Reconciling circularity and growth: The model of qualitative economic growth

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ABSTRACT

The circular economy is a strategy to avoid depletion of natural resources and to mitigate climate changes. With the current level of technology, circularity does not allow for economic growth. However, our cultures are centered on the idea of progress and competition. Without growth, it will be very difficult to find opportunities of social progress and reasonable competition. In this paper, the authors claim that by combining circular economy with qualitative economic growth, it is possible to achieve decoupling of economic growth from the use of natural resources. Qualitative growth is essentially the growth of complexity of products, services, infrastructures, and institutions. Qualitative growth has to be considered genuine growth.

KEY WORDS

Circular economy; Qualitative growth; Economic complexity; Sustainability; Decoupling of economic growth from the use of natural resources

1. INTRODUCTION

The circular economy is widely considered the main strategy for sustainability, requiring products and services to be designed for minimum waste, long operational service, reparability, and, at the end of operational life, for allowing the recycling of all their materials and components. Moreover, it requires that the exploitation of renewable resources does not harm the ecosystem. In addition, it might foster the design of new materials.

The literature discusses the question of the limits of circularity in general. However, a circular economy is an economic system engineered to be circular and therefore it is misleading to discuss the limits of circularity of arbitrary economic systems. The critical issue is whether circular economies are socially acceptable. In particular, our current cultures need growth. In this paper, we argue that qualitative economic growth integrated with circularity achieves the decoupling of economic growth from the use of natural resources. The critical question is whether such a system can be realistically implemented.

The theory of economic qualitative growth has been described in Focardi and Fabozzi (2022, 2023), Fabozzi et al. (2022), and Fabozzi et al. (2021). Qualitative growth is economic growth due to qualitative aspects of products and services. It assumes that qualitative improvement and innovation be considered true growth. Current economics is unable to describe economies that are complex evolutionary systems subject to qualitative growth. In developing the theory of qualitative economic growth, the authors discuss the changes to current economic theory needed to describe these complex systems.

This paper makes two contributions. First, it provides a change of perspective by arguing that we should not address the question if an arbitrary flow of products and services can be recycled but we should discuss if an economy designed to be realistically recyclable is doable from the social and market point of view. The critical question is not if a circular economy is possible but if consumers will accept the changes of consumption habits and culture needed to obtain circularity. Acceptance of the circular economy cannot be based only on fear and government impositions. Modern economies are self-organizing systems that might reject circularity. Circularity must be based on some positive motivations: we argue that growth is a fundamental motivation to allow implementing the circular economy.

Given this global conceptual framework, the research question we address. which is our second contribution, is whether it is possible to integrate qualitative growth and circularity, thus achieving the decoupling of growth from the use of non-renewable natural resources. In order to answer this question we need to discuss critically the concept of economic growth. We do so by using the theoretical framework developed in Focardi and Fabozzi (2022, 2023), Fabozzi et al. (2022), and Fabozzi et al. (2021).

The basic point is that in a complex, evolutionary economy, growth is not an observable. Growth, in various forms that we will discuss later, can only be represented by abstract terms that acquire meaning within the entire theory and through measurement processes. Measurement processes must the basis for sound decision making processes that respect the environment and that integrate with the culture.

The paper is organized as follows. In Section 2 we discuss the early warnings as to whether growth was unsustainable and the criticisms of mainstream economists. Because the discussion on the feasibility of circularity hinges on the thermodynamics of economic processes, in Section 3 we discuss entropy and the entropy law. Our discussion in Section 4 covers growth and how to measure economies while in Section 5 we discuss the circular economy followed in Section 6 by a discussion of its limits.The notion of qualitative growth and reconciling circularity and qualitative growth are the two topics covered in Sections 7 and 8. Our conclusions are set forth in Section 9.

2. **EARLY WARNINGS AND THEIR CRITICS**

In this section, we discuss the early warnings in the 1970s that there are limits to growth and how mainstream economists criticized these warnings. After World War II, the main preoccupation of governments was economic growth. In the first post-war period, the need to reconstruct Europe and the fear of secular stagnation in theUnited States were powerful drivers of growth. Both in Europe and the United States, economic growth was perceived as the main engine for economic well-being. Governments and the general public shared the view that economic growth creates opportunities that are beneficial not only to businesses but to everybody. Critics to growth were perceived as marginal intellectual movements.

It is true, however, that there was an increasing awareness of the danger of pollution. Events such as the Cuyahoga River catching fire in Cleveland, Ohio in 1969 due to decades of waste dumped in the river raised concerns about pollution and became a symbol of environmental degradation. This led to a change of attitude regarding environmental issues and provided support for the creation in the United States of the the Environmental Protection Agency (EPA) in 1970, and the passage of a series of federal acts to protect the environment – National Environmental Policy Act of 1969, the Clean Water Act of 1972, the Clean Air Act of 1977, and the Endangered Species Act of 1973, In Europe, many countries created similar agencies and laws for environmental protection.

These actions were local actions intended to solve local environmental problems. For several decades, neither the government nor the public were seriously afraid that growth in itself could be a problem. However, an intellectual debate on growth started with the publication of the 1972 report *Limits to Growth* and the 1971 book *The Entropy Law and the Economic Process*.

The report *Limits to Growth*, written by three MIT scientists − Donella Meadows, Jorgen Randers, and Dennis Meadows − describes the results of simulations performed at MIT with World3, a global model that uses the system dynamics, a modelling methodology created by MIT professor Jay Forrester. The conclusion of the report was very clear: a world with finite resources cannot sustain unlimited exponential material growth.

The Entropy Law and the Economic Process written by the Bulgarian-American mathematician Nicholas Georgescu-Roegen in 1971, introduced the notion that economies are physical systems subject to physical laws, in particular the entropy law that describes how an isolated system can only perform a finite amount of work because all differences in temperature progressively disappear. (We will discuss thermodynamic concepts including the entropy law in the next section.) The energy stored in an isolated system remains constant but its ability to produce work progressively degrades. This is not true for an open system that receives energy from the outside. The earth is an open system that receives an energy flow from the sun either directly or through the energy stored in fossil fuels.

But Georgescu-Roegen objected that not only energy degrades but also matter. After producing work, matter degrades and cannot produce additional work. For example, after burning fossil fuels it is impossible to recover energy from the ashes. Even if the earth receives a continuous flow of energy from the sun, matter will degrade and will become unable to perform useful work. Therefore, there are physical limits to the ability of economies to grow and, ultimately, to exist for very long periods.

