Understanding Economic Growth

On the work of Paul M. Romer and William D. Nordhaus, Nobel Laureates 2018

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All modern formal thinking on the determinants of long-term economic growth owes a great debt to Solow' s (1956) seminal neoclassical model – a model built around a production function linking output to capital, labor and technology. Solow's key insight was that the growth of per-capita income in a market economy is not driven by investment in the very long term, as was commonly believed at the time, but by the advance of technology. For this landmark contribution to the theory of economic growth, Solow was awarded a Nobel Prize in 1987.

Influential as it was, and still is to the present day, Solow's model left two very big questions unanswered. First, if technology drives growth, what drives technology? Without a model of the creation of new ideas, new products and more efficient production processes, Solow could not address this question. In effect, his theory was not so much a theory of economic growth as a model of a growing economy, taking growth as given. The second question left open by Solow was that of the sustainability of ongoing economic growth in the face of limited natural resources and a limited ecosystem. In the absence of an explicit role for natural resources in the production function and without decreasing returns to scale due to a limited anthroposphere, the issue of sustainability was beyond the scope of the Solow model as well.

The research of the two Nobel laureates of 2018, *William D. Nordhaus* and *Paul M. Romer,* has gone a long way towards closing these two glaring gaps in our understanding of economic growth. In the remainder of this article, their contributions and some of their major implications are sketched.

Paul Romer: The Economics of Ideas

For about 30 years after the publication of Solow's model, the theory of growth did not break out of his framework in any fundamental way. There was work on optimal growth, on production functions, on two-sector models of growth, on the distributional effects of growth, but no decisive progress towards a truly endogenous explanation of growth.[2] As a consequence, growth theory was clearly seen as running into diminishing returns. The young macroeconomists of the 1970s and 1980s were increasingly drawn into the more exciting developments in the macroeconomics of money and the business cycle.

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[2] A notable exception is Arrow (1962), an important forerunner of modern endogenous growth theory.

It was not until Romer's (1986,1987,1990) early work was published that growth theory was awakened to new dynamism. His starting point was a conundrum left behind by Solow. If technology was to be thought of as the outcome of some purposeful human activity requiring resources such as physical and human capital, these resources had to be paid a market wage. But in Solow's perfectly competitive constant-returns-to-scale world, the factor incomes paid out by the final-goods sector exhausted the full national income. No money was left over to pay for the creation of knowledge. Technology was treated as a gift from heaven ("manna"), available to anyone, free of charge.

Paul Romer's key to cracking this conundrum was his focus on the properties of the ideas that constitute "technology". Ideas are peculiar goods in that they are neither fully private goods, in the way capital goods are, nor the fully public goods as which traditional growth theory treated them. Rather, ideas are non-rival, partially excludable goods. Non-rivalry means that an idea, once created, can be used, unlike a capital good, by an arbitrarily large number of producers without detracting from its usefulness for all other users. Partial excludability means that the economic agent who has created a new idea, expending resources in the process, can prevent others from using the idea without paying for it– either by successfully keeping it secret, as e.g. in the case of the recipe for Coca Cola, or through the protection granted by a patent. The excludability is partial because secrecy is imperfect or because patent protection is limited in scope and duration. As a consequence, new technologies are associated with spillovers, both to other firms using them in the production of final goods and to future innovators who push the frontier of knowledge outwards by building on the stock of existing ideas.

Romer's landmark achievement was to grasp the full range of the implications of these features for economic growth and to embed them into a general equilibrium model of endogenous growth (Romer 1990). In his model, the creation of new technologies requires resources, and yet firms combine technology with capital and labor in the production of final goods very much along the lines of the Solow model. To reconcile these two features within a unified model, it is necessary to leave the comfortable world of perfect competition behind and to take into account the market power partial excludability grants to the originators of new ideas. The economies of scale that come with the non-rivalry of ideas rule out marginal cost pricing and hence perfect competition. At the same time, they are crucial for overcoming the growth-inhibiting drag of diminishing marginal returns to capital and labor, opening the door to a world in which an increase in the sheer size of the stock of potentially know-how-producing labor and human capital generates per-capita income growth. This creates, as Jones/Romer (2010, p. 232) state, "powerful incentives for connecting as many people as possible into trading networks that make all ideas available to everyone."

