Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Technological Forecasting & Social Change 160 (2020) 120264

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

journal homepage: www.elsevier.com/locate/techfore

The struggle SARS-CoV-2 vs. homo sapiens–Why the earth stood still, and how will it keep moving on?

Tessaleno Devezas

Atlantica School of Management Sciences, Health, IT & Engineering–Center for Aerospace Science and Technologies (C-MAST–FCT)–Lisbon, Portugal

The above title reminds us of Robert Wise's 1951 science fiction film (and the remake released in 2008 as well), but this time the planet is not threatened by aliens, but by a Terran nanosized enemy with comparable power.

Since the World Health Organization (WHO) declared the new Corona virus a pandemic on March 12th 2020, many friends of mine and colleagues from the scientific community, knowing that I work with Futures Studies and Forecasting Methods, have flooded me with questions such as: What is happening? Why wasn't it predicted? How can the end of this pandemic be predicted? As well as the inevitable question: is it a Black Swan?

Regarding this last question, Nassim Taleb, who created the concept in his 2007 opus '*The Black Swan – The Impact of the Highly Improbable*", has already manifested his irritation in the article published in *The New Yorker* titled "The Pandemic isn't a Black Swan, but a Portent of a More Fragile Global System (Avishai, 2020). In fact, we can't classify this pandemic as a Black Swan, when so many people foresaw the menace and imminence of a serious global epidemic, including Bill Gates (several talks and interviews), Vaclav Smil, Michael Osterholm, Jeremy Konyndyk, and others (For an interesting list see Hoffauer, 2020). In this context it's important to mention two of Taleb's prophetic statements in his 2007 book: "*As we travel more on this planet, epidemics will be more acute; we will have a germ population dominated by a few numbers, and the successful killer will spread vastly most effectively*", and, in my view more impactful, "*I see risks of a very strange acute virus spreading throughout the world*" (Taleb, 2007).

My intention with this article is to contribute new insights that, as far as I know, have not yet been properly considered in the countless analyzes that have already appeared on the topic. Some of my points have close relation with Taleb's general idea but bring to light a few other hidden aspects related to the sciences of Complex Systems and Historical Analysis, and the concept of Kondratieff longwaves as well.

I want to address two main questions:

Primo: Why the surprise? *Secondo:* What comes next?

- Concerning *Primo*: Why the surprise?

As can be inferred from all the above exposition, the surprise lies not in the emergence of the pandemic itself but lies in its profound and breathtaking effect on the global socioeconomic system, in the very short period of less than three months.

History tells us that there have been major pandemics in the past that claimed millions of lives, and even more recent epidemics have caused thousands to some millions of deaths (H2N2–1956–1958, HIV–1976, Ebola–2013–2014, SARS-CoV–2003, H1N1[1] – 2009, MERS-CoV – 2012, just to mention a few), but none of these more recent epidemics have had any significant impact on the global economy. To effectively address the '*surprise effect*', we must analyze the phenomenon according to two main and not related aspects: first, the structure of the global political and economic system, and second, the characteristics of the new virus (SARS-CoV-2).

Regarding the first, I would like to bring to the reader's memory a discussion published in TF&SC in 2010, '*From My Perspective: On Ferguson*', with contributions of mine, George Modelski, Theodore Modis, and Harold Linstone (Devezas, 2010a). The discussion was prompted by Niall Ferguson's article published in Foreign Affairs titled "*Complexity and Collapse: Empires on the Edge of Chaos*" (March 2010). Ferguson's motivation at that time was the same as ours today – an explanation of the worldwide perplexity in the face of the unexpected economic shock that happened as consequence of the defaults on subprime mortgages, which first produced a surge in 2007 in the United States, and then tipped the entire world economy into a financial blackout that lasted for at least two years (2007–2009).

Ferguson expressed his thesis asking: *"What if history is not cyclical and slow moving but arrhythmic—at times almost stationary, but also capable of accelerating suddenly, like a sports car? What if collapse (of Empires) does not arrive over a number of centuries but comes suddenly, like a thief in the night?"*. With this kind of 'what if' questioning, Ferguson was challenging political leaders, who usually think of current economic crises facing the US as being the consequence of just long-term threats.

