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Prospects for economic growth in the 21st century:

A survey covering mainstream, heterodox and scientifically oriented perspectives

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ABSTRACT

Despite the importance of economic growth for the current economy, business and societal planning there are few long-term growth projections undertaken. There is, however, a vivid debate on what is called the 'new normal' - secular stagnation - which is undertaken within academic disciplines. This overview covers mainstream, heterodox and scientifically oriented economic perspectives on the prospects for economic growth in the 21st century. The survey shows that existing long-term projections and scenarios indicate growth rates ranging from around half a percentage point less than during the last two decades (projected by the Organisation for Economic Co-operation and Development, OECD), to dramatically lower growth rates). Differences stem from different perspectives on the determinants of economic growth and the potential for improvements in productivity. Headwinds are: an aging population, especially in OECD countries; resource constraints, including energy; increasing environmental costs in particular due to the consequences of climate change; overaccumulation; increasing income differences; and declining social capital. One conclusion is that policymaking based on the assumption that economic growth will continue at pre-crisis levels is unwise and risky.

1. INTRODUCTION

ECONOMIC GROWTH IS IN MANY WAYS VITAL for the current economic system. The expected long-term growth rate is an important factor for societal planning, for example investment plans, as they indicate future potential tax revenues, savings and pensions. On a global level expected long-term growth rates, and differences in growth rates between countries, affect inter-

national relations, trade and power balances. It should therefore be of great importance to develop as plausible long-term growth scenarios as possible.

Climate change and climate models have, during the last decade, led to additional needs for long-term growth projections. The focus for climate models has, however, been on developing energy scenarios and projections for emissions based on assumptions about technological developments, prices and policy, rather than on revisiting the determinants of, and making projections for, economic growth.

2. AIM

The aim of this article is to explore and provide an overview of the expected prospects for economic growth in the 21st Century. In this article, economic growth is synonymous with GDP-growth or GDP-growth per capita. The review includes projections and scenarios by the Organisation for Economic Co-operation and Development (OECD), alternative projections by other neo-classical economists and alternative perspectives by scientifically oriented economists.[3] Policy making is influenced primarily by mainstream (neoclassical) economics, which typically projects relatively high rates of future growth. One of the most obvious examples is the projections presented by the OECD pointing at future growth rates similar to those experienced in the West during the second half of the 20th century.

Different perspectives are provided by various heterodox and scientifically oriented economists. In Section 4 we explore the OECD projections in some detail and in Sections 5 and 6 we present a range of alternative perspectives. We do not judge the various perspectives and projections in Sections 4 to 6. This discussion is saved for Section 7 in which we discuss the results, draw conclusions and make suggestions for further research and policy. It is not the aim of this article to analyse whether future economic growth is in line with sustainable development and targets for climate mitigation - although this is a very important and timely question. As will be shown, these projections add an additional motive, apart from sustainability arguments, to redirect development towards qualitative development rather than quantitative GDP growth. Since we cover a wide range of perspectives, the review of each one is by necessity not complete. We also focus less on the mainstream economic theories and perspectives, as they are more well-known.

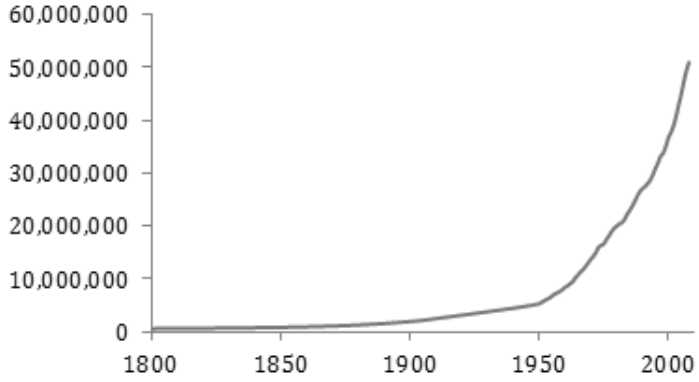
3. GROWTH, AND PERSPECTIVES ON GROWTH

Regular measurement of gross domestic product (GDP) began in the US and other countries during the depression in the 1930s. In order to estimate economic output before that period, British economic historian Angus Maddison compiled economic data to reconstruct levels of output on a country level for the last two millennia. Before the 19th century, the global growth in economic output was essentially zero. Starting around 1820, estimated long-term

global per-capita growth rates varied between 0.5 and three per cent per year (Maddison 2001). The global economy grew modestly during the 19th century. Growth rates did not start to take off until the beginning of the 20th century and started to accelerate by the mid-20th century (Figure 1). During most of this period, growth was restricted to Western Europe and North America.

Many factors have played a role in the increasing economic output accompanying the age of industrialisation. The discovery of new energy sources including fossil fuels, technological advances, access to cheap labour and raw materials, following early globalisation and colonialism, are among the most common explanations.

Figure 1: Global World GDP 1800-2000. Millions of 1990 Geary-Khamis dollars.[a]



[a]The Geary-Khamis dollar is an international currency unit representing the purchasing power of a US dollar in a given year.