Both *The Limits to Growth* and *The Entropy Law and the Economic Process* reached the conclusion that the earth, being a finite system endowed with finite resources, cannot support endless exponential growth. While this academic conclusion had no bearing on political decision making and on public perceptions of growth, it stirred an intellectual debate between those who believed that endless growth was effectively impossible and those who believed the contrary. Farley (2008) discusses the debate on growth and reminds us that in writings and debates, those who believed that there were limits to growth were referred to as "doomsdayers" while those who believed in the possibility of endless growth were labelled "cornucopians". To simplify, we will adopt this terminology.

Prima facie, the conclusion that a finite system cannot sustain endless material growth seems quite robust. How could cornucopians avoid the conclusion that there are limits to growth? In this section, we will explore the strategies that were proposed to solve the problem of supposedly finite resources.

Julian Lincoln Simon was an enthusiastic cornucopian. Simon (1996) claimed that there is no resource crisis as human ingenuity and creativity will always find a way to replace exhausted resources with substitutes. Simon argued that when a resource becomes scarce, its price increases thus creating opportunities for recycling and finally developing substitutes. For Simon, the answer to doomsdayers is that recycling, improving efficiency, and the development of substitutes will ultimately solve any problem of scarcity of resources, who had an almost unlimited faith in the human ability to invent new technologies.

Robert Solow, an American economist who was awarded the 1987 Nobel Memorial Prize in Economic Sciences, was also a cornucopian. Solow (1974) accepts that recycling materials and resources is a viable strategy but admits that recycling cannot be perfect because at every re-cycle there is some loss or degradation of material. However, the lost resource will be progressively replaced by a substitute resource. Describing in detail the market mechanism that leads to the substitution of a resource with a man-made resource, Solow (1974) concludes that: "As you would expect, the degree of substitutability is also a key factor. If it is very easy to substitute other factors for natural resources, then there is, in principle, no problem. The world can, in effect, get along without natural resources so exhaustion is just an event, not a catastrophe." According to Solow, economic growth can be completely dematerialized. In 2003, Eric Neumayer, a professor of Environment and Development at the London School of Economics and Political Science, introduced the distinction between weak and strong sustainability in his book *Weak versus Strong Sustainability*. An economy is weakly sustainable if human made capital can be substituted for natural capital.

In his 1974 book *In Defence of Economic Growth*, Wilfred Beckerman considered the problem of growth from a different point of view. Claiming that growth is an essential feature of modern democratic societies, he wrote that “If growth were to be abandoned as an objective of policy, democracy too would have to be abandoned.” Beckerman accused the authors of *The Limits to Growth* of underestimating the potential of technology improvement.

Doomsdayers, of course, disagreed on the possibility of unlimited substitution of natural capital with man-made capital. Georgescu-Roegen forcefully defended the idea that the economic process entails a degradation of matter especially due to dispersion, so that recycling cannot be perfect and substitution cannot work indefinitely. Daly (1977) partially agreed with Georgescu-Roegen but admitted the possibility of a steady-state economy based on recycling. Population growth was a major point of discussion. Doomsdayers, such as Paul Ehrlich, predicted that population growth would lead to an environmental catastrophe within a few decades (Ehrlich (1968)).

In summary, cornucopians claimed that unlimited growth is possible due to recycling of resources, substitution of natural resources with man-made resources, and technological progress. There was the notion that dematerialization of growth can be achieved also by replacing products with services. However, no general theoretical argument to justify the thesis that natural resources can be always substituted was offered. Doomsdayers, in contrast, claimed that the degradation of resources is inevitable and substitution cannot continue indefinitely. The exponential growth of population and degradation of natural resources would lead to economic catastrophe.

The debate on the possibility of economic growth continues today but on different terms. The debate has left academia and it begins to affect economic decision making of governments and the industrial world. Most goverments and international organizations have espoused the notion of circular economy. The key topic of this paper is the need and opportunity to integrate circularity with qualitative growth. Many environmental activists, however, reject the notion of growth and espouse the notion of de-growth. De-growth has been formulated in many different ways. A widely shared notion of de-growth replaces the notion of growth with the notion of well-being. We will discuss concepts of growth in Section 4. In the next section we will discuss entropy and the second law of thermodynamics. The critical question is whether thermodynamics effectively limits growth.

3. ENTROPY AND THE ENTROPY LAW

Entropy is a concept that originated in physics but it is now used, and sometimes abused, in many other scientific fields and business sectors. The thermodynamic concept of entropy is due to Rudolf Clausius, Sadi Carnot, and Lord Kelvin. The statistical mechanics concept of entropy is due to Ludwig Boltzmann and the information theoretic concept of entropy/information is due to Claude Shannon. Let's start with thermodynamics.

The first law of thermodynamics states that the energy of an isolated system is constant. An isolated system does not allow neither energy nor matter to enter or escape the system. A closed system allows energy to enter or leave but it does not allow matter to enter or leave. The following equation holds for a closed system:

$$DU = DW + DQ$$

where DU is the change of internal energy of the system, DW is work performed in the system or on the system, and DQ is the heat that enters or leave the system. If the internal energy remains constant, $DU=0$ and the work performed in or on the system is equal to the heat exchanged with the outside.

The first law expresses the balance of energy but does not prescribe the direction of the exchange of heat. On the basis of the first law of thermodynamics, heat can be entirely converted into work. The second law prescribes the direction of physical processes and puts constraints on the amount of heat that can perform useful work. To state the second law of thermodynamics, we need the concept of entropy.

Intuitively, entropy, represented by the letter S, is the amount of heat that cannot perform useful work divided by the temperature of the system. In more rigorous terms, an infinitesimal change of entropy dS is equal to an infinitesimal exchange of heat that preserves equilibrium divided by the temperature of the system: $dS=\delta Q/T$. As the system is supposed to be in equilibrium, there is only one temperature level. The change of entropy ΔS between states $f1$ and $f2$ is the infinite sum of all infinitesimal changes; that is, the integral $\Delta S = \int_{f1}^{f2} dS$ computed over an equilibrium path. Lord Kelvin proved that the change of entropy of a reversible process between two states depends only on the states but does not depend on the path followed to move from one state to another.

The above concept of entropy applies to an idealized system in equilibrium. The second law prescribes that in an isolated system entropy cannot decrease. Based on this law, it can be demonstrated that heat flows from a source at higher temperature to a source at lower temperature, that no work can be extracted from a system where there is no difference in temperature, and that there are theoretical limits to the efficiency of thermal engines. In particular, any thermal engine needs at least two sources of heat at different temperatures.