For him, empires, and the human society as a whole, are complex systems operating somewhere between order and disorder – on the edge of chaos – and consist of systems that are constantly adapting and are

[1] Among these mentioned previous epidemics, only the H1N1 was declared by WHO as a pandemic in May 2009, for which many Member States had developed detailed pandemic plans describing the public health measures to be taken, aimed at reducing illness and fatalities. In just four months the epidemic has spread to over 120 countries, killing almost 400,000 people worldwide.

https://doi.org/10.1016/j.techfore.2020.120264
Received 10 June 2020; Received in revised form 4 August 2020; Accepted 12 August 2020
Available online 14 August 2020
0040-1625/

prone to a dramatic and sudden phase transition in consequence of some small contingent occurrence coming from within or without.

In my contribution to the debate titled "*On phase transitions, catastrophes, and sudden changes*" I expressed my opinion that Ferguson's conceptual framework is not all bad, but in the odds considering the exaggeration of some conclusions and the bad use of some basic physical concepts. To a physicist's eye his analysis has a touch of naiveté and under some aspects does not represent anything new.

I suppose that Ferguson was somehow influenced by Taleb's view that '*History does not crawl, but it jumps*' (chapter 1, pg 10, in The Black Swan), but he took his argument in a wrong way — Taleb speaks mostly about unpredictability (and levels of unpredictability) and not about causality. Ferguson tries to lock-in *immediate causes* for disruptive historical events and overlooks the fact that in complex systems jumps are the result of the running of the evolutionary algorithm, which can only be understood through back casting, exactly what historians and evolutionary biologists do, and what Ferguson criticizes. To fundament his arguments Ferguson speaks of 'phase transitions' and uses the canonical example of *SOC* (self-organized criticality) — *avalanches in a pile of sand*. In both cases it is a regrettable misuse of physical concepts, above all because these are phenomena of completely different natures.

The reason why I choose to address here Ferguson's misinterpretation is because I have seen some 'experts' interpreting the current phenomenon as something absolutely unexpected. It would be boring to reproduce here much of the content of my 2010 analysis but would like to address shortly the important aspects of *SOC* and of the *pile of sand*, for they are paramount for correctly depicting the above mentioned "*surprise effect*".

The process of *self-organization in complex systems* takes place over a very long transient period! Complex behavior, whether in history, biology or geophysics, is the result of a long process of evolution. It cannot be understood by studying the system within a time frame that is short compared with this evolutionary process. As very well stated by Per Bak in his 1972 opus "*How Nature Works*" — "the phrase 'you cannot understand the present without understanding history' takes on a deeper and more precise meaning". In other words, there is no such thing, as Ferguson tries to convince us, of an independent event that can be seen as the main causation of a sudden and/or abrupt change — an evolutionary process is the result of the succession of stasis and accelerations.

Now to the case of the pile of sand. A sandpile exhibits *punctuated equilibrium* behavior, where periods of stasis are interrupted by occasional sand slides, or small avalanches, caused when a single grain pushes many other grains and causes them to topple. Sometimes one observes a much larger avalanche, collapsing a large fraction of the sandpile, after which a new period of stasis follows and the sandpile grows again. It is very important to observe in this simple example that large catastrophic events occur in consequence of the same dynamics that produces small ordinary everyday events. This last observation runs counter the usual way of thinking about disruptive events, which looks for specific reasons, but is not the only consequence of the last occurring event. That single grain of sand that caused the larger avalanche would not cause the collapse if all other grains of sand were not there previously, distributed in a given geometric form, under the action of the gravitational field and submitted to their mutual interaction forces. It is important to recognize that the *collapse* (or sudden change) happens because some threshold was reached, and the path until this critical point is a function of the previous evolutionary history of the system. *Summarizing, history does matter indeed and physicists as well as evolutionary biologists know this very well.*