The analysis of endogenous technical change along these lines greatly benefited from earlier work on general equilibrium models with imperfect competition in the areas of international trade and industrial organisation (Romer 1994). The convergence of these three research areas spawned fascinating new research on the linkages between growth, globalization and market structure (Grossman/Helpman 1991,1994). In particular, seen through the lens of the new growth theory, globalization can be seen as a much more powerful engine of growth than suggested by traditional static trade theory. Reviving the old insight of Adam Smith (1776) on the role of the extent of the market for the wealth of nations, Romer's framework emphasizes the way globalization facilitates the flow of ideas. The growth-enhancing effect of globalization then stems both from the elimination of redundancies in research and development and from the amplification of the market potential of non-rival ideas, which helps to channel more resources into the creation of new technologies and thereby accelerates technological progress.

Importantly, the new growth theory allows to address a much broader set of empirical facts than the traditional neoclassical theory did. Whereas the empirical success of the Solow model was essentially confined to its consistency with Kaldor's (1961) stylized facts about the relations between capital, output, labor input and income distribution, the theory of endogenous technical change has greatly broadened the research agenda to shed light not just on the role of market size, but also on the observed variations in the level and rate of change of per capita GDP across time and space, on human capital and the skill premium (Jones/Romer 2010).

One particularly intriguing observation that can be explained with the new framework is the apparent acceleration of both population growth and per capita GDP growth over many centuries and millennia, as shown in Figure 1, adapted from (Jones/Romer 2010). As first pointed out by Lee (1988) and Kremer (1993), this pattern of accelerating growth can be explained simply by combining the effect of the the population size on the rate of discovery of new ideas with the role of technology in determining the population that can be sustained by current production. Whereas for Malthus, any increase in population was bad news as it exacerbated resource scarcity, the economics of ideas maintains that this adverse static effect is more than offset by the dynamic benefits of population size for the creation of knowledge. As the demographic transition eventually breaks the Malthusian feedback effect from income growth to population growth, population size levels out, which in turn induces a slowdown of technological progress. Thus, the 21st Century might witness a break of this age-old pattern of accelerating growth. However, the ongoing economic, institutional and educational catch-up process in much of the developing and emerging world might well delay this slowdown for quite some while (Jones/Romer 2010).

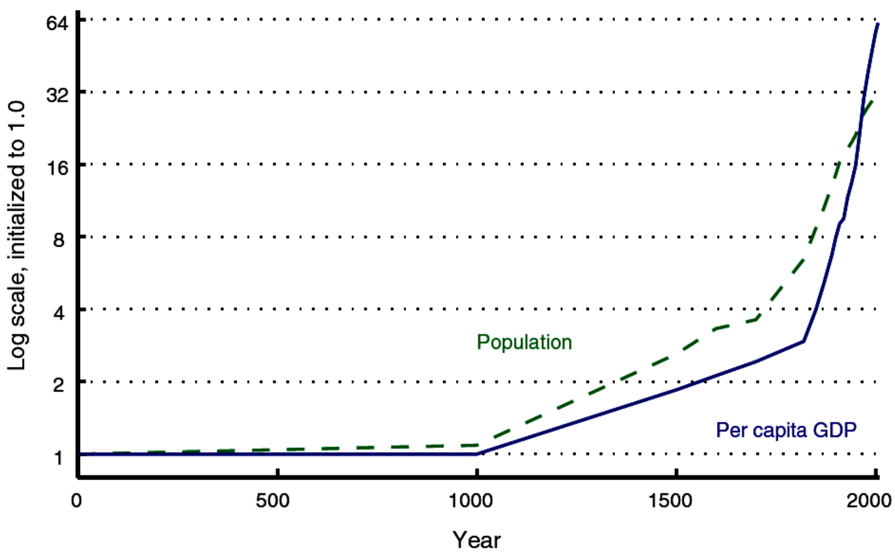

Figure 1: Population and per capita GDP since 1 AD[3]

[3] Source: Jones/Romer (2010), Figure 2, p. 233. The data are shown on a log scale, normalized to 1 in the initial year, 1 AD. They refer to the United States and 12 European countries and are taken from a data set compiled by Angus Maddison.