Source: Data from http://www.ggdc.net/Maddison/

The exponential growth path of the 20th century was not expected by economic theory. Instead most economists (including Smith, Malthus, Ricardo, Marx, Sweezy, Hobson) up until the mid-20th century expected economic growth eventually to slow down, as a result of constraints such as natural capital, land or maldistribution of income (Backhouse and Boianovsky 2016).

The term 'secular stagnation' was introduced by Alvin Hansen (1934, 1938, 1939) after the great depression in the 1920s. Hansen redefined the stationary state and initiated a new era of discussion about secular stagnation which was conducted vividly for a couple of decades. Hansen's theory of secular stagnation was based on the case of the US. He argued that the closing of the frontier (expansion towards the west), a slowdown in population growth and a lack of capital-using inventions, which reduced the opportunities for investments needed to sustain full employment, would reduce the rate of economic growth. He argued that a slowdown of economic growth is a natural

transition for mature economies. While the link between stagnation and maturity was lost, when the empirical facts seemed to prove the theory wrong after World War II, the relationship between investment and savings and its effects on demand continued to be discussed by Alvin Hansen, John Maynard Keynes, Roy Harrod and others (Backhouse and Boianovsky 2016).

Left-wing economists also expected economic growth to slow down but for a different reason. Paul Sweezy, a Marxist economist, argued that stagnation is the normal state in mature capitalist economies — the reverse assumption of mainstream economists (Foster and McChesney 2012). According to Sweezy it is periods of high economic growth that need to be explained as the result of special historical factors. The strong growth during the 1950s and 1960s can thus be explained by: (1) the build-up of consumer liquidity during the war; (2) the second great wave of auto-mobilisation in the US; (3) a period of cheap energy based on the massive exploitation of oil; (4) the rebuilding of the war-torn European and Japanese economies; (5) two regional wars in Asia, and Cold War military spending; and (6) a period of unrivalled U.S. hegemony. According to Sweezy (1942), accumulation is the primary factor in capitalist development and overaccumulation eventually reduces investment opportunities. Once this happens growth becomes dependent on external stimuli such as higher government spending, rising sales efforts, and financial expansion.

Mainstream economists explain economic growth by technological innovation — the Solow residual — and its effect on productivity. This view is the one adopted in the long-term growth projections of the OECD, which we review in the next section. The fact that the global economy continued to grow led to a lack of interest in stagnation theory and might be the reason why the continued research within this field (Kalecki 1938; Steindl 1952; Baran 1957) was not much noticed. The failure of mainstream economists and economic models to predict the financial crisis in 2008 and the slow recovery afterwards have changed this. The term secular stagnation and discussions about it was particularly revived by Lawrence Summers at an IMF conference in 2013 (Summers 2013).

We have, in this short historical review, seen how economic growth, within a historically short period of time, has come to be viewed as the natural state of the economy and an official policy objective in most countries. This view is now once again challenged (for reasons to be discussed in the following sections) also by mainstream economists. Ecological economists and scientifically oriented researchers have for decades questioned the sustainability of continued economic growth from an ecological point of view.

4. The OECD long-term economic growth projection — Looking at 2060

There are very few long-term economic growth projections. In fact we only found one by a large international organisation — the OECD long-term economic growth projection — Looking at 2060 (OECD 2012).[4]

The OECD model provides projections for the OECD-countries, as well as global averages and is, as such, an important reference for all countries, including smaller countries that have fewer resources to perform their own projections.[5] As the sole long-term model, its scenarios dominate perspectives on long-term growth prospects globally. We shall therefore describe the model, its assumptions and results in some detail before reviewing alternative perspectives.

4.1 The OECD model

The OECD (2012 p 9) states that there is no single theory of economic growth but wide support for models in which '…each country will converge to its own steady-state[6] trajectory of GDP per capita determined by the interface between global technological development and country-specific structural conditions and policies (conditional convergence). In the long run, all countries are expected to grow at the same rate determined by the worldwide rate of technological progress, but cross-country GDP per capita gaps would remain, mainly reflecting differences in technological levels, capital intensity and human capital.'

The long-term worldwide rate of technological progress is assumed to be 1.3 per cent per year. This assumption is based on the empirical level of growth in technology in the most advanced OECD countries during the last 30 years. The assumed growth in productivity is thus assumed to increase long-term as it is not a historic average but the average of the most advanced economies. As we shall see in the following sections, this assumption is disputed by some neoclassical economists as well as scientifically oriented economists.

The OECD model is based on a Cobb-Douglas production function with constant returns to scale, featuring physical capital, human capital and labour as production factors, plus technological progress[7] (so-called total-factor productivity).[8]

$$Y_{it} = K^{\alpha}_{it}(A_{it}\ h_{it}\ L_{it})^{1-\alpha}$$

where *Y, K, A, h* and *L* denote output, physical capital, technical progress, human capital per worker, employment and subscript *t* and *i* denote year and country. The income share of capital (α) is set to 1/3.[9] The determinants of economic growth are assumed to be the factors which are represented in the production function. The OECD argues that cross-country gaps in multi-factor productivity (MFP) and, to a lesser extent, in human capital have accounted, historically, for the bulk of cross-country differences in GDP per capita. The gradual closure of these gaps has accounted for the greater part of GDP per capita growth over the last decade. MFP is assumed to be a crucial driver of long-run GDP per capita convergence in the future.