As seen, the surprise does not lie in the emergence of the pandemic itself, for it was predictable, but instead was due to the immense accumulation of *GRAINS* that make up our modern global socioeconomic system, mostly characterized by uncontrolled excesses: ungoverned multidimensional globalization, physical connectivity (mass movement of people and goods), aggression/depletion of the environment, disruption of the wild habitat, and many more. Worse, this whole new establishment that emerged in force for the last 40 years (1980 – 2020) was managed by institutions and conservative policies that had consolidated in the previous 30 years (1950–1980) or earlier. The present picture is of a European Union falling apart, and an accumulation of criticism for the United Nations' (founded in 1945) way of acting and ineffectiveness in resolving enduring situations of regional conflicts. Now, UN's agency for health, WHO (World Health Organization, created in 1948) has notoriously failed to effectively coordinate an international preventive action to mitigate the impact of the already announced possibility of a pandemic. Add to this a global scenario of left-right polarization that is not very different from what we had at the beginning of the 20th century, and a weakening of democratic regimes when compared to the apparent strengthening of totalitarian regimes.

The saturation was reached – *the collapse-like avalanche was unavoidable*.

But in the case of the actual collapse, the threshold was reached through the mutual interaction of two decisive *GRAINS*: too much connectivity and the very peculiar properties of the SARS-CoV-2. This interaction was catastrophic in the sense that it has revealed the fragility of our institutions and led to rapidly cascading effects on governmental and financial systems, which were prone to blow. The question that naturally follows is how to build systems of governance and trade that can handle probable (but unforeseeable regarding their exact timing) random events like a global pathogen outbreak? It is not my intention to address further this point in this short article, but I return briefly to it when considering the other question (*secondo*: what comes next?).

Finalizing now our *primo* question, let us consider shortly the mentioned peculiar properties of this new virus. Among the epidemics I have mentioned earlier (pg2), it is necessary to distinguish between those that require body contact (body fluids) to infect (like HIV and Ebola) and those characterized as airborne infections that spread when bacteria or viruses travel on dust particles or small respiratory droplets that become aerosolized when an infected person sneezes or coughs. This latter group, despite a much lower lethality than the first group, constitutes the greatest threat as a global pandemic due to its greater ease of propagation through the mass movement of people in transport vehicles: trains, busses, ships, and airplanes.

Airborne infections are caused by a wide family of viruses, including those that induce common cold, flu, and/or respiratory syndromes, that, as we know, have plagued humanity with some severity since the beginning of the 20th century. Among these we find the HxNy viruses (H2N2, H1N1, H1N2, etc., depending on the H or N antigen-proteins that express its metabolic synergy with living cells), mostly known as influenza viruses. The last serious pandemic provoked by this strain of virus was the 2009 H1N1 swine flu, which caused about 500,000 deaths worldwide (CDC, 2012). Some strains of this family of viruses are now endemic among humans (seasonal flu). Important to note that there are estimates that globally, influenza causes more than 600,000 deaths per year (Dalzell, ABC News, 2020).

But the target of my analysis here is another family of this group (airborne), also zoonotic pathogens, classified as the 'corona' family, which include the now very well-known viruses causing SARS (Severe Acute Respiratory Syndrome) and MERS (Middle East Respiratory Syndrome) – both resulting of a very recent mutation of a older flu-like virus first identified in 1964 (Combs, National Geographic, 2020). These infections can manifest as bronchitis, pneumonia, or a severe respiratory illness.

The coronavirus that causes SARS is called SARS-CoV (for Corona Virus). According to WHO, the first cluster of SARS cases occurred in China's Guangdong province in November 2002. Studies identified then horseshoe bats as the natural reservoir of SARS-CoV. Civets and other animals in wet markets may have contributed to the virus crossing from animals into humans. On March 2003, the WHO issued a global alert, warning of an atypical pneumonia spreading from China and coined the

name SARS for the disease. Right after the first alerts the organization put out an emergency travel advisory and recommended that airports start to screen passengers coming from countries with cases of SARS – it was the first case in history of an alert about the possibility of an epidemic being propagated through people using air transport.

