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Limits to growth rates in an ethereal economy

Lenore Newman*, Ann Dale

School of Environment and Sustainability, Royal Roads University, 2005 Sooke Road, Victoria, BC, Canada V9B 5Y2

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Abstract

It has been argued that economic growth can continue despite the finite nature of the Earth and its ecological systems if growth is concentrated in an ethereal economy where ideas and information dominate over physical inputs. In this paper, we agree that in a sustainable society continued growth must eventually be concentrated in the ethereal economy; however, we argue that such growth cannot occur at the ongoing exponential rate that currently underpins the constant rate of returns relied upon within our economies. As there is a limit to how fast a population can adopt new ideas, and as such adoption and innovation itself occurs in unpredictable bursts, growth in an ethereal economy will follow a model of punctuated equilibrium composed of exponential bursts, logistic growth, and stable/stagnating periods in a manner similar to ecological evolutionary processes. Although such an economic environment is likely far in the future, lessons in not overtaxing ecological capital and encouraging information dissemination and knowledge diffusion are applicable to problems we face today.

1. Introduction

The debate over whether there are absolute limits to economic growth or whether our economies can continue to grow exponentially for the indefinite future has continued at a steady pace over the last decades. Interestingly, the polarization in this debate has changed little over time; the tension between Paul Eurlich and Julian Simon was mirrored in the tension between Georgescu-Roegen and Solow, and today we can see the same tension between those concerned with ecological limits and the proponents of continued growth. For an excellent historical overview of this debate, see [1].

In this paper, we explore the future of exponential growth including the assertion that an ethereal economy of ideas and innovation could support the exponential growth that underpins our current economic system. In doing this, we assume that current issues such as the depletion of environmental capital and population growth within a finite biosphere will be corrected; that is the economy will continue to evolve without collapsing due to the failure to correct for environmental destruction. This is by no means assured and we are not asserting that it is; we are making those assumptions for the purpose of theoretical discussion in order to discuss the desirability and feasibility of the future of our current economic model.

*Corresponding author. Apt. 5, 234 Frank Street, Ottawa, Ontario, Canada K2P 0X6. Tel.: +1 613 230 5475.
E-mail address: lenore.newman@royalroads.ca (L. Newman).

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Of all the issues currently facing humankind, the impact of economic growth upon ecological systems represents one of our greatest paradoxes. On one hand, growth provides for human material well-being; on the other, it also contributes to environmental degradation. Thirty-five years after the publication of ''Limits to Growth'' by the Club of Rome, we know much more about human impacts upon Earth's ecosystems. The rise of complex adaptive systems theory and the massive advances in available computing power allow us to better understand the growing magnitude of human impacts on nature, but also allow us to study the astounding resilience of ecological systems to these impacts. We also have a better understanding of our ability to innovate and use these innovations to mitigate our ecological impacts. However, our knowledge of adoption of new technologies, and particularly of more sustainable infrastructure, is still partial. We do not sufficiently understand the limits to ecological resilience or the limits to innovation, and we certainly do not know how to practically reshape our societies in order to protect the integrity of ecosystems and societies, particularly with respect to institutional reforms.

This uncertainty has led to an unfortunate polarization of the ''limits'' discussion; to simplify the two positions radically, there are those who believe that fixed ecological limits exist, that there is a fixed carrying capacity to the use of the earth's resources for human societies, and that we shall shortly exceed these limits and suffer from a general social and economic collapse [2,3]. On the other hand, society acts as if ecological carrying capacities will not pose limits to long-term exponential growth due to mankind's capacity for innovation, especially technological innovation (Simon provides a classic and enduring example [4]). In short, widely divergent views of the future still exist at the current time [5], underpinned on both sides by divergent paradigms, myths, metaphors and deeply held values [6].

As the debate has continued, two camps have formed that could loosely be described as the cornucopians and the pessimists, and both have advanced diverse arguments for and against continued growth. Some of these arguments are examined below, as they are relevant to this discussion. A key argument on the side of the cornucopian position in this debate is that our economic systems have in the past delivered exponential returns with only the occasional retraction, and thus there is no reason to think this growth would change. However, past growth was partly driven by exponentially growing inputs: the global population and the amount of natural resources being exploited. As these inputs reach their limits, growth will have to come from other sources.