The OECD argues that there is considerable scope for improvements in educational attainment in many countries. However, in the last decade labour has accounted for an important part of GDP per capita growth — on average 0.5 percentage points. Looking forward, most countries will have ageing populations with adverse implications for labour force participation and growth. In addition, the projections are based on a baseline scenario assuming gradual structural reform and fiscal consolidation to stabilise government debt-to-GDP ratios. Countries with high debt levels are assumed to decrease their debts.

4.1 OECD model scenarios results — looking to 2060

The OECD long-term growth scenario projects global GDP could grow at almost three per cent per year over the next 50 years (Table 1). The per capita growth rate is around 2.6 per cent. This is 0.5 per cent point less than during the last two decades.

Within the OECD, trend growth is projected to average around 2 per cent per year during the next 50 years, which is slightly less than during the last two decades. Growth in non-OECD countries will continue to outpace the OECD, but the difference will narrow substantially. From seven per cent per year over the last decades, non OECD growth will decline to around 5 per cent in the 2020s and to about half of that again by 2050. The average growth rate in non-OECD countries between 2011 and 2060 is projected to be 3.9 per cent. One consequence of this scenario is a major change in the relative size of the world's economies.[10] Even so, large cross-country differences in living standards will persist in 2060.

Table 1 Average growth rate in trend GDP and trend GDP per capita in USD 2005 PPPs, per cent.

	Annual GDP-growth		*Annual per capita GDP growth*	
	1995-2011	*2011-2060*	*1995-2011*	*2011-2060*
World average Weighted	3.5	2.9	2.5	2.6
OECD average Weighted	2.2	2.0	1.5	1.7
Non-OECD Weighted	6.7	3.9	5.6	3.7
Sweden	2.5	2.0	2.1	1.6

Source: OECD (2012, Appendix 8, Table A8.3. Comparison of trend GDP projections)

4.3 Scenarios 'going for growth' rather than projections

The OECD long-term results are not named projections but growth scenarios. The reason for this is that it is very difficult to make long-term projections. Even short-term economic projections have failed regularly.[11] The long-term

scenarios are, in turn, even more unreliable than the short-term projections — as small errors accumulate to create significant errors over time.

The OECD admits that the estimated long-term economic growth scenarios are to be considered optimistic. The scenarios are, as noted above, based on the empirical level of growth in technology in the most advanced OECD countries during the last 30 years. They also assume that the best economic practice is followed around the world in order to promote growth. The burden of an aging population is expected by the OECD to be alleviated by changes in retirement ages. Impacts of climate change or resource constraints, including oil, are not included in the projections.

The OECD does not discuss the reliability of its scenarios but lists a number of areas in which the model could be expanded, including: more country specific estimations, explicit modelling of the fiscal pressure from aging populations, more detailed modelling of oil prices, endogenous corrections to persistent account imbalances and further enriching the convergence framework.

Even though the scenarios are optimistic, the OECD argues that there is potential to further increase growth through additional, more ambitious growth enhancing policies, compared with the moderate policy reforms of the baseline scenario. Ambitious product market reforms could, according to the OECD, increase global GDP by 10 percentage points relative to the base-line scenario by 2060. Policies that induce convergence towards best practice labour force participation (Switzerland) could increase GDP by another six percentage points on average.

5. Different perspectives on the prospects of growth from mainstream economists

The optimistic views represented by the OECD and others have been criticised, both by critics who share the basic theoretical foundations of the OECD model and by those with a different theoretical perspective. In this section we present the critique by the first category — mainstream neoclassical economists. Differences in perspectives on the prospects for long-term economic growth among mainstream neoclassical economists stem primarily from different assumptions about the growth in total factor productivity

5.1 The last 30 years was an anomaly

Robert Gordon (2012) has received a lot of attention for his 'headwinds' against future economic growth in the US. He argues that 19th and 20th century growth rates were exceptional and that a likely development is a significant slowdown of GDP growth in the coming decades. Beginning in the 19th century, GDP growth in the US increased gradually until the mid-20th century and has since then slowed down, from 2.5 per cent to less than 1.5 per cent at the beginning of the 21st century. Gordon projects future US growth to decline towards just 0.2 per cent per year, which is close to growth rates before the industrial revolution.

The main argument in Gordon's work is that revolutionary transformations of the economy and living standards are unlikely in the near future. Although technological innovation will certainly continue, he does not think it will have the same pervasive effects as historical advances. He does not, for example, believe that the third industrial revolution of computers and the internet will deliver major growth in the years to come.

In addition to this general hypothesis, Gordon lists six 'headwinds' that may contribute to a slowdown in the US economy. The first of these headwinds is the aging population, contributing to a declining number of hours worked per capita. Second, the cost of higher education is increasing, which is hampering growth in human capital. Gordon does not further analyse the reasons for this 'cost disease' but the phrase is reminiscent of the work of William Baumol (1967), indicating that growth in service sectors (including education) may result in slower productivity growth. The third headwind concerns the fact that the richest one per cent of the population presently receives around 50 per cent of the GDP growth, which means that actual growth for 99 per cent of the population is much lower than the growth in GDP. At the same time households and government in the US are heavily indebted which, in Gordon's presentation, is not connected to the income distribution but is nevertheless listed as another headwind.