In 2012 it happened the outbreak of MERS, whose route of infection was probably the direct or indirect contact with dromedary camels. WHO coined the causing pathogen as MERS-CoV, and since then about 30 countries have reported cases of MERS. Curiously, the R_0 (R naught – the measure of transmission among people) of MERS is far lower than that of SARS, but its mortality rate is far higher (~34% for MERS, and ~10% for SARS).

Before considering the case of our actual COVID 19, caused by the SARS-CoV-2, as well as some important comparisons with the outbreaks of SARS and MERS, it is paramount to make a point about air traffic. In a recent article of mine submitted to TF&SC (Devezas, 2020) I call attention to the exponential growth of air traffic in the last 50 years. According to World Bank data (https://data.worldbank.org/indicator/IS.AIR.PSGR), the number of passengers carried in 2002 amounted to 1.64 billion, in 2012 to 2.89 billion, and in 2019 to 4.54 billion, which implies in total growth of 177% in seventeen years, or a growth rate of about 10% per year! In other words, the best vector for transmitting the virus has expanded vigorously.

A corona virus consists in a single-stranded RNA genome enveloped by a nucleocapsid (protein shell) of helical symmetry. An important characteristic of this virus family is that they are the largest RNA viruses, measuring about 30 kbp (kilo base pair), ca. 1 μm, the double of the HxNy viruses, which measure in average 15 kbp. As evolutionary biologists known, viruses are an important means of horizontal gene transfer, which increases genetic diversity. The fact that corona viruses are the largest class of RNA-virus in action, allows them a *key evolutionary feature*: having a much longer RNA strand they have a greater chance for mutations and plastic adaptability to the environment (living organisms where they reproduce). This is the core point of my present analysis, one of the *GRAINS* referred previously – a powerful new characteristic favorable to their aggression to homo sapiens.

I suggest that the reader reflect on this key issue: *what would be the best strategy for a virus to fulfill its main objective, that is, to reproduce the most efficient way?* Certainly, it is not killing its host, but instead keeping it alive as long as possible to allow its maximum reproductive capability, or in other words, the most effective way to fulfill the purpose of its existence. And that is exactly what the SARS-CoV-2 does, and what distinguish it from the previous corona species.

Resuming some of the until now identified main features of the new SARS-CoV-2 and of its corresponding disease coined as COVID 19:

- It has a lower fatality rate (3–4% in average), if compared with SARS-CoV (~10%) and MERS-CoV (~34%);
- Infected people present mostly mild symptoms, or may even do not present any symptom (asymptomatic), being able to spread the virus much more effectively;
- It presents a broader capacity of attacking the human organism; besides the usual infections in the upper respiratory tract, or more severe respiratory illness, some other symptoms have been reported about loss of taste and smell, effects on the cardiovascular system, and changes in the skin;
- *and probably the most important feature:* A much longer incubation time (time to show the first symptoms), at least 14 days, compared to 3–5 days for the manifestation of symptoms by SARS or MERS.

The latter reflects the height of the power of the new virus, a favorable mutation to achieve its ultimate goal, by which it can spread in a silent and subtle way. Furthermore, the longer incubation time allows it to accumulate a more intense *viral load*, so that, in the time span of 8 to 14 days (before the infected person manifests any symptom) used for reproduction, it is able to discharge an immensely larger amount of its descendants in the environment. In other words, people with COVID-19 may be transmitting a large viral load earlier in the course of the infection, just as their symptoms are developing, but before they begin to worsen.

It is paramount to consider that a virus is fundamentally a '*replicator*', and the new virus has reached, for the time being, the pinnacle of the functional capacity of a replicator. At the time I am writing these lines we are surpassing. 17 million people infected worldwide (>11 million recovered) by the SARS-CoV-2, and a death toll of more than 680,000. This number pales when compared with the sum of deaths already provoked by other epidemics or with the yearly death toll of influenza mentioned early. But we must consider that the numbers of the actual statistics are very probably false, largely underestimated, for it depends to a larger extent on the number of tests, which as we know is far below what would be necessary. We have not yet a conclusion about a possible treatment (the family HxNy can be treated with several types of antiviral drugs) and much less is certain that we will have an efficient vaccine (as well as for the other SARS and MERS).

