). Basically the models are identical to the ones suggested by Baumol et al. (1989), including variables such as the scope for catch-up, investment in physical capital, education, population growth and others, reflecting , for instance, differences in the policy stance.

Much of this work has been summarised by Ross Levine and David Renelt (1992). In their paper the various factors that have been emphasised in the empirical literature were tested in a systematic way in order to establish how sensitive the findings are for inclusion of other possible explanatory variables. The method consists of selecting a set of basic variables which always are included in the regression. These are basically the variables we already have discussed (the scope for catch-up, investment, education and population growth). Other possible variables were included one by one and the sensitivity of the result is then tested by including up to three other variables drawn from a large pool of possible explanatory factors. If the result is always significant, it is termed "robust". If it is insignificant in at least one case it is considered as "fragile". This, it may be noted, is not a test of causality but of what can be established with

some degree of certainty in single equation cross-country regression framework, given the available data. Important relationships may well be found to be fragile following this methodology. The principal finding of Levine and Renelt was that the most robust relationship is between growth and investment. Some support was also found for variables reflecting the scope for catch-up (proxied by GDP per capita gaps) and educational efforts. All other explanatory variables were found to be fragile, including a large number of policy variables, openness (defined in different ways) and political factors (such as democracy, stability etc.). In a later study (Robert King and Ross Levine 1993) the level of financial development of the country was added to the list of robust relationships.

What is there to learn from this new generation of empirical research? Not very much I will argue. That investment is correlated with growth should come as no surprise. Indeed, this is something that would be consistent with most theories in this area, including those that consider investment as endogenous to the growth process, as available evidence on time series data seems to suggest (see Christopher Carroll and David Weil 1993). It is also worth noticing that the studies by Levine and others fail to include R&D and innovation, and thus throw little light on the mechanisms highlighted by the most recent versions of the new growth theories. However, the results from the empirical literature are useful in the sense that they urge us to use some caution when assessing the impact of policy on growth. This is especially relevant for those who believe that a so-called "correct" set of macro policies is enough to foster development and growth, as argued, for instance, by the World Bank.[3]

[3] For instance, in the World Bank report on the East Asian miracle (World Bank 1993), the bank argues that 60-90 % of productivity growth of the so-called high-performing Asian economies can be

Another relevant strand of research attempts to measure private and social returns to R&D and innovation. This type work has gone on for a long time, independently of the developments in growth theory, but attracts a growing interest due to the recent changes in formal theorising. Generally, these empirical exercises[4] tend to find high private returns to investments in R&D, about twice as high as for other types of investment. This, of course, runs counter to traditional neoclassical perspectives on investment, according to which returns to different types of investments should be equalised. Hence, one of the central issues in this area, which we will not venture into here, has been how these high private returns can be explained. However, high as these private returns may be, social returns are commonly found to be even higher, indicating important positive spillovers from R&D, especially when conducted in private firms. These are, of course, results that concur very well with recent theorising in this area.

Recently, there have been some attempts to address these issues from a perspective that draws more explicitly on the advances in the growth literature. Central questions in this more recent literature are to what extent diffusion processes are influenced by geographical (and other) boundaries, whether country size matters and what the most efficient carriers of technology diffusion are. Although research in this area is still in early stage, the available evidence seems to indicate that diffusion of technology (knowledge spillovers) is hampered by distance (Adam Jaffe 1986, Jaffe, Manuel

explained by accumulation and thus that other "unconventional" factors were of relatively little importance. I have shown elsewhere (Aadne Cappelen and Jan Fagerberg 1995) that this conclusion is not warranted. Indeed, the models applied by the World Bank predict very poorly for the fast-growing countries of Asia. A careful reading of the reported results shows that the only variable that really contributes to the explanation of the difference in productivity growth between these countries and those of the OECD area is the scope for catch-up (GDP per capita). There are also other attempts in the report to prove the case; these are not more convincing. See Dani Rodrik (1994).

[4] The literature has been surveyed by Zvi Griliches (1992) and Pierre Mohnen (1992). For a more recent overview see Bart Verspagen (1995).

