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Analysis

Do Mature Economies Grow Exponentially?☆

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ABSTRACT

In academic discussions and in public debate, economic growth is commonly presumed to be exponential. Economic theories model growth in an exponential manner and central policy institutions regard growth rates of 2–3% to be normal, also implying growth to be exponential. In this paper we investigate empirically whether economic growth is indeed exponential by estimating autoregressive integrated moving average time series models based on gross domestic product data for 18 mature economies from 1960 to 2013. Our findings cast doubts on whether these commonly discussed economic growth paths reflect the economic reality: only two out of 18 mature countries depict exponential growth rates above these levels. Five have lower exponential growth and the development of eleven countries exhibit rather linear growth. Additionally, we show that prominent theories of economic growth assume growth to be exponential and that a more heterogeneous set of theories is needed to explain different patterns of growth across time and space.

1. Introduction

The idea that economic growth is exponential is deeply rooted within economic discourses. In economic theories, growth is commonly depicted as a (constant) *fraction* of the level of production and therefore tends to be regarded as exponential.[1] Public economic debates also refer to the *rate* of economic growth, also implying exponential growth. The assumption of a *normal* growth rate of 2% or more also finds its way into political agendas. The USA's central bank, the Federal Reserve (FED), discusses "normal" growth rates between 2 and 3%, and the 2017 US government is even more optimistic, targeting 4% annual economic growth and "assuming" 3%.[2] This presumption is not only followed by governments, but also international institutions, such as the World Bank, who predicted a continuous growth in gross domestic product (GDP) of 2.5% in industrialized countries (Shaw et al., 2001) or the International Energy Agency which assumes the GDP in North America and Europe to grow at around 2.4% between 2000 and 2010 and around 2% between 2010 and 2030 (Birol, 2002). All these refer to the GDP and not gross domestic product per capita (GDPPC), which is at the core of this analysis. GDPPC is the more relevant variable with regard to economic theory for three reasons: in welfare economics, income per capita (and not overall income) is decisive. Concerning employment, economic growth per capita has to be equal to the rate of increases in labor productivity in order to prevent increasing unemployment. Further, several of the prominent theories of economic growth discussed below do not take into account changes in population. Therefore, we investigate the pattern of growth of GDPPC rather than GDP. Due to population growth, the formulated expectation of GDP growth of 2–3% translates into an expectation of GDPPC growth of about 1.3–2.3%.[3]

But do mature economies grow exponentially in reality? One emerging strand of literature argues that economic growth after World War Two has depicted a *linear* rather than an exponential pattern. The non-empirical literature on the issue includes Altvater (2006), and

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[1] Formally, exponential growth is given by $Y_t = Y_0 * (1 + r)^t$ in which r is the growth rate. If r is > 0 and stays constant over time, we observe exponential growth. For example, when the economy has the size Y in period 0 and grows by amount X which is the share r of Y, then in the second period the economy has the size of $Y + X$. This means that — if r stays constant — it grows by $r * (Y + X)$ in period two. So at a constant growth rate r, the absolute amount by which the economy grows becomes bigger each period.

[2] Central bank's figures taken from the FED's Monetary Policy Report (Federal Reserve System, 2014). Government figures taken from official White House press releases: the 4%-target is cited in Metro (2017, p. 106) and the "sustained, 3-percent economic growth"-assumption is being made in Mulvaney (2017).

[3] The population in the countries in our sample grew on average (unweighted) by 0.7% in the time frame of consideration between 1960 and 2013. When correcting the predictions of GDP growth of 2–3% for a population growth of 0.7%, this results in projected per-capita growth rates between 1.29% and 2.28% $\left(\text{formula:} \quad g_{GDPPC} = \frac{g_{GDP} - g_{Population}}{1 + g_{Population}}\right)$; population data from OECD database (OECD, 2017), accessed on 09.12.2017.

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Pollitt et al. (2010). The empirical literature on this pattern of growth is similarly scarce. Glötzl (2011), Seidl and Zahrnt (2014), Gordon (2012) and Reuter (2002) provide anecdotal evidence for Western countries, industrialized countries, the US, and Germany, respectively. Wibe and Carlen (2006) and Bourcarde and Herzmann (2006) use descriptive statistical tools to conclude that the majority of mature economies follow linear (and not exponential) growth paths. While the latter analyses and findings are interesting, their conclusions are not backed up by a rigorous application of econometric methodology.

Another recent strand of literature refers not to exponential or linear growth but to so-called *secular stagnation*. Especially after the recent economic crisis, authors in this debate do not only argue that growth rates have been declining over time but also give explanations for decreasing growth rates. Influential economists such as Lawrence Summers (2016, 2014b), Robert Gordon (2015) and Paul Krugman (2014) argue that the United States and other mature economies have entered a long phase of low growth. Explanations for such growth range from slow technological change to insufficient investments to satisfied markets (see Section 5.2).