This means that, in despite of the very efficient measures undertaken to limit the virus spread, it is still around us accomplishing its ultimate goal - several million people are still infected. It is possible that the herd immunity finally emerges – but the most important aspect to consider is that, while the virus is still travelling among humans (and animals), its mutations continue, and some new specimen will appear with other more efficient munition to defeat homo sapiens. As is often said, it is not a question of *if*, but *when. The struggle SARS-CoV-2 x Homo Sapiens will still endure.*

- Concerning *Secondo*: What comes next?

On this point I would like to recall another paper of mine published also in 2010 in the pages of TF&SC titled "*Crises, Depressions, and Expansions: Global Analysis and Secular Trends*" (Devezas, 2010b). The objective of the work at that time was to offer an interpretation of the 2007–2008 financial crisis (also coined as Great Recession) in the framework of the Kondratieff waves, as well as comparisons with previous crises. Moreover, I offered an interpretation of the reason for the crisis and a forecast on the paths of the global economy for the next 20 years. Four main economic agents – world population, global output (GDP), gold price, and the Dow Jones index – were minutely examined using data from several sources. Without going into details about the methodology used, I summarize the main conclusions below:

(1) Fingerprints of Kondratieff longwaves are ubiquitous in all observed time series used in this research—world GDP growth rates, succession of economic expansions–contractions in the US, purchasing power of gold and the historical ratio DJIA/gold price;
(2) Regarding the present crisis we can state that it has some unique characteristics, which distinguish it from all previous economic depressions. Despite its unique characteristics a parallel with the panic of 1907 may be drawn—both have occurred amidst a strong international growth period and are perfectly symmetric in the observed space–time pattern;
(3) The most important conclusion concerning this crisis is that it seems to sum up a mix of a self-correction mechanism that brought the global output back to its original logistic growth pattern and signals an imminent transition to a new world economic order;
(4) The next decade will be probably one of worldwide economic growth, corresponding to the second half of the expansion phase of the fifth K-wave, but that will saturate soon after the 2020′s;
(5) There are strong signals that we are already witnessing a transition to a new global socioeconomic system, which will carry within it a profound restructuration of world economic affairs, with a multipolar world leadership and a new world currency.

These results were reached through application of trend analysis

using logistic curves, spectral analysis of time series, and the singularity approach, all of them converging to the same general result of an evolutionary trajectory leading the world system toward a probable age of transition.

Regarding the conclusions of points 2, 3 and 4, I have to say that I'm confident in affirming that they were correct, because in the following years after the publication the trajectory of the global economy corresponded to perfection the extrapolated curve presented in the Figure 13 of the paper (Devezas, 2010b). In 2010 the global GDP jumped up to a growth rate of 4.3% p.a., and in the following years exhibited a slight downtrend with an average of about 3% p.a., signaling the approaching peak of the 5th K-wave.

Concerning the point 5, the transition to a new global socio-economic system, also mentioned in point 3 (an imminent transition to a new world economic order) I have not delved into the analysis because I was not sure about two main points (see below) which would require a more detailed research. I limited myself to indicating only the trend of the curves and commenting on the observation that real growth rates of low-income countries have been growing increasingly apart from those of high-income countries. The fact is that since the onset of the Industrial Age high-income countries have contributed with at least about 70% for the global output measured as world GDP growth rate. This trend was maintained up to the mid-1990s, but after this point, and up to 2007, growth contribution from low-income countries surged by more than threefold, from around 10% (mid 1990s) to almost 35% (2007). In the mid-1990s high-income countries contributed with 77% for the global output growth, and low/middle-income countries contributed with 23%. Presently these numbers have radically changed to 95% from low/middle-income and only 5% from high-income countries. See for instance that, according to IMF (2020), in 2018 the world GDP grew at 3.6%, with advanced economies growing at 2.2%, while developing economies grew at 4.5%. *Such change may well be interpreted as a signal to a transition to a new world economic order with a multipolar world leadership*. As demonstrated by Devezas et al. (2017) the driving force for this radical change was China's modernization, a process that has started slowly in the 1980s, but accelerated enormously in the 1990s – in 1992 China's annual GDP growth reached the incredible mark of 14,3%. After a slight decline in the second half of the 1990s, China's output continued to growth unabated in the first decade of the 21st century maintaining the two digits mark during most of this period. Importantly, during this period, China's global economic significance of course increased and in 2010 China became the world's second largest economy, and now more than twice as large as that of Japan.