Trajtenberg and Rebecca Henderson 1993), and is generally easier and quicker within than across country borders (Jonathan Eaton and Samuel Kortum 1996). There is also some evidence suggesting that returns to R&D investment are higher in large countries (David Coe and Helpman 1995, Maury Gittleman and Edward Wolff 1995), consistent with some of the suggestions from recent advances in growth theory

On the last question, regarding carriers of technology, the evidence is shakier. New technology may diffuse in many different ways; embodied in goods or services that make use new technology, through foreign direct investments by multinational firms or by imitative activities by domestic firms, drawing on a multitude of sources, as well as (necessary) complementary assets/capabilities. Some recent exercises point to R&D embodied in imports of goods and services as a very efficient way of transmitting new technology (Coe and Helpman 1995, Coe, Helpman and Alexander Hoffmaister 1997). The conclusion, then, is that foreign R&D embodied in imports is the primary source of growth in most countries, particularly the developing ones, and that openness to trade is what is required if a country is going to benefit from the global process of innovation and diffusion. However, others, using essentially the same type of indicator, fail to reproduce these results (Gittleman and Wolff 1995). Verspagen (1997) shows that the impact of foreign R&D, whether embodied in trade or otherwise, are much stronger in the time series than in the cross-sectional dimension, indicating that there - in addition to differences in "openness" - exist persistent differences across countries in their capacity to absorb foreign technology. Other recent contributions also point to differences in absorptive capacity (education, infrastructure, technological capabilities etc.) as the most important factor explaining differences in growth and welfare across countries (Gittleman and Wolff 1995, Eaton and Kortum 1997).

CONCLUDING REMARKS

While traditional neoclassical theory treated technology as exogenous, and hence failed to explain growth, recent advances in formal theorising have gone a long way in incorporating technology and innovation. This has led to the creation of more complex models, that may explain growth in a better way than before. These models are also more open in the sense that many different outcomes are possible, depending on what the key assumptions are. Many of these assumptions cannot be established on a priori grounds, at least not at the current state of formal theorising in this area, but need to be verified through empirical research. This has led to a new agenda for empirical research that is both more meaningful and more interesting than what we had before.

Previously, on easily got the impression that theoretical and empirical work on growth proceeded at very different levels. With the risk of exaggerating a bit, one may describe it as follows. At the one hand you had the theoreticians, sitting in their ivory towers, making a priori "true" models. On the other the empiricists, applying these assumedly true models to data, using ever more sophisticated techniques, leaving out an increasingly large share of the actual variation in the data as irrelevant. There were very little feedback from empirical work on formal modelling. Arguably, what is in most need of empirical research is not so much the concrete shape of the various relationships that formal models entail, as the basic assumptions that these models embody (including areas where our current knowledge is so limited that assumptions are made essentially ad hoc). The most important contribution, I will argue, that empirical work can make to formal modelling is to raise the quality of the assumptions that theoreticians make use of.

While formal modelling in this area has greatly improved in terms of how technology is handled, other basic neoclassical features have retained, such as the idea of "the representative agent". While this may be a useful simplification in some instances, it certainly runs counter to one of the most basic arguments of evolutionary theory; that agents are different (heterogeneous), that this creates diversity, which is what drives innovation. Hence, following this view, to explain diversity of growth patterns, one has to allow for heterogeneous agents, whether at the level of the individual entrepreneur, firm or nation state. This is an area where more empirical work is needed, and which potentially could be of great importance for formal theorising as well. However, to be able to respond to this challenge, empirical researchers have to go beyond empirical approaches that essentially consist of filtering out heterogeneity. Probably, to get a firm grasp on heterogeneity, one will need more case-oriented research of the type undertaken in many other disciplines, as well as by the grand economic masters of the past, such as Karl Marx and Alfred Marshall. This does, of course, not invalidate the use of other methods that are currently in more use in economics. Arguably, empirical work will need to proceed at several levels, not in isolation, but in interaction.

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