3.1 Statistical Mechanics

The entropy concept defined thus far is based on classical notions of heat, temperature, and work. Ludwig Boltzmann demonstrated that we can approach the second law of thermodynamics from the point of view of statistical mechanics. Given an ideal gas in thermodynamic equilibrium, Boltzmann defined entropy, denoted by *SB*, as

$$SB = klog\ W$$

where W is the number of microstates corresponding to a macrostate and k is a constant, called the Boltzmann constant. If there are different macrostates, then the Boltzmann formula becomes

$$SB = k \sum p_i \, logp_i$$

Boltzmann was able to demonstrate that this formula corresponds to classical entropy. The second law of thermodynamics becomes a statistical principle: a system evolves towards its most likely configuration which is given by equiprobable macrostates. This principle is often represented as a “march towards disorder”. An isolated system naturally looses internal structures and evolves towards a disordered state.

3.2. Information

The same formula $SB = k \sum p_i \, logp_i$ has been used by Claude Shannon to define information. Let’s point out immediately that information theory was created as a theory of communication. The starting point of information theory is that the information content of a message depends on its probability: receiving a highly probable message is not very informative while receiving a highly unlikely message brings information. Hartley (1928) defined the amount of information contained in a message as $-logp_i = log(1/p_i)$. This quantity is zero if a message is certain, that is, it has probability equal to 1, and tends to infinity if the probability of a message tends to zero. That is, learning that something very unlikely has happened brings a lot of information.

Consider now a source of messages. Building on the work of Hartley, Shannon (1948) defined the information associated with of a source of messages as the average information of its messages.

$$H = -\sum p_i \, log p_i.$$

Following a a suggestion of John von Neumann, Shannon called *entropy* the average information of a source (i.e., the average uncertainty of a source). Shannon demonstrated that the entropy of a source is equal to the average length of messages after optimal coding.

These definitions might appear to contradict common sense. In fact, one would expect that a message with a lot of structure has a high information content. But entropy H reaches its maximum when all messages have the same probability. If there are N possible equiprobable messages, we can write:

$$H = -\sum p_i \, log p_i = N \times \frac{1}{N} \times log\left(\frac{1}{N}\right) = log N$$

The quantity H, the entropy of the source, measures the average uncertainty of the messages and it is equal to the average length of optimally codeded messages.

To illustrate, consider two computer screens, one screen is covered with random points without any structure and correlation, while the other screen exhibits a photo. Intuitively, the screen that has a photo has more structure and seems to carry more information than the other one. But information theory is interested in the average uncertanty associated with the screen, measured by entropy H . Transmitting the content of the random screen requires a longer message than transmitting a photo, because a photo has many correlations that allow one to reduce the length of messages through optimal coding. A random point carries more information than a photo

There is no theoretical information theory equivalent of the second law of thermodynamics. The reason is that changes of information are related to the material support of information. For example, a communication channel cannot increase the information associated with the message. A communication channel can add noise and therefore increase the entropy of the received messages. However, this is a physical property of the channel. A photo looses definition with time and therefore the entropy associated with a photo increases. But again, this is a physical property of the photo not a logical feature of entropy.

As discussed thus far, entropy is related to energy. The second law of thermodynamics states that, a closed system has limits to the ability of transforming heat into work. However, an open system can receive low-entropy energy from outside (i.e., energy at high temperature) and perform work. The laws of thermodynamics do not constrain the ability of performing work and reducing entropy through the inflow of energy. Almost all products and processes that we encouter in our lives, from refrigerator and air-conditioners to trains and cars, exploit this principle.

3.3 Material Entropy

Nicholas Georgescu-Roegen introduced a different type of entropy, called material entropy, and proposed the fourth law of thermodynamics. Material entropy is not formally defined. It is the energy stored in a material object due to its internal structure. The fourth law of thermodynamics claims that matter produces work at the expense of its structure. In this way, a material system increases its material entropy irreversibly.

The fourth law is a law of material degradation: by performing work, matter degrades and is dissipated. For example, a piece of coal has internal energy due to its structure. Coal produces heat by burning and trasforming its structure into ashes that cannot produce any useful work. Georgescu-Roegen claimed that degradation of matter is an irreversible process that ultimately limits the ability of an economy to recycle.

3.4 Why Is Thermodynamics Important For Economics?

Georgescu-Roegen is credited for being the first who introduced thermodynamics into economics. He strongly criticized classical economics for not taking into account the physical nature of economic processes and, therefore, the irreversibility of many economic processes. However, he understood that the second law of thermodynamics constrains efficiency of engines and transformations but, in open systems, it does not imply a progressive degradation of economic systems.

This is why he introduced material entropy as the ultimate source of economic degradation. He postulated a fourth law of thermodynamics to explain how in some processes matter degrades irreversibly. Recall that in Section 2 we discussed various reactions to the report *The Limits to Growth*. The report concluded that limitless exponential growth is incompatible with the earth's finite resources. Optimists (i.e.,cornucopians) criticized the conclusions of the report with four main arguments:

1. Recycling of resources is possible but imperfect.
2. Substitutions of exhausted resources with new, eventually man made, resources is possible and fundamentally limitless.
3. Dematerialization of growth is possible.
4. Technology will always find a solution due to the power of human ingenuity.

Cornucopians accepted that recycling can only be partial (we will discuss this point in Section 4) but believed that substitutions could solve any problem of exhaustion of resources. Substitution of resources is a very vague notion. How can anyone claim that materials can always be substituted for new materials? And in any case, substitution only pushes the exhaustion problem from one material to another one. The faith in substitutions implies that the earth has infinite resources distributed over a number of materials: Once one material is exhausted, we can always find another one.

A modern form of faith in substitutions might claim that we have, or we will develop, a technology for creating materials synthetically. Though there are many research efforts devoted to study the synthesis of materials, we are still very far from being able to synthesize arbitrary materials. We are not even certain that it is doable. For the moment, the belief in the possibility of endless substitutions is clearly false in a finite system.

Banning limitless substitution of natural resources, given that the earth is an open system, recycling is limited by the growth of material entropy, but it is not limited by the second law of thermodynamics. The fourth law was not accepted by the scientific community because it was not formulated rigorously and because it lacked both empirical and theoretical support. Many critics, such as Ayres (1999), claimed that resources can be recycled indefinitely but did not offer strong theoretical support for his claim.

The biological ecosystem is a system that has been growing for very long periods by recycling resources. This shows that a full circular system is possible. However, the biological ecosystem is subject to many constraints as regards what and how it produces. As we will discuss, a fully circular system is probably impossible unless we place constraints on what is produced and how it is produced.