With regard to the two main points mentioned above, about which I was not sure at the time I published that work, they were: 1 - *the phenomenon of dematerialization*, and 2 – *the possible end of the pattern of the Kondratieff longwaves*, at least as we have interpreted them until now. Both points are somehow inter-related and have to do with the aspect of the growing relevance of intangible assets in the current socio-economic system.

In the last few years, I have driven my attention more intensively to the investigation of point 1, which resulted in the publication of three articles– Magee, Devezas (2017), Magee, Devezas (2018), Devezas et al. (2017). The objective of this research, which was conducted in collaboration with my colleague Chris Magee (MIT, Materials Division), was to survey the worldwide production and consumption of a basket of 98 materials most used in modern engineering applications in order to find patterns of dematerialization and or materialization during the last half century. The results do not enable us to state that human society is '*dematerializing*', but we have pointed out that there are some positive trends which allow us to be optimistic regarding a reduced per capita consumption of materials in the future and less harm to the environment as well. In a nutshell, the patterns found indicate that *business is not simply proceeding as usual*, for the *ever-increasing technological capability is contributing to an ever-improving efficiency in the usage and production of materials*, allowing a hopeful vision of a future scenario that, if not showing absolute dematerialization, is evidencing a stabilized and sustainable path allowing economic growth without continuing increased material consumption.

Our results demonstrated that among the 98 materials investigated, at least 51 materials were evidencing some type of dematerialization or reducing their per capita consumption. Some may argue that this result is mainly due to a global picture of economic degrowth in the last couple of years. But regarding this point it is important to consider that many economists are suggesting that we are experiencing neither a global recession, nor a normal economic crisis, but instead that the global economy will not return to the roaring economic growth verified in several periods of the last sixty years. We call the attention to the fact that economic growth is not happening as it used to be, in other words, wealth is being created without necessarily more material consumption – our analysis demonstrated that, from the basket of 98 materials studied, humans needed to consume 480 g to produce one dollar output in 1960, and now can produce the same dollar with only 200 g.

Regarding the second point (end of the pattern of K-waves), unfortunately I have not published about it yet, but my students are witnesses of how I have insisted in this idea in my classes over the past few years. *The reason is simple:* past Kondratieff longwaves (K-waves for short) were supported at large by material-based radical innovations and novel artifacts, and huge industry complexes to produce them. Now we are witnessing the burgeoning of a completely new economy, not so strongly based on the exponential growth of material and energy consumption, but instead in a new vast and invisible digitalized '*second economy*' (Brian Arthur, 2017), and a series of intangible innovations that are forming a very strange new virtual world. This a completely new 'technosphere', without any comparison with the previous ones.

It might be better to devote some more objective words on this subject, which is relevant to our final consideration about <u>*what is next?*</u>

Over the past 250 years, since the inception of the Industrial Revolution (IR for short), the occurrence of at least four K-waves has been observed, and we were now experiencing the end of the expansion phase of the 5th K-wave. Each of these previous K-waves defined a clear 'technosphere' (Devezas, Corredine, 2001) designed by the leading basic innovations of that period, a not very different view from that of the successive IRs (1st, 2nd, 3rd) defended by mainstream economists (Schwab, 2016), who say we are experiencing now the 4th IR. According to the neo-Schumpeterian school of economics (or evolutionary economics) the global economy is a far from equilibrium open complex system with an endogenous self-regulatory mechanism, characteristic of the self-organized complex systems. Such mechanism consists in the periodic swarming of basic (or disruptive) innovations that concentrate during the phase of economic recession, with a period of about a half-century. According to the Schumpeterian concept of creative destruction, these downwave swarming of innovations triggers the following upwave phase of economic expansion, during which the bunch of new radical technologies interact synergistically giving birth to a completely new 'technosphere'.