Globalisation and ICT are yet other factors putting a downward pressure on US growth, since outsourcing and imports reduce the bargaining power of the domestic work force, resulting in lower wages and diminishing purchasing power. Here Gordon refers to the Heckscher-Ohlin-Samuelson factor-price equalisation theorem. Convergence theory thus comes into play and the catch-up process of developing nations finds its counterpart in a hold-back process at the frontier. The final headwind concerns energy and the environment, basically assuming that carbon taxes and other policy instruments designed to reduce climate impacts will reduce the disposable income of American households.

Thomas Piketty (2014)[12] received even more attention than Gordon two years later when he, based on an extensive historical dataset, in line with Gordon suggested that economic growth in the wealthy nations can be expected to be significantly lower in the future. Piketty showed that growth rates as high as three to four per cent were never sustained for any lengthy period of time. The high growth rates in Europe in the decades following World War II (3.8 per cent between 1950 and 1970, 1.9 per cent between 1970 and 2012) were, according to Piketty, the result of a catch-up process after a slowdown caused by wartime destruction. At present China and other emerging countries are catching up with the frontier.

What comes out from this historical record is that per capita growth rates above 1.5 per cent are exceptional, and this is true for every period of time during the last 2000 years. 0.5 per cent or one per cent would be more typical values in most situations. Simply expecting the growth rate to assume

levels obtained in Europe during the last 30 years is, according to Piketty, to ignore a significant amount of historical information. Unless specific circumstances generating growth rates above 1-1.5 per cent can be identified, high growth rate scenarios do not appear to be entirely convincing (Piketty 2014).

5.2 Low interest rates indicate stagnant economic growth

Others (Summers 2014; Haldane 2015) reuse the theory of the natural interest rate and argue that the current low interest rates indicate stagnant economic growth. According to this hypothesis, the interest rate needed for full capacity use, including employment, has fallen during the last couple of decades and may now be significantly negative. One reason is that the propensity to save has increased, which holds back consumption. At the same time, investments have fallen. The increased propensity to save may depend on factors such as increased average length of life and a more unequal income distribution. Increased insecurity concerning economic development further increases saving and reduces investment. Haldane suggests that low interest rates may reflect a dearth of profitable investment opportunities, which implies low returns to innovation and low future growth. In this case, falling real interest rates is a sign of stagnation.

5.3 Sociological and institutional factors

Andrew Haldane (2015) points towards additional headwinds from an endogenous growth perspective. According to endogenous growth theory, the determinants of economic growth include sociological and institutional factors such as social capital, human capital, efficient institutions and investments in infrastructure. These factors are mutually supporting, not exogenous and idiosyncratic. They build in a cumulative, evolutionary fashion, rather than spontaneously combusting. Haldane shows that these factors have not developed in a positive way in most countries, which in turn affects growth prospects negatively. Social capital is depreciating in most countries, along with one diagnostic of social capital-income inequality. Dabla-Norris *et al* (2015) at the IMF and OECD (2015) have shown that income inequality significantly slows growth. Human capital has improved in terms of literacy but numeracy skills have declined.

5.4 Decline in manufacturing and resource scarcity

Additional perspectives on the prospects for future growth are provided by Grantham (2012). Starting from Gordon's (2012) projections, Grantham adds additional headwinds to the picture. He observes that manufacturing represents a decreasing share of mature economies (presently only nine per cent of the US economy), gradually replaced by services. Since productivity growth is at least one per cent lower in service sectors compared with manufacturing in the US compound growth is, according to Grantham, gradually slowing down. This is in line with arguments provided by Baumol (1967) and more recently

by Reinert (2008). What Baumol did not foresee is that since 1980 the financial sector's share of the service sector has increased substantially (which will be discussed further in the next section).

Further, Grantham's reasoning concerns the consequences of increasing resource prices at the global level. According to Grantham the price of 33 important resources (including food, metals and oil) exhibited a long-term decline until 2002, when a shift occurred. From that year, a conservative estimate finds that resource prices increased at seven per cent annually, as a net result of increasing extraction costs (ten per cent) and productivity gains (-3.25 per cent). As a result of global resource constraints and rising demand, Grantham projects this development to continue in the coming century. This, in turn, results in an increasing proportion of raw materials in the composition of GDP at the expense of other goods and services. Hence, after 2002, the growth in resource costs reduced the growth in other goods by 0.4 per cent annually. This does not, according to Grantham, affect GDP as such, but it results in a loss of utility which is not reflected in the official data.

If resource prices were to rise at nine per cent, then obtaining sufficient resources will absorb all of the *real* growth potential in just 11 years (Grantham 2012). After that, the balance of the economy will be in reverse. If, instead, resource prices were to rise by only five per cent a year, actual growth will reverse in 31 years. The share of resources in the economy is larger in developing economies, indicating that the drag on real growth in the developing world is potentially larger than in the US and other OECD countries. This 'resource squeeze' (Grantham's phrasing) points towards the arguments offered by the scientifically oriented economists which will be discussed in the next section.

Two other headwinds suggested by Grantham are reduced capital spending on real investment, which is a recent trend seen since 2005 (investors tend to spend more on financial speculation than real investment) and increasing environmental costs, in particular arising as consequences of climate change. The final projection presented by Grantham is an annual GDP growth rate in the US of 0.9 per cent up to 2030 and 0.4 per cent from 2030 to 2050.