However, the argument of most interest to us as researchers is the argument that our economy can dematerialize into an ''ethereal'' state in which growth can continue based on innovation and information alone. Though researchers discuss the ethereal economy [7,8], very few consider what such an economy would be like both at the macro- and micro-economic level. The theoretical question we want to raise is a simple one: what form would economic growth take in an ethereal economy and could an ethereal economy support a system reliant upon constant exponential growth?

2. Looking for limits

Though it has roots in earlier dialogues, the debate over the limits to growth really began in earnest with the work of the Club of Rome, which was founded by British scientist Alex King and Italian industrialist Aurelio Peccei. The first meeting of roughly 40 international thinkers occurred on 7 August 1967 in Rome, Italy. The Club of Rome funded the *Limits to Growth* report, which features models created by Donella and Dennis Meadows. Their most advanced model, World Three, shows three possible futures: overshoot and collapse, overshoot and oscillation, and sigmoid growth [9]. The futures predicted in World Three were highly pessimistic of future progress; continued exponential growth was not one of the predicted outcomes.

Limits to Growth focused on what the authors called the ''world problematique''. This group of linked problems included poverty amid plenty, environmental destruction, urban sprawl, and economic problems [10]. In the opinion of Meadows and her co-authors, we are far past the point at which overshoot has occurred. Her models commonly predict overshoot and collapse [9].

Response was immediate and was highly polarized. It was pointed out that World Three underestimates the ability of technology to postpone catastrophe [11]. The models rely on tables composed of extrapolated data generated through an iteration process, causing runaway errors [11]. *Limits to Growth* was heavily critiqued for ignoring innovation and technological adoption [12]. Others argue that the report's Achilles heel was twofold; the absence of the role of technical progress, and the absence of the role of the money system [13]. However, by ignoring these factors, was *Limits* ignoring a path to unlimited exponential growth, or merely a path to delayed leveling off of the economy?

When the Club of Rome published *Limits to Growth*, it sparked intense international debate over its basic premise, challenging the tenets of traditional economics. The prevalent economic vision sees the economy as an isolated system: a circular flow of exchange value between firms and households. The economy is the system of interest and natural systems are simply sources of resources and sinks for wastes. Nature may be finite, but these natural sources and sinks can be infinitely substituted for by human capital, without limiting overall growth in any important way.

The problem with exponential growth in a finite system is simple enough to describe: economic growth strains natural sources and waste sinks [14]. In effect, the finite expanse of the natural world has a carrying capacity that can be expressed in different ways; economic carrying capacity is the maximum global economic welfare derivable from the sustainable throughput flows of the ecosphere, [15] for example. In short, if one only looks at throughput of resources and wastes, long-term economic growth in a wide range of circumstances is unsustainable due to environmental change. [16]. The ideal in this situation would be to know what the carrying capacity is, and avoid exceeding it; knowing carrying capacity allows for more rational decision-making [17]. However we cannot calculate the upper limits to growth; carrying capacity is normative [18] and is heavily affected by the capacity of human innovation and technologies to respond to change.

Can exponential economic growth be maintained in a finite ecology? As some areas of the economy have much less impact upon the finite ecology than others, the possibility must be considered. The next few sections consider this possibility.

3. Can substitution support unlimited exponential growth?

In the early days of the debate over limits to growth, the concept of a carrying capacity was further blurred by economists who asserted that even if there were limits to certain sources and sinks, a substitute could always be found by the market, and in fact this process was effortless [19,20]. The optimism in this position was striking. As Solow said, "the world can, in effect, get along without natural resources" [19]. This outlook is one way of describing what is called "weak sustainability", which argues that "the total value of all capital stocks is to be held constant" [21]. We can liquidate natural stocks as long as they are replaced with technical substitutes.

