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Economic Growth in the Age of Ubiquitous Threats: How Global Risks are Reshaping Growth Theory

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Abstract: One of the most outstanding accomplishments of the economic science over the last decades is the development of a sound and coherent theory of economic growth. Research in growth theory has demonstrated that significant and systematic increases in well-being are attainable whenever the right formula is implemented. When combined with efficiency, the ingredients of this formula - innovation, the diffusion of ideas, and human capital accumulation - can drive the economy towards a virtuous path of sustained growth. Notwithstanding, this is an overly optimistic view of growth that does not account for the many obstacles that the creation of wealth may encounter. The current essay surveys cutting-edge research on growth theory to conclude in favor of a paradigm shift: the main concern is no longer just with how to correctly combine production inputs, but with how their efficient use is eventually hampered by a large collection of worldwide risks and threats. Global risks come in many shapes (they can be classified as economic, environmental, geopolitical, societal, and technological) but, in any case, they call for a reexamination of growth theory.

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JEL classification: O41, O33, O43, O44

1. Introduction

The World Economic Forum, an independent international organization whose main purpose is to foster public-private cooperation at the highest levels of decision-making, publishes every year, since 2006, the *Global Risks Report*. The aims and scope of this publication consist in a thorough systematization and assessment of the main and most pressing threats that humanity currently faces. The report defines global risk as "the possibility of the occurrence of an event or condition which, if it occurs, would negatively impact a significant proportion of global GDP, population or natural resources." (2023 Report, page 5). As characterized, the notion of risk should be interpreted loosely, to include every danger, menace, and potential disaster that threatens our fragile collective existence.

The mentioned report compartmentalizes risks into five broad categories: economic, environmental, geopolitical, societal, and technological. The contents of each category are self-explanatory. On the economic front, macroeconomic risks are highlighted; these include the prospect of economic stagnation and recessions, rising inflation and unemployment, asset bubbles, and debt crises, especially in large economies. Also relevant, regarding the threats posed to the world economy, are the possibility of commodity shocks, the collapse of supply chains, and the proliferation of illicit activities, such as organized crime, trade in counterfeit goods, and tax evasion and fraud.

In what concerns the second category, the environment, a long list of threats can also be enunciated, including human-made environmental damages, overexploitation and mismanagement of critical natural resources, climate change, the loss of biodiversity, extreme weather events, and geophysical disasters. Geopolitical risks encompass terrorism, the threat posed by weapons of mass destruction, geoeconomic and geopolitical confrontations, civil wars, and the dismemberment of multilateral organizations and arrangements.

The societal category covers a wide array of risks, from those associated with the spread of infectious diseases (epidemics and pandemics) to many other issues raised by our coexistence in society (e.g., the erosion of public institutions and social cohesion, the deterioration of working conditions and job opportunities, the disillusionment of the youth, or the emergence of large-scale involuntary migrations). Finally, technological risks are, currently, associated with cybercrime and cyberespionage, digital inequality and digital power concentration, and, among others, the eventual inadvertent or malicious breakdown of critical information infrastructures.

Most of the aforementioned risks do not manifest themselves in isolation. Although a global crisis may erupt from a single *seed of dystopia*, this can spread fast, to other areas of the economy and the society, creating what one might designate as a *perfect storm*. The COVID-19 pandemic and the recent escalation of geopolitical tensions are two prototypical examples of seeds of dystopia that fueled the uprise of many other meaningful threats (e.g., soaring inflation, increasingly worrisome cybersecurity breaches, deeper social fragmentation, massive refugee crises, or the rise of inequalities within and among countries). The substantiation of some of the enunciated threats, and even the mere perception that they might somehow materialize, may seriously hamper economic growth in a variety of ways. The challenge that growth theorists nowadays face is precisely to incorporate these threats into their models and to effectively explain how they might influence the pace of material progress as we know it today.

This essay undertakes a selective survey of growth theory (of contributions published from 2020 onwards) to clarify that most recent additions to the theory acknowledge and are aware of the main obstacles that worldwide economic growth faces. This contrasts with earlier contributions, which were much more focused in efficiency issues and on how countries should successfully combine the available physical, human, and technological inputs with the objective of maximizing intertemporal utility. Although the aim continues to be the same, i.e., the promotion of material well-being, the focal point is that scholars have, today, a much clearer perception that the existing risks might threaten the efficacy of the conventional formulas leading to sustained economic growth.

The remainder of the article is organized as follows. Section 2 highlights the pieces of literature that directly and generically approach the impact of probable significant disasters and rare events over the economy's growth rate. Special focus is placed on an analytical framework capable of quantifying the growth effects of a disaster and, also, the growth impact of the risk itself. In section 3, technological risks are addressed. The relevant literature is surveyed, and the typical endogenous growth model is reinterpreted in light of the presence of an additional input: robotic capital or artificial intelligence.

Section 4 proceeds with a reflection on the interplay between the spread of infectious diseases and economic growth. To share ideas and knowledge, human contact is required; however, with increased human contact comes the possibility of faster dissemination of diseases. The worldwide fast dissemination of the COVID-19 pandemic was the direct consequence of the globalized and interconnected world we live in today, what leads to an undeniable piece of evidence: the closer the globalization process brings us together, the stronger it becomes the risk of catastrophic public health events. In section 5, environmental risks are highlighted. Environmental concerns are progressively becoming an inseparable part of growth analyses. This is illustrated by exploring an adapted version of a recently proposed model of climate change and growth. In section 6, geopolitical risks are briefly debated. These may take many forms and they can be associated with growth models in many ways. A typical neoclassical growth model allowing for political instability is characterized to illuminate about the impactfulness of this type of risk.