But whatever school of economic thought we follow (evolutionary with K-waves, or mainstream with successive IRs), the fact is that now we are witnessing the birth of a completely new socioeconomic paradigm, probably the most important global change ever experienced by the human civilization. Things are now very different, the concept of innovation itself has changed a lot, means of wealth production are no longer what they used to be. During the previous IRs, or the equivalent K-waves, we have had the emergence of massively materialized industrial sectors based on the introduction of radically new material-based artifacts, generating a myriad of new jobs and professions. Today's means of wealth production are not more based in the mass production of artifacts, but instead increasingly decoupled of material consumption and cardinally based on intangible innovations and assets; the Internet, e-mail, home banking, e-commerce, artificial intelligence, augmented reality, social networks, and much more, are the hallmark of

our modern life (Linstone and Devezas, 2012). Millions of jobs are being vaporized in a rhythm never seen, while other are emerging, towards the creation of billion-dollar companies, the so-called unicorn companies, which are conducted by a reduced number of highly skilled professionals.

A consequence of the present pandemic is the emergence of what has been coined as the "new normal", a situation that probably will last for many years as consequence of health concerns. The necessary social distance may dampen travel demand, business travelers probably take to use more remote working, driven by cost reduction as well while as having become accustomed to remote business practices during the pandemics.

In summary, we have now a very different reality, strongly based on the virtual cyber-physical systems world, which carries with itself the necessity of a profound structural change of production means, trade, education, and social organization. Governments, entrepreneurs, businesses, and every citizen in the world need to adapt to this new globalized digital landscape. *INFORMATION* is now the most valuable commodity and we can not assign it any value. How much is 1 bit of information worth? This new and extraordinary digital landscape is allowing a gargantuan accumulation of KNOWLEDGE with easy and immediate access to every human being. Considering then this completely different context it is very difficult to envisage the unfolding of a 6th K-wave. The pattern is probably broken, to give place to another still unknown one.

Final remark

I would not like to deepen the discussion here on '*what is next*', as I intend it to be the theme for a more extensive essay using scenario building and other forecasting tools.

My main conclusion, considering all previous presented arguments, is that the *pandemic of SARS-CoV-2 has precipitated an imminent collapse*, triggered by a new agent (the new virus, with its enhanced properties) that has acted upon an accumulation of oddities existing in the present organization of the world system, most notably the excessive and deregulated connectivity.

For now, it is difficult to speculate how long it will take to a complete recovery. If the pattern of K-waves is to be maintained, we probably will have about one to two decades of slow recovery, during which a new bunch of radical innovations will emerge. But in my opinion the picture that we will assist will be one of a relatively faster recovery phase (about five to six years) after which many things will happen in the geopolitics and socioeconomic order.

But, *how about to look at this pandemic as a disruptive innovation itself*, which will bring with it a bandwagon of socioeconomic and biomedical innovations, which will interact synergistically with already existing technical innovations that will potentialize a profound global transformation? For sure we will have an accentuated spike of digitization and a speeding up development of artificial intelligence; homeworking will turn to a most common practice and the boom of e-commerce will be accelerated. It is not to discharge the hypothesis of a renewed interest in cryptocurrencies.

One important goal of this opinion article regards to offer new perspectives and paths for research, which can be subsumed as:

(i) we had the catastrophic interaction or co-action of different agents, namely a new virus with evolved new properties (mainly regarding its longer incubation time and new symptoms, other than flu-like symptoms) and an excess of physical connectivity. The interaction was catastrophic in the sense that it has revealed the fragility of our institutions and led to rapidly cascading effects on governmental and financial systems, which were prone to blow. The research question to be pursued is how to build systems of governance and trade that can handle probable (but unforeseeable regarding their exact timing) random events like a global pathogen outbreak.
(ii) researchers of K-waves should further investigate if the pattern of K-waves may be broken or not, and alternatively, investigate the possibility of interpreting the pandemic as a radical innovation itself.