In addition to broadening the empirical scope of growth theory, the exploration of endogenous technical change also permits an analysis of the institutional conditions for the creation and diffusion of ideas. Of course, key elements in the institutional set-up of an economy are the mode and extent of intellectual property protection. Romer's theory offers a new perspective on the old question of the optimal design of patents, in particular the balance between the required financial incentives for inventors and society's interest in limiting their monopoly power once the useful new knowledge exists. Since ideas generate positive externalities in the form of spillovers both to the final goods production and to the R&D sector, Romer's theory suggested that the amount of resources devoted to the creation of knowledge is systematically too small. Questioning this result, later research pointed out that new ideas often crowd out older, but still useful ideas in a process that Joseph Schumpeter (1942) had dubbed "creative destruction." (Aghion/Howitt 1992).

More generally, Romer's research revived interest in the broader role of institutions for the process of economic growth. It paved the way for and helped to shape the agenda of a huge theoretical and empirical research effort directed at identifying the specific institutional variables that account for the staggering differences between rich and poor, growing and stagnant, prosperous and failed nations (e.g. Acemoglu/Robinson 2012). In this sense, Romer's contribution to the theory of economic growth has generated the very thing that is at the center of his theory: massive, productivity-augmenting spillovers to the subsequent creation of knowledge.

William Nordhaus: Economic Growth, Natural Resources and the World Climate

William Nordhaus is an economist whose research interests cover a wide range of topics, not only in the economics of long-term growth, but also in short-run business cycle theory where he has pioneered the theory of the political business cycle (Nordhaus 1975) – a branch of public choice theory that may well see a renaissance these days. Also, he is widely known as the co-author of the more recent editions of Paul Samuelson's celebrated textbook on the principles of economics (Samuelson/Nordhaus 2010). The interaction between the economy and the environment was a life-long concern of his. An early scientific discussion of the issues involved was sparked by the widely hailed publication of "The Limits to Growth" by the Club of Rome (Meadows et al. 1972). In a review of the underlying model (Forrester 1971), he levelled a sharp critique against the impressive-sounding "system dynamics" used to derive the crass apocalyptic projections of the "Limits to Growth". Without an empirical validation of the underlying relationships between population, the economy and resource consumption, and without any allowance for abatement, price signals, substitution and technological innovations, Nordhaus maintained, there is not much to be learned from letting a computer simulate a system of "43 variables connected by 22 non-linear (and several linear) relationships" (Nordhaus 1973, p. 1157). Sure enough, the doomsday scenarios painted in the "Limits to Growth" never materialised.

Nordhaus did not hold the view that the concerns of the club of Rome should not be taken seriously. Rather, his point was that any analysis of the impact of economic activity on natural resources and the environment should be strictly based on a sound empirical basis. His own early empirical work convinced him early on that the main threat from growth was not the exhaustion of resources, but the effect of energy consumption on the earth's heat balance (Nordhaus 1974). This insight set him on the research track that would eventually earn him a Nobel Prize.

With Solow's canonical model of economic growth as a starting point, he began to build climate change into his models. This research led him to his celebrated integrated assessment models (IAMs) which combine chemistry, physics and economics to illuminate the interaction of economic activity, the atmospheric CO_2 concentration, and global warming (The Committee 2018). The chemistry part determines the effect of CO_2 emissions on the CO_2 concentration in the atmosphere. Physics is required to assess the impact of the CO_2 concentration on global temperature, and economic analysis provides an estimate of how global warming feeds back to economic activity and human welfare. The fully quantitative IAMs can be simulated to track the effects of alternative policies and to evaluate the sensitivity of the model predictions to the pervasive uncertainty associated with parameters, structural relationships, time lags and policy responses.