5.5 Financialisation

The growth of the finance sector in recent decades has been argued by different economists to improve growth, to hamper growth and to act as a growth steroid. While there has been a long-term decline in the growth rate of industrial production, there has been an increase in finance, insurance, and real estate (Fire), The Fire portion of GDP in the US has doubled since the early 1980s (Foster and McChesney 2012). Mainstream economists have generally seen the growth of the financial sector as a natural development, reflecting the comparative advantage of developed countries. The negative potential effect on the financial sector was, for example, an argument in the UK against Brexit.

Others have argued that investments in financial assets hamper investments in productive capital and, as such, have a negative effect on economic growth. Adair Turner's latest (2015) book provides an example of this argument. According to Turner, credit has played an important role in fostering productive capital accumulation, but the expansion of credit since the 1980s has increasingly been directed towards already existing assets, above all real estate. In order for economies to be more stable in the future, he suggests radical structural reforms.[13]

Sweezy and others (Baran, Magdoff), who, at the height of economic growth in the 1950s believed in stagnation theory, were among the earliest to analyse the expansion of the financial sector. Sweezy is also the one who started using the term 'financialisation', to describe what he sees as a development of the capital accumulation process. According to Sweezy, financialisation emerged as a response to the stagnation tendency of mature capitalist economies — a desperate and ultimately dangerous saviour (Baran and Sweezy 1966; Magdoff and Sweezy 1987).

Sweezy argues that monopolisation, stagnation, financialisation and globalisation are intimately related and have produced a new historical phase. In this phase, the developed countries are locked in a stagnation-financialisation trap. The central problem is overaccumulation, especially in the US, the EU and Japan. There is a surplus of investment capital but investments in productive capital are declining because of a lack of demand, which in turn depends on the increasing income inequalities. The remedy is increased financialisation and debt, but this only worsens the situation in the long run. In line with the Sweezy Normal State, the long-term trends associated with economic growth, industrial production, investment, financialisation, and capacity utilisation all point to the same phenomenon of a long-term economic slowdown in the US and other advanced industrial economies.

5.6 A downward shift in world oil production

Kumhof and Muir (2012) at the IMF analyse the implications of a downward shift in the growth rate of world oil production for the world economy.[14] Their focus is on GDP, current account imbalances, and oil prices. For their analysis they use the IMF's Global Integrated Monetary and Fiscal Model (GIMF) which is a six region dynamic general equilibrium model of the world economy. In GIMF, oil is a separate and exhaustible factor of production. In their analysis Kumhof and Muir distinguish between short-term spikes in oil-prices and long-term — persistent — oil scarcity.

The main result of their study is that the extent to which persistent oil scarcity could constrain global economic growth and current account imbalances depends critically on a small number of key factors:

- The rate of oil output decline - whether oil output decline is modest, -1 per cent per year, or if the reduction in oil output is larger, -3.8 per cent per year (which is in line with some more pessimistic estimates).

- The substitutability between energy (oil) and other factors of production. As argued in the study, there are limits to substitutability in the face of scarcity.
- The economic role of oil relative to its cost shares. The standard production function might underestimate the economic role of oil under conditions of scarcity.
- The income elasticity of oil demand. The income elasticity of demand could be one third rather than one, as in the model base line. A lower income elasticity could mean that the GDP effects from a reduced supply of oil could be larger.[15]

Kumhof and Muir conclude that if the trend growth rate of oil output declines only modestly, and if the economy is adequately represented by a standard production function with capital, labour and oil, world output would eventually suffer, but the effect might not be dramatic. However if the reductions in oil supply are more in line with the more pessimistic studies in the scientific literature, the effects on GDP could be extremely large.[16] The same would be true if, as claimed by several authors in the scientific literature (Ayres and Warr 2005, 2010; Hall and Klitgaard 2011; Kümmel 2011), the standard production function misses important aspects of the economic role of oil under conditions of scarcity. These aspects have primarily been analysed by ecological, biophysical and other scientifically oriented economists and are reviewed in the next section.

5.7 Technological leaps

Brynjolfsson and McAfee (2014) provide an optimistic perspective, arguing that rather than approaching an age of mature decline we are in the midst of a technological leap, which will transform the economy and lead to hugely improved productivity and economic growth. 'Smart' machines will take advantage of the exponential growth in computer processing, advances in artificial intelligence, networked communication and the widespread digitalisation.

Brynjolfsson and McAfee argue that this is a major economic opportunity, but they also caution that there are social sustainability risks that need to be managed. The main challenge to society is the risk of the decoupling of GDP-growth and employment. This in turn leads to increased inequality, resulting in a lack of demand[17] which, in the end, hampers further growth. In terms of real GDP growth, consumers will take advantage of low prices on computer related services.

6. Determinants of growth according to scientifically oriented economists and natural scientists and the implications for growth forecasts

In this section we present the perspectives of one group of heterodox economists, the scientifically oriented economists, of which ecological economists

are perhaps the most well-known. A common position for the theories of scientifically oriented economists is that the economy is embedded in nature and fundamentally dependent on interaction with nature in a number of ways. One of the earliest critics of the neoclassical theory of economic growth and one of the first ecological economists was Nicholas Georgescu-Roegen, an economist, mathematician and statistician who argued that the second law of thermodynamics governs economic processes (Georgescu-Roegen 1971, 1975).