3.5 Summary

In this section, we explored the early warnings of an impending environmental crisis and discussed different responses to the warnings. Starting in the 1970s, the environmental crisis was identified with scarcity of resources, both at the level of energy and materials. The issue of global warming was not yet important. The optimists objected that there is no scarcity of resources because we can at least partially recycle materials and resources and there is a limitless supply of substitutes for those resources that eventually become very scarce. For a number of researchers, an unspecified faith in human inventive ingenuity, and therefore in technology progress, was always present.

The notion of entropy and the second law was introduced in economics by Nicholas Georgescu Roegen. However, as the earth is an open system and the inflow of solar energy is abundant, the second law constrains efficiency but does not dictate the progressive degradation of economies. Material entropy was introduced as a stronger concept. It was theorized that the growth of material entropy results in a progressive irreversible degradation of matter due to dispersion.

For at least three decades, environmental issues had very little impact on government and business actions. It is only at the beginning of the twenty first century that governments started acting to reduce global warming. Today the circular economy is the accepted strategy for decoupling consumption from the use of natural resources. It is widely believed that clean energy will be provided by the sun, either directly or indirectly through other phenomena such as winds or tides. However, nuclear energy is considered almost clean.

4. GROWTH AND HOW TO MEASURE THE SIZE OF AN ECONOMY

From the previous discussion, it is clear that growth is the central concept for studying the eventual environmental crisis. Growth is considered a positive development that brings prosperity and well-being. In this section, we will discuss the concept of growth. Despite its centrality in any “green” plan, growth is a term difficult to define. Material growth seems to be responsible for the possible exhaustion of natural resources but perhaps there are other forms of growth that might be more environmentally friendly.

The report *Limits to Growth* describes the results of simulations performed with the World3 model based on Forrester’s system dynamics. World3 uses five main variables that characterize growth: population growth, food production, non-renewable resources, industrial output, and pollution. The model uses 41 internal state variables and computes several scenarios with many interactions between variables. That is, World3 does not use a single parameter that summarizes growth but instead uses several variables that represent different views of a growth scenario, including growth of population and industrial output. The conclusion reached by the model is that an exponential growth of population and of industrial activity will soon exhaust non-renewable resources.

The problem of measuring economic growth is a difficult problem from the point of view of scientific methodology, economic theory, and cultural and social values. It should be clear that it does not admit a single solution but possibly an entire spectrum of possible growth notions. Most likely, future debates as well as decisions on economic strategies to achieve growth will be strongly influenced by what we consider growth. One might observe that growth is an intrinsically multidimensional concept as it involves several variables. However, if we want to determine if an economy is growing or not, we have to find a criterion that weighs the different aspects of growth and produces a single number.

We can recognize different forms of growth: (1) material growth, (2) qualitative growth, (3) growth of economic value, and (4) alternative forms of growth.

4.1 Material Growth

Intuitively, material growth is measured by the growth of the quantity of output. However, this concept is very difficult to define because the output of modern economies includes a very large number of different products and services that, in addition, change qualitatively and are subject to outright innovation. It is impossible to measure material growth aggregating a large number of heterogeneous variables. We cannot aggregate the quantities of bananas, laptops, cruises, and all the 5,300+ categories of the Harmonized System of products classification.

In order to aggregate heterogeneous variables, one might produce indexes. An index is made by averaging rates of change instead of variables. Rates of change are pure numbers and can be averaged. However, in order to determine the weights for averaging one needs to compare heterogeneous variables. More importantly, it is impossible to create indexes of products and services that change qualitatively and innovate. Still, it is material growth that is responsible for the exhaustion of natural resources. We will discuss a possible solution below in this section.

From the point of view of sustainability, we need to measure consumption of natural resources and not only the quantity of output. Several measures have been proposed and are used by different agencies. The most complete measure is the material footprint (MF) which is the total amount of natural resources needed to produce the output of an economy. MF is measured in tons of materials extracted.

4.1.1 Qualitative Growth

There are two types of qualitative growth: qualitative growth of products and services and qualitative growth of the economy at large. Defining qualitative growth is difficult. How do we define quality? We can look at quality as perceived quality or objective quality. To ascertain perceived quality, one could imagine conducting polls asking consumers to evaluate the quality of products and services. However, this would be a cumbersome process and would be largely subject to cultural biases. The individual judgment of quality is determined by many cultural factors.

In order to define an objective measure of quality, a possible solution is to identify quality with complexity. There are well established measures of complexity for products and economies. In a series of papers, Hausmann, Hwang, and Rodrik (2007), Hidalgo et al. (2007), Hidalgo and Hausmann (2009), and Hausmann and Hidalgo (2011) introduced two measures of economic complexity, the Economic Complexity Index (ECI) and the Product Complexity Index (PCI), both computed from export data. ECI is a measure of the complexity of a country while PCI is a measure of the complexity of products. These measures are computed from a bipartite network that links nation *m* to product *i* as the quantity of product *i* exported to nation *m*.

Intuitively, ECI measures the capabilities present in an economy while PCI measures the capability needed to design and produce given products. Measures of complexity are holistic measures obtained through dimensionality reduction processes. Measures of complexity offer the empirical underpinning of theories of quality and quantity as we will explain in the following paragraphs.

Luciano Pietronero and collaborators at the University of Rome have introduced alternative measures of complexity. Tacchella (2012) describes these alternative measures, the

Country Fitness and Product Complexity. These measures are still based on export data but use coupled non-linear maps whose fixed point determine fitness and complexity measures.

4.1.2 Growth of Economic Value

The value of economic output is the sum of all final transactions. Theoretically, the value of output is a well-defined observable quantity. However, in order to compute growth of economic value we need to filter purely financial phenomena, that is inflation. But computing inflation for economies that are evolutionary complex systems is a difficult and partially arbitrary process. In fact, inflation is the change of price of products and services that do not change. If products and services are subject to qualitative changes their price change is not purely inflation. In addition, it is not possible to associate inflation to products that innovate. We will come back to these problems later in this section when we discuss methodologies.

The problem of measuring growth, and consequently to measure an economy, is relatively recent. Before World War II, there was no notion of economic growth. States wanted to expand geographically through military conquests and wanted to conquer colonies rich in natural resources. Governments did not have the statistical tools to measure an economy. In a report to the Congress of the United States in 1934, Simon Kuznets, recipient of the 1971 Nobel Memorial Prize in Economics, proposed Gross Domestic Product (GDP) as a measure of the magnitude of economic output. GDP is the sum of all final transactions.

After the 1944 Bretton Woods conference, GDP became the *de facto* standard to measure the magnitude of the output of an economy. That is, it was tacitly stipulated that the growth of a country is represented by the growth of the value of its output. GDP was heavily criticized because it does not represent an assessment of the welfare of an economy. However, despite criticisms, GDP remained as the main measure of the magnitude of an economy. After World War II, the primary objective of governments was to make GDP grow.