The use of an IAM for computing the consequences of alternative scenarios is illustrated by Figure 2, below, from Nordhaus (2018). The baseline is conditioned on policies currently in place and shows a relentless increase of global industrial CO_2 emissions over the course of the 21st century. In contrast, the scenario labelled *T < 2.5* assumes carbon taxes high enough to keep global warming below 2.5%, which requires a sharp reduction of CO_2 emissions to zero before mid-century. The widely discussed Stern report (Stern 2007) calls for similarly radical abatement. What Nordhaus himself favors as an optimal course of action – the scenario labelled *Opt* – prescribes a middle course between the preceding two extremes, lowering emissions moderately and gradually over the second half of the 21st century.

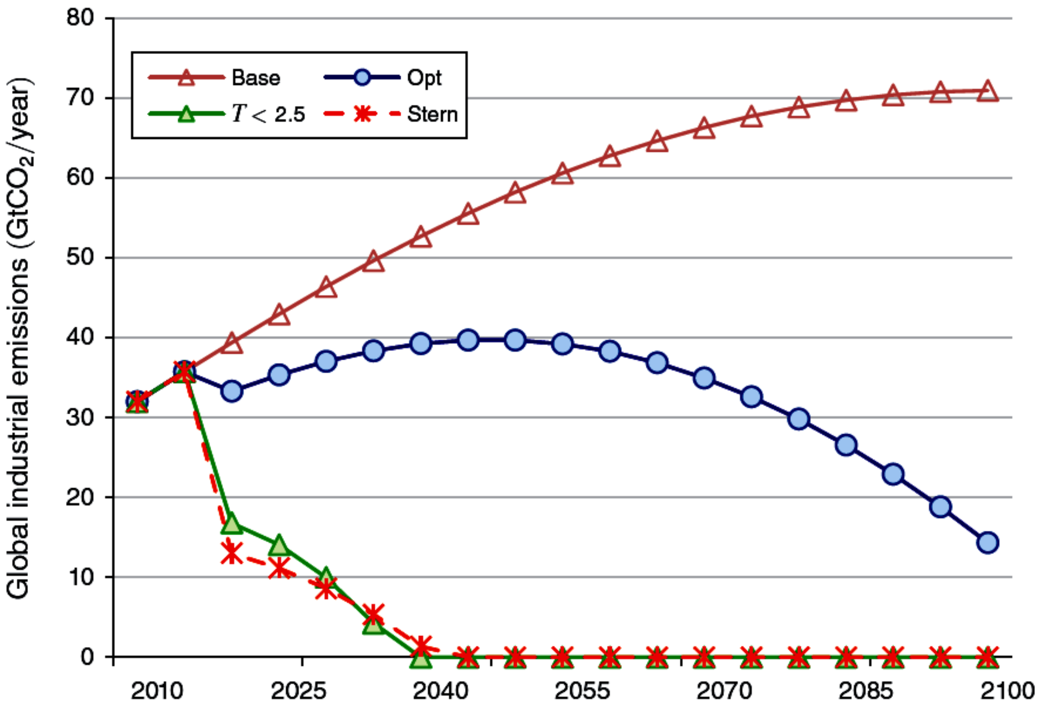

Figure 2: Projected emissions of CO_2 in alternative policy scenarios[4]

[4] Source: Nordhaus (2018), Figure 2, p. 347.

The Figure vividly illustrates the radical change in policy that would have to be put in place immediately if the widely propagated target of keeping global temperatures from rising by more than 2% is to be realized. What distinguishes Nordhaus's more moderate scenario from that in the Stern Report, in particular, is the significantly higher discount rate applied to future costs and damages. The ambitious abatement effort required by the Stern Report and by the *T < 2.5* scenario are very costly in the near term. At the same time, the inertia inherent in the carbon cycle and the climate system mean that the benefits of abatement are felt only with significant delay. Under these circumstances, a high discount rate conditioned by observed capital market rates and saving behavior does not justify to incur the high near-term costs of the more radical proposals. Stern's near-zero discount rate, in contrast, attaches a much higher weight to damages occurring in a distant future und thus calls for heavily front-loaded abatement measures. The assessment is sensitive to the assumed economic damage function which maps global warming into the value of the damages caused. But beyond this technical issue, it becomes apparent that the optimal strength and speed of action against global-warming critically depends on the relative valuation of the welfare of current and future generations. Economics cannot make this value judgment on a scientific basis, but it can quantify the terms of the trade-offs involved. To put the differences between the Nordhaus proposal and its more radical alternatives into perspective, one should keep in mind that even the more gradual policies recommended by Nordhaus are far more decisive than anything envisioned by actual policy to date.