6.1 The world model — Limits to Growth

The influential World 3 model, commissioned by the Club of Rome and the basis for the Limits to Growth report by Meadows *et al* (1972), represents an example of a different approach to modelling future economic growth compared with economic models such as the OECD model. World 3 modelled data up to 1970 and then developed a range of scenarios out to 2100. The model is based on modelling the interactions between population, industrial growth, food production and limits in the ecosystem of the Earth. The World 3 model was created by Donella Meadows, Dennis Meadows and Jørgen Randers. There have been two subsequent updates, Beyond the Limits (1992) and a 30-year update (Meadows *et al* 2004). In 2012 one of its authors, Jørgen Randers (2012) published '2052: A Global Forecast for the Next Forty Years'. The latter is based on educated guesses, i.e. based on available facts and internally consistent.

The results of the model scenarios suggest dramatic developments ahead, where population and global GDP grow exponentially until around 2050, after which GDP and population decrease as a result of resource limits and environmental degradation. The model projects 'overshoot and collapse' — in the economy, environment and population — before 2070.

The book and the model have been heavily criticised by mainstream economists (e.g. Nordhaus *et al* 1992), especially the central assumption that 'the earth is finite' and that the quest for unlimited growth in population, material goods etc. would eventually lead to a crash. There have, however, been several evaluations of its predictions. The latest evaluations by Graham Turner (2008 and 2014) show that 30 years of historical data compares favourably with key features of a business-as-usual scenario called the standard run scenario, which results in a collapse of the global system midway through the 21st century. Other evaluations come to the similar conclusions (Simmons 2000; Meadows *et al* 2004; Hall and Day 2009; Bardi 2011; MacKenzie 2012).

6.2 The role of energy versus technology in economic growth

The role of energy in the economy has, since the critique by Georgescu-Roegen (1971), remained central to the divide between neoclassical economic theory and the theories by scientifically oriented economists.

Numerous studies have examined the correlation and causal linkages between energy and GDP. The results are not unequivocal, but most studies reach the conclusion that there is a strong connection and that it works both ways (Stern 1993, 2011; Lee 2006).

In the neoclassical framework, energy is not included in the production function (see the OECD model in Section 4), in spite of its acknowledged importance, but is an external factor along with natural resources and ecosystem services. According to Ayres *et al* (2013) most models with resources exclude realistic constraints on the substitution possibilities between energy and capital. They argue that models which include more realistic assumptions arrive at the conclusion that future growth will be severely hampered by scarce energy and material resources. While neoclassical economists agree that energy is a necessity, they argue that technology is the key determinant of economic growth and that technology trumps energy by developing alternative energy sources if one source of energy runs out.

Most scientifically-oriented economists, on the other hand, argue that access to high quality energy is the most important determinant of economic growth and trumps technology. The discovery and use of fossil fuels in the 19th century are argued to be what caused the industrial revolution and the historically unprecedented economic growth that followed (Cleveland *et al* 1984; Stern 1993, 2011; Kander 2002; Murphy and Hall 2010; Hall *et al* 2012; Ayres and Voudouris 2014).They also find that technological development and innovation have been other key factors, but these are of a secondary nature. The reason is that technology, in the great majority of cases, is the tool for effective exploitation of the high-quality (fossil) energy. Without access to this energy, technology would not have taken off. Technology is said to have been developed primarily in order to put energy to work.

Ayres and Voudouris (2014) have developed a production function which includes (useful) energy as a third production factor.[18] They show that this improves significantly the fit of macroeconomic models. Applying the model to explain economic growth in the US, UK and Japan since 1900, they conclude that growth since the industrial revolution has been driven largely by declining energy costs resulting from the discovery and exploitation of fossil fuel resources. They further conclude that economic growth presupposes the availability of increasing quantities of useful energy. Given the climate change problem they conclude that extraordinary efforts will be needed to increase efficiency, in addition to scaling-up renewables while phasing out fossil fuels.

6.3 Accounting for the quality and energy return on energy invested (EROEI) of energy sources as a determinant of economic growth

Some scientifically oriented researchers argue that it is not only access to energy which is important but access to high quality energy:[19] not all types of energy are equally productive. During the 20th century, developed countries

moved their energy system up an energy quality ladder, starting with a dependence on human muscle, horse power and biofuels (wood), moving to coal, oil and electricity. High quality fuels are much more productive than the low quality fuels. The conversion of oil to electricity means a loss of energy but results in a form of energy which is very productive.[20] Using electricity, a machine can be run efficiently and the processes controlled in detail. Oil has unique qualities in terms of energy-density, storage, transportability and, historically, has a high energy return on energy invested (EROEI) i.e. net energy.[21]

EROEI is the ratio between the quantity of usable energy delivered by an energy source and the quantity that has been expended (invested) in order to gain access to the energy. The EROEI of a country's energy system is, according to Murphy and Hall (2011), one determinant of its potential GDP level, as the net energy (EROEI) determines how much energy is left for sectors other than the energy sector.