Ecological economists immediately argued that there are strict limitations to substitution [22,23]. Most natural goods, they argued, are compliments, not substitutes. In reality, nature produces trillions of dollars worth of goods, which have no known technological replacement [24]. As an example, we cannot reproduce the oxygen generation in forests or replace the atmosphere as a shield from solar radiation, yet these things have no value in current economic calculations. In an economic system designed in the image of statistical mechanics, two very important features of complex systems are missing. These are irreversible processes and elements that have no substitute. Within the framework of the economics of substitution, there is really no concept of irreversible damage as needed systems can either be reconstituted or replaced with an acceptable substitute.

Our markets are not complete; it is impossible to determine whether a given market can produce a good or service [25]. Innovation is not flawless; consider Homer-Dixon's examples of nuclear fusion and a cure for cancer as two things we really need that we have worked hard on but failed to produce [26]. There are critical, dynamic complex living systems and processes that simply cannot be replaced with human-made substitutes, and in the long-term innovation. Even if this is not entirely correct, it is in some sense irrelevant. As the biosphere is finite, the liquidation of the biosphere can only provide a finite amount of economic growth. Unlimited exponential growth is thus not possible upon the back of ecological capital alone, even if we were to liquidate the biosphere entirely in favor of technological substitutions.

4. Can efficiency support exponential growth?

The argument for an ethereal economy begins in the realm of efficiency. Pro growth advocates argue that almost everything we do could be much more efficient. This is in fact true; we are very far from theoretical limits, and vast opportunities for efficiency exist [27]. Indeed, Germany, Japan, and the US reduced material intensity in many processes by 20–30% over the last 20 years [14]. Paul Hawken argues that we can build an ecological capitalism precisely because the process of industrialization has been so inefficient. Calling the US the most wasteful nation on earth, Hawken notes that we use 3200 pounds of material to produce each 100 pounds of consumer goods. [24]. Waste has simply never been addressed aggressively.

Efficiency gains could support growth that did not increase impacts on natural sources and sinks until certain thermodynamic limits to process efficiency were reached. However, we have ample evidence that efficiency gains do not always lower resource use. For example, though family size has decreased since 1960, the size of the average house in North America has doubled [28]. This was partly made possible thanks to lower heating costs created through efficiency improvements. In short, people do not just turn efficiencies into free time, but further consumption, which fuels a rebound effect [29]. This is also called the ‘‘Jevons’’ paradox, in some cases efficiency can increase use [21]. Efficiency gains can fuel economic gains without increasing the impact upon ecological systems, but there are theoretical limits to consider and experience shows that the gains are likely to be smaller than expected, as social adaptation and adoption of new technologies, soft and hard, are unpredictable and highly dynamic. Eventually any efficiency effort will run up against the laws of thermodynamics; systems can only be made as efficient as the theoretical maximum. In the short term, we must pursue efficiency as boldly as possible to lower our ecological impact, but in the long term, efficiency cannot rescue exponential growth. Efficiency gains are finite, if potentially very large.

5. Can dematerialization support unlimited exponential growth?

Efficiency allows a greater level of economic activity to be based on the same amount of ecological capital, but the gains from efficiency are limited by the laws of thermodynamics and human adaptation. The next rational step, many argue, is to focus on growing the portions of the economy that can be completely detached from an ecological base. In short, we should pursue an economy of ideas and innovation in which the innovation recycles the finite amount of physical material in the system. Dematerialization substitutes information for material [30]. An environmental policy of stimulating innovation could grow the economy and lower impact according to Vollebergh and Kernfert [8], and Columbo states there are no fixed limits to our use of nature, this use depends on science and technology [31]. Others have argued that perpetual economic exponential growth is possible with a constant rate of learning [30]. Others are more skeptical; information technologies, Berhout and Hertin remind us, are not as ‘‘clean’’ and ‘‘weightless’’ as we often assume, as they do consume resources and energy [32].