An important lesson from Nordhaus's quantitative work concerns the role of the distinct uncertainty associated with all of outcomes estimated far into the future. It might be tempting to conclude that the prudent way of dealing with this uncertainty is to wait with any major policy initiative until the picture becomes clearer. However, the opposite is true. With the extremely long lags between any action and its effects, waiting until it is too late would be a dangerous choice. Thus, uncertainty strengthens the case for early and strong policy action on global emissions (Nordhaus 2018). And yet, the analysis leaves no doubt that the vision of a zero-growth society, which is favored by some environmentalists as a response to the environmental costs of economic activity, would be a grossly inefficient and economically very expensive scenario. Nordhaus is also very clear about the most effective instrument to be used to achieve a reduction of CO_2 emissions. Following the standard economic efficiency argument for a Pigou tax as the best choice for dealing with externalities, he proposes a globally uniform carbon tax, to be imposed on all countries.

Nordhaus is not ignorant of the high hurdles in the way of turning his policy conclusions into actual policy. Whereas much progress has been made in tackling environmental problems that are strictly local by their nature, slowing climate change is a global public good problem for which it is much harder to organize collective action. Being an accomplished expert in matters of public choice, William Nordhaus gives valuable advice on this front as well. In his Presidential Address to the American Economic Association (Nordhaus 2015), he developed a mechanism by which free-riding could be contained and a large and stable coalition of countries could be formed that would join forces to maintain high levels of abatement. Drawing on club theory and on his climate model, his plan sketches a "Climate Club" which agrees on target carbon pricing and is held together by modest trade sanctions against non-participants. The plan is not just an abstract idea, but puts numbers on the key parameters of the agreement, derived from quantitative estimates of the key relationships between the climate, the economy and international trade.

Conclusion: The Case for Proper Rules and International Cooperation

If there is a major common theme that pervades the work of both laureates, it is the simple idea that good things do not happen by themselves. As Paul Romer (2016) puts it:

> "We make progress because of things that people do. This is what it means for technological progress to be endogenous… [W]e should encourage people to do a lot more of whatever it is that they are doing to generate progress."

This statement not only contrasts with the notion of technological advance as a "manna"-like free gift to humanity as which it was treated in older growth models. It also highlights the need for active encouragement. Economic growth does not come about as a natural by-product of a free-market, laissez-faire economic system. Rather, it requires an appropriate set of rules and institutions to correct the market imperfections that inhibit the development of new and better ideas. Public policy must encourage invention and innovation because those who invest into the development and economic application of new ideas generate large positive externalities and hence capture only a fraction of the economic benefits they create.

Of course, externalities are at the center of William Nordhaus's work as well. Climate change is influenced by zillions of individual decisions on production, consumption and the implied emission of pollutants. But no individual has an incentive to take his particular impact on the climate into account since that impact is too small to be perceptible. Again, collective action in the form of public policy is required to align incentives towards the common good. What makes the collective action problem particularly hard to solve in this case is the global nature of the common good. As described above, Nordhaus has explicitly addressed this problem and devised a scheme which can work even in the absence of a supranational authority that could simply enforce the required change in behavior.

Thanks to Nordhaus's research, we know that a workable solution to climate change does exist. Is this cause for optimism? No. It is at best cause for what Romer (2016) calls "conditional optimism". In contrast to "complacent optimism" - the unconditional Panglossian expectation that all will be good -, conditional optimism is the confidence that with proper action, a problem can be solved. Proper action on global warming, as Nordhaus points out, calls upon nations to negotiate a set of rules rewarding good behavior and penalizing bad behavior. At this moment in history when America's government appears to turn its back on the idea of international cooperation, cultivating instead its perceived national self-interest and a complacent optimism with regard to the world climate, the Nobel Prize for Americans Paul Romer and William Nordhaus is as much a political statement as it is a tribute to two milestones in our understanding of economic growth.

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