Returning to my 2010 essay '*From My Perspective: On Ferguson*', where I point out the fact that '*History matters*', I would like to close this opinion article with the same conclusion, which remains very actual:

What happens, for the time being, is that we don't know yet how to tackle with this history dependence, in order to bring it into our favor.

Acknowledgment

The author thanks Prof. Fred Phillips for his interesting suggestions and observations when reading the first version of this manuscript.

References

Avishai, B. (2020) – Daily Comment, Nassim Taleb's interview to The New Yorker on April 21th. - https://www.newyorker.com/news/daily-comment/the-pandemic-isnt-a-black-swan-but-a-portent-of-a-more-fragile-global-system.
Arthur, B. W. (2017) "Where is technology taking the economy?" McKinsey Quarterly, October 5th, https://www.mckinsey.com/business-functions/mckinsey-analytics/our-insights/where-is-technology-taking-the-economy.
CDC (2012) – Center for Disease Control and Prevention, "First Global Estimates of 2009 H1N1 Pandemic Mortality Released by CDC – Led Collaboration", June 25 - https://www.cdc.gov/flu/spotlights/pandemic-global-estimates.htm.
Combs, S. (2020) – "She discovered coronaviruses decades ago—But got little recognition", National Geographic, April 17th, https://www.nationalgeographic.com/history/2020/04/june-almeida-discovered-coronaviruses-decades-ago-little-recognition.html.
Dalzell, S. (2020) - Coronavirus is less deadly than SARS and experts say that's why it's killed more people overall, ABC News, April 10th, -https://www.abc.net.au/news/2020-04-10/coronavirus-sars-comparison-contagious-mortality-rate/12139122.
Devezas, T., Corredine, J., 2001. The biological determinants of long wave behavior in socioeconomic growth and development. Technol. Forecast. Soc. Change 68, 1–57.
Devezas, T., et al., 2010a. On phase transitions, catastrophes, and sudden changes. From My Perspective: On Ferguson In: Linstone, H. (Ed.), Technological Forecasting and Social Change 77. pp. 1412–1422.
Devezas, T., 2010b. Crisis, depressions, expansions – global trends and secular analysis. Technol. Forecast Soc. Change 77, 739–761.
Devezas, T., 2020. Trends in aviation: rebound effect and the struggle composites vs. aluminum. Technol. Forecast Soc. Change 160, 120241.
Chapter 13Devezas, T., Vaz, A., Magee, C.M., 2017. Global pattern in materials consumption: an empirical study. In: Devezas, T., Leitão, J., Sarygulov, A. (Eds.), Industry 4.0 - Entrepreneurship and Structural Change in the New Digital Landscape. Springer, Heidelberg, Germany.
Hoffauer, H. (2020) – "12 people who seemingly predicted the corona virus pandemic", Business Insider, May 13th - https://www.businessinsider.com/people-who-seemingly-predicted-the-coronavirus-pandemic-2020-3.
IMF, 2020. International Monetary Fund. Real GDG Growth. https://www.imf.org/external/datamapper/NGDP_RPCH@WEO/OEMDC/ADVEC/WEOWORLD.
Linstone, H., Devezas, T., 2012. Technological innovation and the longwave theory revisited. Technol. Forecast Soc. Change 79, 414–416.
Magee, C.M., Devezas, T., 2017. A simple extension of dematerialization theory: incorporation of technical progress and the rebound effect. Technol. Forecast. Soc. Change 117, 196–205.
Magee, C.M., Devezas, T., 2018. Specifying technology and rebound in the IPAT identity. Procedia Manuf. 2, 476–485.
Schwab, K., 2016. The Fourth Industrial Revolution. World Economic Forum, Geneva.
Taleb, N.N., 2007. The Black Swan – The Impact of Highly Improbable. Penguin Books, N.Y.