It is sometimes assumed that any energy source that generates a positive EROEI value is worth investing in and scaling up to a level that satisfies our energy needs (Hall *et al* 2009). Discussion of ethanol from maize, for example, has focused to a high degree on whether ethanol production generates a positive or negative EROEI. The conclusion is that even if a low EROEI may make a particular activity worthwhile, this kind of reasoning does not apply for society as a whole. Instead, the energy system must typically be based on an EROEI of approximately 14:1 in order to sustain present-day Western societies (Hall *et al* 2009). The reason for this is that there is a lot of 'overhead energy costs'. Infrastructure is, for example, needed to transport energy from the point of production to the end user.

Historically, fossil fuels have shown an EROEI far exceeding 14:1. Oil extraction in the US, for example, had a peak in terms of EROEI of 30:1 in 1970, but has since declined to a figure today of just over 10:1. For the majority of renewable energy sources, wind turbines being the exception (18:1), the estimated EROEI falls below 14:1. Nuclear power, according to Hall *et al* (2014), has an EROEI of between 5:1 and 10:1. Coal continues to have a high EROEI (>80:1) but the climate consequences of using it may be severe. A recent publication using hybrid LCA methods arrives at a higher EROEI for most renewable energy sources (Sandén and Arvesen 2014). If these higher EROEI are correct, then they indicate a potential for higher future GDP levels. The new EROEI measures have, however, not been scientifically evaluated in relation to the previously-published EROEI values.

Based on their perspective on energy, Murphy and Hall (2011) draw the conclusion that the economic growth of the past 40 years is unlikely to continue. The reason is what they call an economic growth paradox: increasing oil supply to support economic growth will require high oil prices that will undermine economic growth.

Murphy and Hall describe the economic growth model as a feedback loop which, to a large extent, depends on accessibility to high quality energy,

i.e. oil, and it will thus be dramatically affected by what they refer to as peak oil. Peak oil is defined as the point in time when the maximum rate of extraction of petroleum is reached, after which the rate of production is expected to enter terminal decline.[22] Murphy and Hall do not, however, provide an alternative projection for economic growth during the coming decades.

Kjell Aleklett argues in his book, *Peaking at Peak Oil* (2012), in line with Murphy and Hall, and the Limits to Growth model, that peak oil also means peak growth. Also Aleklett does not provide any alternative growth projections.

6.4 Steady state economics — Daly

Herman Daly, one of the founders of the field of ecological economics, has long argued for the need for a transition to a sustainable steady state economy (Daly 1996). A steady state economy is an economy with stable or mildly fluctuating size. To be sustainable, a steady-state economy must not exceed ecological limits. A sustainable steady-state economy can be reached after a period of growth or after a period of downsizing or degrowth.

According to Daly, economic growth is an increase in the physical scale of the matter/energy throughput. Throughput begins with depletion and ends with pollution - a perspective which is in accordance with the empirical correlation between GDP and use of resources (UNEP 2011). According to Daly, the current economy may be moving towards a steady state faster than we think. The reason is that current national accounting conventions do not subtract the costs of negative effects on the environment from the value of production (Daly 1996). Daly distinguishes between (quantitative) growth and (qualitative) development. Growth cannot be decoupled from energy and resource use. Qualitative development on the other hand can.

7. Concluding remarks

This overview of prospects for economic growth during the coming 50 to 100 years exposes, not surprisingly, great uncertainty and a large range of possible outcomes. The projections, however, lean more towards the negative side, i.e. there are more factors indicating headwinds and lower growth rates than factors pointing towards good prospects for economic growth.

The historical review shows that the currently dominating perspective on economic growth as a natural state of the economy was not expected by economists prior to the high growth period in the middle of the 20th century. Instead most economists expected mature economies to transition to lower growth rates or a steady state economy. In a short period of time this perspective was almost lost and replaced by a dominant growth paradigm in which economic growth is assumed to persist.

The OECD model, which is based on conventional economic theory, estimates a growth path much like the last 30 years, although at a slightly lower pace. It does not take into account the potential effect of climate change or the effect of resource constraints. The model scenarios project global economic growth of almost 3 per cent per year up to 2060. Non-OECD countries

are projected to grow faster than OECD countries, but growth will slow down. Non-OECD countries are expected to have an average growth rate of 3.9 per cent between 2011 and 2060 and OECD countries an average growth rate of 2 per cent per year.

The OECD model offers a scenario which assumes that the worldwide technological progress will equal the productivity level in the most advanced OECD countries during the last 30 years, along with a number of policy adjustments. The optimism reflected in the OECD model has been criticised by mainstream economists such as Gordon and Piketty, who argue that the economic growth during the 20th century was an anomaly in history and that we probably will face much lower growth rates ahead. According to Piketty, a more likely growth rate will be between one per cent and 1.5 per cent. Gordon projects growth rates for the US to level at around just 0.2 per cent.

Left-wing heterodox economists persist in their belief in stagnation theory. They argue that the current rise in the Fire sectors, finance, insurance and real estate, is a response to the stagnation of the real economy; and that financialisation in the short-term has postponed stagnation, but at the same time worsened the core problem of overaccumulation. This, consequently, will worsen the situation in the long term. According to these left-wing economists, the long-term trend in economic growth, industrial production, investment, financialisation, and capacity utilisation all point towards a long-term economic slowdown, but they do not provide any numerical projections.