As prices are relative prices, GDP, at any point in time, is defined up to a multiplicative constant. In order to compare GDP at different moments, we need to determine the multiplicative constant. This is the problem of inflation. However, in economies that are evolutionary complex systems that output a very large number of heterogeneous products subject to a process of continuous qualitative change and innovation, the concept of inflation is somewhat arbitrary. In fact, inflation is defined as the change in the price of products that remain unchanged. However, if products and services change qualitatively and innovate, inflation is to be replaced by “generalized inflation” based on estimating the correct price of innovation. With the current methods to estimate inflation, qualitative changes and innovation are computed as inflation. As a consequence, inflation is overestimated and real quantities, such as real GDP, obtained discounting nominal quantities by a cumulative price index are underestimated.

4.1.3 Economic Theory Wants Quantity

GDP is the value of economic output of a nation, it is not its “quantity”. Economic theory would like to model the real economy and would like to model the dynamics of a variable that represents the quantity of output and put it in relationship with another variable that represents the quantity of capital plus another variable that represents labor. Unfortunately, the products and services that form both output and capital are highly heterogeneous and cannot be aggregated. Notions such as quantity of capital and quantity of output are idealizations that do not correspond to any observable.

Economic theory, and more specifically economic growth theory, studies an idealized economy that outputs a single good that can be either consumed or invested as capital. But this is an idealization that does not correspond to anything real because quantity of output and quantity of capital cannot be defined and cannot be observed. There is a fundamental separation between the theory and practice of economics. Theory uses idealizations of real quantities while practice uses the value and not the quantity. In some instances, the real GDP is assumed to be proportional to the quantity of the single good produced by the idealized economy. This assumption is an idealization that does not have any empirical basis. We will see later in this section how we propose to solve the problem. For the moment, let’s remark that current economic theory suffers from a critical conceptual problem.

4.1.4 Alternative Forms of Growth

Thus far we have discussed concepts of growth based on material growth, qualitative growth (complexity), or growth of economic value. The growth of economic value is compatible with both qualitative and material growth. However, the environmental impact associated with the previous forms of growth lead to consider different types of growth based on well-being. Given that material growth seems to be unsustainable, a movement referred to as de-growth claims that we should abandon outright the notion of growth.

Many different forms of de-growth have been proposed. The common thread of de-growth is to return to a simpler life, enjoying simpler things of life. De-growth is often presented not as a necessity imposed by scarce resources, but as a new philosophy of life, closer to nature and far from the stress of modern life. In this sense, it can be considered an alternative form of growth.

In general terms, however, there is no agreement on measures to be used and how to compute them. The Stiglitz-Sen-Fitoussi *Report by the Commission on the Measurement of Economic Performance and Social Progress*[1], lists many different sources of well-being as a measure of economic magnitude. However, these measures are highly subjective and suffer from cultural relativism. Many other global measures have been proposed for specific purposes, such as the Gini coefficient to measure inequality.

4.1.5 Questions of Scientific Methodology

Modern economies output a huge number of different products and services. Products and services change qualitatively and are subject to a process of continuous innovation. New products are brought to the market while old products disappear. It is therefore impossible to aggregate the heterogeneous variables that represent the quantities of each product. There are two scientifically sound methodologies. We can create multi-agent systems that have a level of complexity similar to the real economy or we use an abstract approach to modelling.

Multi-agent systems are very useful for simulation but are not parsimonious theories. If we want to summarize an economy with a small number of variables, then we have to create theories that include abstract variables. These variables are not directly observable but acquire meaning through the entire theory. That is, we form theories and models that include abstract variables, equations and relationships, and measurement processes that involve the entire theory.

[1] https://ec.europa.eu/eurostat/documents/8131721/8131772/Stiglitz-Sen-Fitoussi-Commission-report.pdf. This report was commissioned in 2008 by the then-President of France Nicolas Sarkozy to understand how to measure an economy.

But economic considerations might not suffice to create a theory. We might need to add social and cultural considerations that help deciding what concepts of growth are useful, if any. We might want to define concepts of growth that agree with the prevailing culture. In defining growth we should use variables and measurement processes that are in agreement with cultural perception of growth.

4.1.5 The Abstract View of Growth

The integration of circular economy and qualitative growth that we propose in this paper follows this methodological principle(see Sections 5 and 6). Once established, the methodological principle of using abstract variables, economic considerations will suggest what variables we need to include in our theories.

Focardi and Fabozzi (2023) have presented a different view of growth. Their starting point is that the value of an economy measured by nominal GDP is the product of several factors that depends on the economy. They chose three factors, *quantity, quality,* and *generalized inflation.* Following the methodology of modern science, they argued that economic models must be integrated monetary models where monetary variables such as nominal GDP are observable while quantity, quality, and generalized inflation are abstract hidden variables that acquire meaning due to the entire theory and measurement processes that link these variables to observables such as material footprint and Economic Complexity Indexes.

5. THE CIRCULAR ECONOMY

Current economic systems are referred to as "linear systems" because they are based on the "linear" principle of:

extracting→manufacturing→using→waste.

In opposition to linear systems, in the last two decades, the concept of circular economy has gained traction. The United States, Europe, and China have all adopted some form of circular economy. There are many definitions of a circular economy that imply different degrees of circularity. The ultimate objective of the circular-economy concept is to transform economies into self-sustained systems that do not exhaust natural resources. The basic principle of the circular economy is designing products that have long operational lives, can be repaired and eventually refurbished, and, above all, generate little waste and can be recycled at the end of their lives. Production should use renewable resources as much as possible. A broader concept of circular economy includes social objectives of well-being that are supposed to replace the objective of economic growth.

The report *Jobs For Tomorrow: The Potential For Substituting Manpower For Energy* by Stahel and Reday-Mulvey (1977) prepared for the Commission of the European Communities can be considered the first organic statement of the principles of circular thinking. However, the idea of recycling products appears in Solow (1974) and, earlier, in the concept of the Spaceship Earth in Boulding (1966).

The Policy Brief N3 Industry 5.0 issued by ESIR, a consulting group of the European Commission comprised of high-level experts, agrees with the above definition, and implies that the future European circular economy should achieve the objective of decoupling growth from the use of natural resources (European Commission's Directorate-General Research and Innovation, 2022). However, Industry 5.0 states that growth should not be intended in the classical sense of GDP growth but should be measured by several new, yet-to-be-defined measures and indicators. Industry 5.0 discusses in broad terms the social changes implied by the transition to a truly circular economy. Bauwens (2021) introduced the concept of post-growth circularity claiming that the circular economy should strive to maximize well-being.