The present study combines an empirical study of exponential vs. linear growth with the question, how this can be explained theoretically. In the empirical part, we differentiate between countries depicting linear growth, low exponential growth (< 1.3%) and high exponential growth (> 1.3%). The investigation goes beyond existing approaches of pure descriptive statistics and uses adequate econometric models — autoregressive integrated moving average time series models — which allow us to make credible quantitative statements about the long-term trends in the time series at hand. It contributes further to the literature by building upon most recent data and decidedly longer time series than the two empirical analyses mentioned above (see Sections 3 and 4). In the theoretical parts, it combines well-established theories of economic growth with less common approaches such as the new debate on secular stagnation and insights from the study of economic history.

The paper is structured as follows: Section 2 shows the ways in which the concept of exponential growth is implemented in prominent theories of economic growth. Sections 3 and 4 are devoted to the question of whether the common assumption that economic growth is exponential holds empirically. Section 5 poses the question, how theories of economic growth need to change in order to explain our empirical results — so that a wider range of patterns of growth can be covered. Section 6 concludes with suggestions for future economic theory.

2. Economic Growth Theories

Economic growth is a highly researched topic and well-represented in typical economics curricula. In the following, theories of economic growth patterns will be analyzed, including influential theories within mainstream, as well as heterodox, economics. The presentation of the theories is based on original contributions where one specific model is commonly referred to. Where a large number of similar models exists, a prominent textbook version is chosen.

2.1. Neoclassical Growth Theories

Solow presented a first growth model in line with neoclassical thought, a model subsequently followed by many others. In the following, four prominent neoclassical models are analyzed.

2.1.1. The Solow Model

In the theory of Solow (1956), the growth rate of the capital stock $\left(\frac{\dot{k}}{k}\right)$ is determined by investments, which depend on savings ($sF[k]$) and the depreciation of the capital stock (δk):

$$\frac{\dot{k}}{k} = s\frac{F[k]}{k} - \delta \tag{1}$$

This model implies that capital per worker has decreasing marginal productivity. As the depreciation rate of the capital stock is a constant proportion, capital accumulation comes to an end when the marginal productivity of capital equals the depreciation rate. If Harrod-neutral (i.e. labor-augmenting) technological change is included, capital accumulation can continue to take place over time, as the marginal productivity of capital increases. In this scenario, the steady state rate of economic growth per capita is entirely determined by the speed of technological change x (Barro and Sala-i-Martin, 2004):

$$g = x. \tag{2}$$

As x is given exogenously, the model in principle allows for all types of patterns of growth per capita. At the same time, the model suggests exponential growth as there is no reason why x should change over time. We are not aware of any attempts to incorporate explanations for a change in x within these models.

2.1.2. The Neoclassical Textbook Growth Model

While Solow assumed a certain savings rate and a certain investment behavior of firms, neoclassical growth models are based on the behavior of a representative household and a representative firm. Households maximize utility due to a utility function. Their savings depend on their preferences and the interest rate. Firms maximize profits. They invest until the marginal productivity of capital is equal to the real interest rate plus the rate of depreciation. Subsequently, in these models savings and investments are brought into equilibrium via the real interest rate (Barro and Sala-i-Martin, 2004). The equilibrium growth rate of the capital stock per capita is similar to the Solow-model. The change in capital stock is determined by the difference between output and consumption. Additionally, the capital needed for depreciation, and due to technological change, is subtracted:

$$\frac{\dot{\hat{k}}}{k} = \frac{f(\hat{k}) - \hat{c}}{\hat{k}} - (\delta + x). \tag{3}$$

However, the savings behavior, the state of technology and the depreciation rate have only level effects but no growth effects regarding production: ‘A greater willingness to save or an improvement in the level of technology shows up in the long run as higher levels of capital and output per effective worker but in no change in the per capita growth rate’ (Barro and Sala-i-Martin, 2004, p. 210). The growth of per capita income (g) depends — as in the Solow model — primarily on the rate of technological progress (x): ‘the steady-state per capita growth rate equals the rate of technological progress, x, which is assumed to be exogenous' (p. 205).

$$g = x. \tag{4}$$

The neoclassical textbook model therefore leads to the conclusion on the nature of economic growth, that as long as technological change is assumed to be of a constant *rate*, growth per capita is exponential.

2.1.3. Endogenous Growth I: The AK-model

Endogenous growth models have the advantage that they include an explanation of the central determinant of growth in the model — compared to earlier theories in which the determinant was most of the time exogenous to the model. In the AK-model, capital has constant instead of diminishing marginal returns, due to the fact that capital is understood in broader terms, including human capital. Production in this model depends on the technological state (A) and the amount of capital (K): $Y = AK$. Growth of capital $\left(\frac{\dot{K}}{K}\right)$ and income $\left(\frac{\dot{Y}}{Y} \text{ or } g\right)$ depend, without technological change, on the size of net investments, which depend on the savings rate (s) and the depreciation rate (Aghion and Howitt, 2009):