Would an ethereal economy support growth in the long term? We agree with Ayres and Van Den Bergh that dematerialization strategies could keep our economy growing for a practically unlimited amount of time, at least on any time scale meaningful to us. However, we see no reason why this economic growth would be exponential. In a finite system, no exponential growth pattern can continue forever. Exponential growth has occurred as an exponentially growing population has accessed ecological capital at an exponentially growing rate with an efficiency that at times has improved exponentially thanks to innovation. However, we can already see the end of this first exponential age in site. Human population growth is slowing, as it must. We are nearing the absolute maximum resource extraction and waste disposal rates that ecological systems can handle, if we have not passed them already. And efficiency, though it might likely spur another sustained burst of exponential growth in the near to medium term will eventually reach a point of decreasing returns near to the thermodynamic maxima possible. In short, all of these drivers of growth will shift from exponential drivers to logistic drivers, and will eventually reach steady states.

What then, can we say about innovation? The first hurdle to exponential growth of an ethereal nature driven by innovation is that it will occur among a steady state population. However this is not by any means the major hurdle. The bigger problem is that the discovery of technology is intrinsically uncertain [33]. Metcalfe and Ramlogan explain the growth of knowledge as a complex evolutionary process, as it involves choice, judgment, and creativity; uncertainty is thus unavoidable [34]. Beyond discovery, at some point diffusion of innovation will slow simply because there are not enough hours in the day for us to absorb all of the new information being produced. We will reach a point at which the flood of the new exceeds our ability to meaningfully interact with it. At this point we will have hit a human bottleneck in production growth, and growth will slow to match the rate of absorption.

It is well known that diffusion is not automatic; it can be a difficult process. Sociologists Richard Florida and Martin Kenney argue that there is a failure between innovation and diffusion. They lament that "we mistakenly believe innovation is synonymous with technological breakthrough" [35]. In his seminal text *Diffusion of Innovation*, Rogers notes that most innovations diffuse at a disappointingly slow rate [36]. In fact the acceptance of a new product is at times excruciatingly slow. For example the telephone was invented in 1876, but only 40% of households had one by 1940 [37]. The telephone was originally seen as a business tool, and was largely used as such.

Our research into sustainable infrastructure in Canada has revealed the same frustratingly unpredictable resistance to innovation diffusion. As one example, we studied two similar public private partnerships promoting deep water cooling technologies. One of these projects created a great deal of attention and is expanding rapidly. The other, though also a successful project, did not spur additional adoption of the technology. We found a similar reluctance to innovative change in case studies of transportation, energy, and waste management. Results of this research are available at (www.sustainableinfrastructure.crcresearch.org).

In addition, technological changes are not usually well synchronized with complimentary structural changes, and thus, conflicts occur in society again as a result of the time lapse in adjustment of corresponding structures and institutions to these changes. As well, there is typically an initial slowdown in productivity, as the new technologies become integrated into existing structures. When the old structures adapt or new ones are created in response to the new technologies, then productivity increases as a function of this restructuring.

Change, its depth of penetration and optimization of its range of benefits is limited by the ability of people to adapt, respond and accept their potential, coupled with a need for new skill requirements in the labor force, while others should become obsolete. Time is needed for the absorption by the labor force of these new skills, and there are powerful barriers and incentives for maintaining the status quo [6] and preventing widespread diffusion. Diffusion must also overcome lock in of inferior technologies. Lock in occurs due to increasing returns associated with adoption of the dominant technology [38]. During lock-in development of related infrastructure becomes so large that the equilibrium employment in researching options falls to zero [33]. Governments can overcome lock-in through fiat, but as Castellacci argues, governments in Western society have lost much of their ability to conduct large-scale public interventions due to the current political climate [39]. The limits of technological change lie generally not with science and technology, which tend to evolve much faster than governing institutions, but with the organizational, social, and institutional changes that facilitate or inhibit the diffusion of new technologies [40].