The circular economy is one of the key strategies proposed to achieve the goals set by the European Union Green Deal and by the equivalent New Green Deals in the United States, Australia, and Canada. The Ellen MacArthur Foundation has done a lot to promote the concept of circular economy.[2]

As we can see from the above statements, the circular economy is a set of recommendations and eventually policies to achieve circularity. However, the concept of circular economy leaves open many technological questions. The concept of "green growth" is a more global concept that might include circularity as a strategy. Green growth is based on the belief that technology will solve all environmental problems without major disruptions of consumption habits. It might or might not use circularity. For example, replacing fossil fuels with clean energy sources is part of green growth as a technology change. Circularity might mitigate the energy problem but, per se, does not supply new energy sources. We might also

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[2] Ellen MacArthur was a professional sailor who in 2005 established the world record for solo circumnavigation of the globe. In 2010 she left professional sailing and established the EllenMacArthur Foundation with the objective of promoting the circular economy.

develop a technology to synthesize needed materials from abundant sources. Such technology would reduce the importance and role of circularity.

Currently, the rate of circularity − defined as the ratio of the quantity of recycled materials and the quantity of material inputs – is low. According to the 2023 Circularity Gap Report prepared and published by the Circle Economy, the global circularity rate is 7.2% down from the 9.1% for the prior five years. Europe is doing better. According to a Eurostat report[3], in 2021 the circularity rate of Europe was 11.7%, slightly down from the peak of 12% reached in 2019. The total consumption of materials in 2022 surpassed the 100 billion tons equivalent to 12 tons per person while it was 28.6 billion tons equivalent to 7.4 tons per person in 1972 when the report *The Limits of Growth* was first published.

There are different levels of circularity. The simplest level of circularity includes recycling waste. A higher level of circularity includes reusing components of products. The full implementation of a circular economy is described in the European Union Parliament Article (2023) as follows:

> "The circular economy is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible. In this way, the life cycle of products is extended. In practice, it implies reducing waste to a minimum. When a product reaches the end of its life, its materials are kept within the economy wherever possible thanks to recycling. These can be productively used again and again, thereby creating further value. "

The Ellen MacArthur Foundation Circular Economy Introduction gives a similar definition of the Circular Economy.They claim that the circular economy is a global framework. The circular economy, according to the Ellen MacArthur Foundation, is based on three principles. These principles are driven by (1) the elimination of waste and pollution, (2) the circulation of products and materials (at their highest value), and (3) the regeneration of nature. Moreover, "the circular economy is based renewable energy and materials. A circular economy decouples economic growth from the exhaustion of non-renewable resources.

[3] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Circular_economy_-_material_flows

Korhonen et al. (2018) observes that the current definitions of circular economy have been proposed by practitioners and consultant not by academics. The authors propose a scientific notion of circular economy that uses cyclical materials flows, renewable energy sources and cascading-type energy flows. Successful circular economy contributes to all aspects of sustainable development. Circular economy has a tolerable impact on nature and utilises ecosystem cycles respecting their natural reproduction rates.

There are several points to note. First, circular economies are designed economies. Products should be designed to last longer and to be repaired. Products should be constructed with materials that are renewables or that can be recycled and that do not harm the environment. The design rules and objectives of a circular economy are different from the design objectives of the current industrial system. Second, the relationship with the biological ecosystem should change. Today many industrial processes are very harmful to the biological environment. This must be changed because the biological environment is the basic frame of human activities and it needs to be protected. Finally, all the above implies changes in human behavior and cultures. The circular economy is not a technology for recycling waste, it is a main rethinking of our societies. In the next section we will discuss the limits of this process.

As discussed in Focardi and Fabozzi (2022), Fabozzi et al. (2022), Fabozzi et al. (2021), economies are complex evolutionary systems. The concept of growth is problematic. We cannot measure physical growth because there is no possibility of aggregating the quantities of evolving heterogeneous products and services. We can measure the monetary value of economic output but in order to model its evolution we have to take an abstract view of the physical economy and we have to introduce a concept of inflation. Economies exhibit emerging behavior, and self-organization that makes them systems that are very difficult to predict. The supposedly linear systems have an intricate web of interactions and non-linear, complex, feed-back loops. In addition, humans develop cultures whose evolution interacts with the evolution of economies in complicated ways.

There are different levels of engineering a circular economy. It is relatively easy to reach a small rate of circularity by imposing rules to recycle wastes and by imposing rules that require some materials, such as plastic and textiles, to be recyclable. But modern economies are producing a flow of innovative products and services that are very difficult to recycle. Modern high-tech products evolve rapidly and rapidly become obsolete, contradicting the principle that we should prolong the life of products through design for long life, reparability, and possibility of recycling.

Circularity seems to impose going back to a simpler, slow moving, lifestyle. But changing lifestyles is not an easy task. It can be impossible. Planning a circular industry, with additional constraints of provisioning materials that come from politically difficult areas, might prove to be an extremely difficult task.

The project of circularity is also based on social justice. The *2023 Circularity Gap Report*, on page 9 of the Executive Summary states that: “There is currently enough wealth and materials in the world to provide a good quality of life to every single human being on this planet.” This is probably true, but it implies social changes of an unprecedented magnitude. And it does not consider the fact that “good quality of life” is not a concept shared by all humans. What is good life for one individual is sinful for another.

Circularity implies redesigning products, and this implies, in turn, that consumer habits should change. For circularity to work, not only products but society at large must be redesigned. In fact, circularity affects not only products but work, transport and mobility, finance, and leisure. Assuming it is possible to implement these changes, circularity is a long-term process. It will require a long time to produce the needed social changes.

It also affects the financial system. Discussing the unsustainability of inequality, Galbraith (2019) concludes that: “…. economic inequality is tied to the most unstable and unsustainable element of the world system, which is global finance. Achieving anything sustainably….. requires a financial order that is broadly reformed ….” Sustainability, which is the objective of economic circularity, is not only a question of industrial strategy, technology, and culture but also of finance. It is a truly global phenomenon.

6. THE LIMITS OF A CIRCULAR ECONOMY

In this section we will discuss the limits of a circular economy from both a theoretical and a practical point of view. Let’s state upfront that in the current situation where the circular economy is proposed as a re-engineering of industrial production and society at large, the critical questions are not the theoretical limits of circularity, because the economy will be designed to be circular, but the consequences of circularity. Stated differently, we should not ask if circularity is possible because we are planning to design products and services to be circular. We should ask instead if the constraints of a circular economy are compatible with the values and motivations of modern advanced societies. This will be the true test of circularity.