Neither have the scientifically oriented-economists provided alternative projections of growth rates, but they conclude that the economic growth of the past 40 years is unlikely to continue. Some scientifically-oriented economists argue that current economic models have been designed based on data for how the economy acts in the absence of limits. One of those limits — probably the most important one — is access to cheap (abundant) high-quality energy, i.e. oil. Other crucial resources are soil, water, wood, metals and petrochemicals. When we approach limits, diminishing returns lead to growing inefficiencies in production, rather than efficiencies. The reason is that we tend to use first the highest quality resources and the ones that are easiest to extract. Also, the scientifically-oriented economists argue that the current economic model will not easily contract but could collapse, i.e. see a steep decline during which production and societal institutions do not have time for a managed adjustment.

For many different reasons, the conditions necessary for the rapid economic growth during the last 200 years — globalisation, cheap energy sources and pervasive technological change — may be challenged in the coming decades. It is clear that there are significant uncertainties concerning future economic growth. From a societal planning perspective we conclude that policymaking based on the assumption that economic growth will continue is unwise and risky.

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ENDNOTES

1. KTH, Royal Institute of Technology, Environmental Strategies Research (fms).
E-mail address: evaalf@kth.se. Corresponding author. The authors are supported by a FORMAS project grant. They are also grateful for very valuable comments on an earlier version of the paper by two anonymous reviewers and from seminar participants at FMS, KTH.

2. IVL, Swedish Environmental Research Institute. E-mail address: mikael.malmaeus@ivl.se.

3. Scientifically oriented economists are economists whose interests cross the boundary between social and natural science, and whose work includes the scientific, and especially environmental, implications of economic policy, trends and phenomena. The expression in no way negates the 'scientific' nature of the classical economists' reasoning and methods, or economics as a (social) science.

4. The long-term growth scenarios are based on a modelling project initiated in 2010, aimed at creating a model to provide scenarios to 2060. The model created within that project is now used also for the short-term projections. (OECD 2012).

5. Communication with one of the authors of the OECD report, Åsa Johansson, OECD.

6. Steady state in this context means a pace set by the frontier technological progress.

7.Multi-factor productivity is measured as the difference between output and total inputs. It is equivalent to the equally common Total Factor Productivity.

8. For more details about the model see OECD 2012, 2013.

9. Income shares of capital were stable up until 1980 but have increased since then. A report by the ILO and OECD (2015) show that between 1990 and 2009 the share of labour compensation in national income declined in G20 countries from 66.1 per cent to 61.7 per cent. Thus the income share of capital is close to 40 per cent rather than 33 per cent and there is no sign of this trend being reversed. According to the same report, declining labour income shares tend to evolve hand-in-hand with widening income inequalities and negatively affect macroeconomic aggregates.

10. Fast growth in China and India will soon make their combined GDP measured in Purchase Power Parities, surpass that of the G7 economies and exceed that of the current OECD members by 2060.

11. The IMF and the OECD regularly adjust previous projections. All large forecasters failed to predict the financial crisis in 2007 which has had a negative impact on the reputation of these models and modellers.

12. Piketty in turn bases his figures largely on the work of Maddison. See Section 3 in this article.

13. Including abolishing banks and taxing debt pollution.

14. the analysis does not make any predictions about when oil will peak but assumes

that at some time oil production will start to decline.

15. If it really only takes one third of a percentage point increase in oil supply per annum to support additional GDP growth of one percentage point, then it must also be true that it would only take one third of a percentage point decrease in oil supply gr owth to reduce GDP growth by a full percentage point (Kumhof and Muir 2012).

16.The scenarios in which changes are large can still, technically, be modelled but the effects become so large that some aspects are no longer plausible. Most importantly, real oil prices would increase by over 400 per cent on impact, and by around 1400 per cent after 20 years. Despite this, there is no sharp crisis in the short run, and the subsequent reduction in annual GDP growth rates in oil importers equals a steady crisis-free 3 percentage points!

17. Increasing inequalities reduce demand as the propensity to consume declines with income.

18. According to Ayres and Voudouris the real economy is an evolving material processing system. The flow and conversion processes are governed by the laws of thermodynamics. At each stage, until the last (consumption), mass-exergy flows are split into (i) useful energy and (ii) waste energy. Value is added to the useful energy flows, reducing their entropy content and increasing their exergy content per unit mass, while the high entropy waste is returned to the environment.

19. 'Energy is measured in calories, BTUs, kilowatt-hours ... but energy has a scale of quality which is not indicated by these measures. The ability to do work ... depends on the energy quality ... measurable by the amount of energy of a lower quality grade required to develop the higher grade.' (Odum 1973).

20. For a discussion on energy quality see Stern 2010. See also Du Boff (1967), who describes the effect of electrification on American Manufacturing.

21. The production process, from extraction to combustion, is also a relatively clean and environment-friendly process compared with coal, uranium, oil sand, shale gas and other energy sources.

22. The term Peak Oil, based on M. King Hubbert's peak production theory, was introduced by Colin Campbell and Kjell Aleklett in December 2000.

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