There are several social reasons that diffusion may occur much more slowly than desired. As diffusion of an innovation is linked to other innovations, an innovation sometimes cannot diffuse until certain infrastructure is constructed [41]. Diffusion is also constrained by the rate at which need ideas are accepted. This is called the MAYA principle, the "most advanced yet acceptable". If an idea is too progressive it may evoke fear [42]. Or as writer David Korten says, if technologies of the information marketplace become too complex we would not use them [43]. Diffusion can thus fail when there is social resistance because social values are inconsistent with adoption [41]. There is some evidence that the MAYA principle might be becoming more limiting; Karlsson argues that the public has lost much of its optimism for technological solutions and is now much more afraid of risk [44]. These factors cast the long-term prospects of steady exponential growth in doubt: in Metcalfe and Ramlogan's words, "that knowledge feeds on knowledge through the intermediary of understanding is a perfectly sensible idea, but that it does so at a uniform geometric rate seems particularly hard to swallow" [34].

6. An age of punctuated growth

If an ethereal economy is not likely to grow at an exponential rate due to the unpredictable nature of invention and innovation and social constraints on diffusion, what will growth in such a system look like? We propose that the answer might resemble the growth found in the world's most advanced economies: the economies of ecosystems. Punctuated equilibrium, a model of growth that includes both exponential and logistic elements, emerged from the study of the biosphere, where evolutionary "innovation" occurs in irregular and unpredictable bursts. Upon reading Thomas Kuhn's descriptions of systems of thought undergoing sudden paradigm shifts after periods of stability, Gould and Eldridge wondered if perhaps a similar process could explain the lack of evidence for gradualism in the evolutionary record. At a presentation in 1971 on models in palaeobiology they introduced the idea of punctuated equilibrium [45]; evolution, they argued, occurred in quick bursts intermingled with long period of stability. Evolution, occurs smoothly over periods of thousands of years during punctuations, but does not occur gradually over millions of years [45]. At that scale, incorporating a condition of punctuated equilibrium, change happens in bursts, much as the change Kuhn describes during a paradigm shift [46].

According to the model of punctuated equilibrium, we will enter a period during which change will occur more slowly. A long breathing period, perhaps, before another burst of innovation occurs. Such an economy will proceed in fits and starts as new ideas emerge, lock-in is overcome, and ideas are accepted by the public. The economy will experience exponential growth at the beginning of an innovative cycle, logistic growth during late diffusion, and periods of steady state or even decline between innovation bursts. Such an economy might be sustainable, it might be vibrant and wealthy, but it will not provide a constant rate of return on investment.

7. Conclusions: on the road to the ethereal economy

In the above we suggest that an ethereal economy would allow continued growth through innovation, and that this growth could continue for what is in effect an unlimited period of time. However it is not likely such growth could proceed at the exponential pace needed to provide the constant rate of return required by capitalist economies as there is a certain "lag" associated with the diffusion of new ideas, and there is likely a limit to the amount of new material a consumer can absorb. The limiting factor might well prove to be time; we only have time to evaluate and adopt so much innovation. It is important to note, however, that though this might provide economists of the future with an interesting dilemma, we are still a long way off from the end of exponential growth; for example we have barely begun to tap the gains possible from greater efficiency. We do, however, have a pressing need for human society to question and discuss just how much growth can be supported by the ecological systems of the earth.

Our first worry is that we are about to or have already exceeded the sustainable limits of reliance on the Earth's ecosystems. Overshoot, possible due to the time lag in nature's response [15], should be one of our worst fears. The social curbs to innovation that might bedevil ethereal economists in the far future are equally applicable to current attempts to shift to sustainable technologies; given lock-in and barriers to diffusion, it is not prudent to wait for the economy to self-correct, because survival depends on a constantly functioning environment [16]. We must particularly fear the sunk cost effect; we are reluctant to abandon what we have even if it does not work [47]. Innovation of clean technology is important, for example, but so is diffusion of existing technology [38].

The dilemma that humans of the future might face as they reach the limits of their ability to adopt new innovations is the same dilemma we face today; in order to address ecological issues such as global climate change we need to innovate and adopt faster than lock-in and lag will allow. Further study of how innovation diffusion can be aided is needed for the sake of both the ethereal future and the very material present.

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