It is difficult to believe that societies and economies can be peacefully engineered by decree. Societies are self-organizing systems that evolve under endogenous forces. Regulations can steer the path of economic and social evolution but cannot change it completely. Historically, abrupt changes happened in situations of great social stress. In particular, we believe that democratic capitalistic system requires some form of growth.

As we have seen, after the publication of *The Limits to Growth* and Georgescu-Roegen's *The Entropy Law and the Economic Process* economists were divided between cornucopians, who believed in the possibility of limitless growth, and doomsdayers who believed the contrary due to degradation of resources and exponential population growth.

Cornucopians thought that circularity, substitution, and still-to-come technology progress would grant the possibility of continuous growth. The key issue was circularity. Georgescu-Roegen believed that many economic processes are essentially irreversible because of the dispersion of matter. Therefore, he believed circularity can only be partial. Ayres (1999) claimed the opposite on the basis that the second law of thermodynamics does not forbid recycling if sufficient energy is available.

Today, proponents of circularity, such as the Ellen MacArthur Foundation, seems to espouse the thesis that full circularity is possible provided products that products and services are appropriately designed to be circular. There are perhaps three main questions related to circularity:

1. Can chemical reactions always be reversed?
2. Can materials be separated even if massively dispersed?
3. Can we produce sufficient energy to perform the above?

First, manufacturing products implies creating material structures, such as a plane or a bridge, made of materials that are often the result of complex chemical reactions. The general notion of full circularity implies that any chemical reaction can be reversed and that any assembly of materials such as an alloy can be separeted.

If enough energy is available, the second law does not forbid that chemical or even nuclear reactions can be reversed. But this fact does not imply that we have a technology that allows reversing any chemical or nuclear reactions. For example, many chemical scientists are currently working on the problem of creating new materials. Szczypinski et al. (2021) discusses the use of computers to predict what new materials will have useful properties and, given that a possible new material is useful, predict if it can be realistically synthesized. Therefore, circularity is not guaranteed, in practice, because we do not have a technology to reverse any possible reaction. However, we can constrain the economy to use materials that can be recycled.

The impossibility of separating or recovering dispersed materials was the main argument of Georgescu-Roegen against circularity. Although it is probably very difficult to give a general theoretical answer, a full theoretical answer is also not very useful because, in practice, recycling every possible situation of dispersion would require too much energy.

This leads to the third question: can we generate enough low-entropy energy to provide full circularity? Again, the theoretical answer is probably negative if we really want to cover every possible situation. However, the framework of the current notion of circularity is different from the framework of the early discussions on the possibility of circularity. In fact, the current notion of circularity requires that products and services be designed having in mind circularity. If products and services are designed having in mind circularity it seems clear that full circularity can be achieved.

The Ellen MacArthur Foundation is very clear on this point: we have to change the way we design and manufacture things. Circularity implies a deep rethinking of economies and societies. But how? This question cannot have a complete theoretical answer because economies will self-organize in largely unpredictable ways. Of course we can list the requirements for full circularity, for example that all chemical reactions be practically reversible with the enrgy provided by the sun. However, it would be very difficult to state what actual limitations are implied by the requirement of circularity.

Modern economies are complex systems subject to emergent properties and self-organization. Both are difficult, perhaps impossible, to predict. Therefore, describing a complete characterization of future circular economies is an impossible task. We can only enunciate general principles, but the fine details remain unknown.

To summarize, the real issue is not if an arbitrary economic system can be made circular, but what systems are fully circular? The critical question is whether a fully circular economy can grow. Recall that Beckermann (1974) claimed that growth is so important that planning an economy without growth would destroy democracy. This statement is probably not exaggerated. Growth allows people to have objectives, to improve, but also to compete in order to arrive at a superior social standing. In a situation of no growth, competition becomes a true fight because the success of a person is the failure of another one. When there is economic growth, there is room for everyone to grow.

This is the current cultural situation of capitalistic economies. It is possible that in the future cultures will change and people will learn how to enjoy life without competing. But for the moment, we are very far from that situation. Presently we have to deal with excessive competition that leads to extreme, unsustainable inequalities and precarity. It is therefore critical to understand if circularity allows growth.

We have seen in the previous sections that there are many different concepts of growth and that each concept of growth is problematic. In fact, growth of the value of economic output is subject to the problem of inflation, while material growth cannot be realistically defined because of heterogeneity and evolution of products and services, and qualitative growth is conceptually difficult to define. Growth of well-being is subject to cultural relativism.

Today, in practice, material growth is measured by the growth of real GDP, that is, nominal GDP divided by cumulated inflation. But given the evolutionary nature of modern economies and the way we measure inflation, price changes due to qualitative changes are computed as inflation depressing growth.

Recycling cannot increase the quantities of materials of an economy. However, we could possibly create new materials and new production techniques that allow economies to increase, in some sense, the quantity of output. But with the circular economy, we have to admit that growth will come primarily from qualitative improvement of economic output. The next section is devoted to qualitative growth.

7. QUALITATIVE GROWTH

Qualitative growth is the notion that economic growth is due to increasing quality of products and services, and, possibly, the infrastructure. Focardi and Fabozzi (2022), Fabozzi et al. (2022), and Fabozzi et al. (2021) discuss various aspects of the theory. The basic ideas are the following. Modern economies are evolutionary complex systems subject to continuous innovation. Products and services are highly heterogeneous, and their quantities cannot be aggregated. Therefore, it is impossible to compute the quantity of output of an economy. We can only compute the value of the output, the GDP. But GDP is subject to generalized inflation: if we want to study the dynamics of an economy, we need to compute generalized inflation.

Current methods to compute inflation, based on computing a price index on a selected basket of goods, cannot identify quality changes and therefore they compute quality changes as inflation. To solve this problem, we can follow the methodologies of modern science constructing models that include variables that are directly observable, such as monetary variables, plus abstract, hidden variables that acquire meaning through the entire model and are connected to observations through the entire model.[4] Following this methodology, we can write economic models as monetary models that include hidden abstract variables quantity, quality, and inflation so that:

Nominal GDP= quality × quantity × generalized inflation.

Qualitative growth as a global feature of the economy started in the 19th century but until World War II, qualitative growth was slow.[5] After the war, in Europe there was the cogent need to reconstruct after the destruction of war: roads, bridges, trains, and all infrastructure had to be reconstructed. Demand was driven by well-defined elements: housing, home appliances, cars, children education, and travels. In the United States, there was no reconstruction but the spectrum of secular stagnation that was evoked after the 1930s recession loomed large and pushed government to stimulate the economy.

Changes happened in the 1970s due to technological innovation as well as social changes. Electronics opened the door to a new generation of products. Automation began to change the process of design and manufacturing of products. Social changes included a new level of freedom and the beginning of an extensive symbolism associated with consumption. Ownership of products was not only a statement of social standing but began to have social and cultural meaning.

It is fair to say that in the last 50 years growth has been both quantitative and qualitative. Consumers could choose from an ever-growing menu of new products and services. Qualitative features were instrumental for selling more products and services. The

[4] Economics does use abstract, hidden variables such as states of Markov-switching models.
[5] Historically, several periods in selected places exhibited an extraordinary progress of artistic achievement. However there was no precise notion of the economic contribution of the arts.

price of products and services reflected the growing cost of marketing and the image building process.

In the studies by Focardi and Fabozzi cited earlier, the authors stipulated that quality can be identified with complexity. Products and services have become progressively more complex, and the structure of the economy has become more complex with the building of different networks, *in primis* the World Wide Web (WWW) and social networks. Therefore, they assumed that quality can be identified with complexity. This is not to say that quality is complexity. It is simply the statement that complexity translates some of the meanings of quality and it is a useful quantity for economic modelling.

In general, we can distinguish two types of quality. The first is quality associated with products and services. For instance, a global positioning system (GPS) or navigational system is a major qualitative improvement for cars and mobility in general. Especially in the last 30 years, we have witnessed a stream of qualitative improvements of products and services. Then we have qualitative improvements associated with services that are almost dematerialized. One is tempted to say that services associated with the WWW are almost dematerialized, but this is not true. Today, the Internet reaches almost 70% of the world population and is globally a big consumer of energy and materials.

However, there are areas of qualitative growth that are dematerialized or related to regenerative materials. For example, adding green spaces to cities is a qualitative improvement related to regenerative materials. Most events related to culture are almost dematerialized. In general, aesthetical improvements of products and infrastructure are close to being dematerialized.

Going forward, to meet the objectives of green deals, it will become imperative to push dematerialized qualitative growth as well as qualitative growth of products and services. This topic, however, is related to circularity as discussed in the next section.

8. INTEGRATING QUALITATIVE GROWTH WITH THE CIRCULAR ECONOMY

If we had a perfect recycling technology plus sufficient clean energy, the circular economy would have little impact on consumption. We would reduce the extraction of minerals, metals, and materials by extracting only what would be needed for growth or what was not included in past products and services. Unfortunately, though green growth places a great deal of faith on technology, we are still very far from the objective of perfect recycling.

All definitions of circular economy suggest serious changes of consumption patterns. Perhaps the most serious issue is innovation. In the last three decades, we have seen an accelerating trend towards innovations to satisfy consumers' needs. Not only this, but aggressive marketing actions have created needs that people did not know they had. Every available innovation and every aspect of human behavior, even the most questionable, have been exploited to sell products. Innovations have allowed the selling of more products or more expensive products.

All this is in stark contrast with the objective of building products that have a long operational life, that can be repaired and recycled. Unless there will be unforeseeable technology changes, circularity requires that the design of many products and services must point in a direction which is the opposite of current trends. It seems that circularity points backward to less innovation.

Still we need to conserve the possibility of growth. The studies by Focardi and Fabozzi cited earlier proposed qualitative growth. This means that an economy must become more complex still reducing its material footprint. Stated differently, consumption must be pushed towards complexity, preferably dematerialized complexity. Is this compatible with circularity?

Many aspects of circularity are perfectly compatible with qualitative improvement. It is fair to say that products designed to have long operational life must be good quality products. We can even say that qualitative improvement is built in the concept of circularity. In practice, there are many aspects of quality. The requirement of longer operational life of products implies designing and building products of better quality. It will not be easy to push people to consume a smaller number of products of better quality but probably it can be done. For example, in several countries purchasing second hand products, from furniture to apparel, has become fashionable. The basic requirement of circularity to reduce the turnover of products is perfectly compatible with quality improvement.

But we need more dynamic elements of qualitative growth compatible with circularity. Innovation due to complexity is the most critical issue, especially for highly sophisticated products based on electronics. It will be necessary to reach some compromise in function of the "weight" of each product category on the material footprint and the technology involved.

For example, sectors such as textiles have a natural path to increasing quality sacrificing quantity. The construction sector is also a sector where quality can replace quantity. However, many sectors, medical equipment for example, need innovation.

We have to make an important consideration. We should not judge changes in function of their economic justification. If material resources were available, many changes could not be justified economically. But material resources are being depleted. Many changes will be costly but inevitable. The increased cost will generate increased revenues to manufacturers. Consumers will buy less of higher quality. The relative attractiveness of products and services will change. Market forces will have to work with unprecedented constraints.

The aesthetic dimension of life can become a source of qualitative growth. From infrastructure projects to the recovery of urban areas aesthetics can play a big role. The recovery of green spaces in cities is certainly a main target of qualitative growth. Of course it requires a change of attitude. Traditionally, aesthetics played a big role in transforming cities and nations. For example, the Renaissance was a vast movement that reshaped Europe.

It is very difficult to predict what will happen but it seems clear that if economies want to grow, reducing the impact on natural resources consumption must become increasingly dematerialized. The three main areas of dematerialized growth might be aesthetics, culture, and the relationship of humans with nature. Qualitative growth can place a structure of complexity on top of products and services that are becoming simpler at the level of their material implementation.

9. CONCLUSIONS

The world is now facing two environmental challenges: climate change due to global warming and the exhaustion of natural resources.[6] There is some consensus that climate changes are, at least partially, due to human activity. In particular, it is believed that global warming is due to the emission of greenhouse gases. Governments are now issuing regulations that in principle should stop the emission of greenhouse gases. It is reasonable to

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[6] Although there are other cogent problems such as population growth, wars, the growing gap between different populations, in this paper we limited our discussion to the environmental problems of advanced economies.

predict that the problem of climate change will be solved because alternative clean energies exist and the switch to clean energies is perceived as a big, profitable business.

Exhaustion of natural resources is a more difficult problem to solve. Lacking a technology for artificially creating resources from abundant elements, the current proposed solution is to replace the linear economy − extracting→manufacturing→using→wastes − with a circular economy based on creating products and services with long operational life, repair, share, reuse and finally recycle components and materials.

Given that the earth is an open system that receives abundant solar energy, the entropy law does not forbid full circularity. However, engineering a circular economy might put constraints on the products and services that can be made available to consumers. A key preoccupation of the circular economy is to ensure growth.

In this paper, we propose integrating qualitative economic growth into the design of a circular economy. The required long life of products leads naturally to increasing quality. However, if policy makers want their economy to grow, they must integrate factors suchs aesthetics, culture, and a new relationship of humans into the natural environment.

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