In section 7, a few additional notes on economic risks are added to the survey, and section 8 concludes.

2. The Accommodation of Risks and Disasters in Growth Models

Global economic growth is subject to a wide variety of risks. Although these may be somehow interconnected, they are different in nature and, therefore, as expected, different strands of literature deal with the impact of dissimilar threats in distinct ways, as the sections that follow will highlight. Despite this diversity, there are a few recent studies that address, in a generic and abstract way, the potential impact of menaces and actual disasters on growth. These include Douenne (2020), Hao *et al.* (2020), Barro and Jin (2021), Jovanovic and Ma (2022), and Krishna *et al.* (2023). The common point in the mentioned studies is the presence of uncertainty associated with some aspect of the growth process: the outcome of the adoption of new technologies might be uncertain, investment decisions might be unpredictable, or stochastic rare events may cause unforeseeable changes in consumption.

The model by Douenne (2020) is particularly well-suited to approach the impact of risks on growth. It is a relatively standard optimal growth model where the combination of recursive utility with a stochastic capital accumulation process allows for the quantification of the effect of disaster risks and of the consequences of actual disasters over the growth rate derived under an endogenous growth setup. In this section, Douenne's framework is recovered, and its discussion further extended.

Let $K(t)$ represent the stock of physical capital at date *t*. In this setting, the risk is defined as the probability of occurrence of a negative shock affecting the stock of capital. If the shock materializes, $K(t)$ falls to $\widetilde{K}(t) = \omega K(t), \omega \in (0,1)$; the lower the value of parameter ω, the stronger are the damages caused by the disaster. Although the impact of the disaster on growth is unequivocally negative, the risk that it poses may accelerate or decelerate growth, depending on the effect over consumption and savings. When faced with a risk, the representative agent may either transfer consumption from the present to the future (precautionary savings) or the other way around (precautionary consumption). The key element in this regard is the intertemporal elasticity of substitution: a low elasticity of substitution (lower than 1) stimulates an increase in savings; a high elasticity of substitution (higher than 1) leads to an anticipation of consumption in face of the risk. Evidently, the precautionary savings scenario is the one conducting to faster long-term growth.

Douenne's model is particularly appealing because it allows for a clear distinction between the notions of intertemporal elasticity of substitution and the coefficient of relative risk aversion. This separation is feasible if the agent's preferences are represented through a recursive utility function of the Epstein-Zin type. In this model, the utility function takes the form:

$$U(t) = \frac{1}{1-\gamma}\left\{C(t)^{1-\theta}dt + e^{-\rho dt}[(1-\gamma)\mathbb{E}U(t+dt)]^{\frac{1-\theta}{1-\gamma}}\right\}^{\frac{1-\gamma}{1-\theta}} \quad (1)$$

In expression (1), $C(t)$ and $U(t)$ stand for consumption and utility, respectively. The operator $\mathbb{E}$ designates the expectation about future utility. The parameters are the following: $\rho \geq 0$ is the rate of time preference; $\theta \in [0, +\infty)\backslash\{1\}$ is the inverse of the intertemporal elasticity of substitution; and $\gamma \in [0, +\infty)\backslash\{1\}$ is the coefficient of relative risk aversion (CRRA); the higher the value of γ, the stronger is the aversion to risk.

The maximization of utility is subject to a constraint on the accumulation of capital. This is a stochastic differential equation, which is represented under the following form:

$$dK(t) = [Y(t) - C(t)]dt - \sum_{i=1}^{n}\left[K(t) - \widetilde{K}_i(t)\right]dq_i(t) \tag{2}$$

In equation (2), $Y(t)$ represents output. In order to guarantee the tractability of the model and also an endogenous growth outcome, constant marginal returns are taken, such that $Y(t) = AK(t), A > 0$. In the expression, the accumulation of capital can be hit by n different shocks of amplitude $K(t) - \widetilde{K}_i(t) = (1 - \omega_i)K(t)$; the frequency of the shocks is determined by a Poisson process, such that $\mathbb{E}dq_i(t) = \lambda_i dt$ represents the probability of the occurrence of a disaster of type *i*; λ_i is a positive parameter. No other eventual fluctuations besides those triggered by the rare catastrophic events are considered in this setup, as presented.

For the characterized dynamics, the average growth of the stock of capital writes as,

$$\mathbb{E}\left[\frac{dK(t)/dt}{K(t)}\right] = A - \frac{C(t)}{K(t)} - \sum_{i=1}^{n}(1 - \omega_i)\,\lambda_i \tag{3}$$

The maximization of utility in (1) subject to capital accumulation constraint (2) requires employing optimal control techniques for stochastic problems. Following the same procedure as in Douenne (2020), the computation of the Hamilton-Jacobi-Bellman equation conducts to an optimal solution in which the consumption-capital ratio is constant. Under the proposed formulation, on the optimal path the consumption-capital ratio is,

$$\frac{C(t)}{K(t)} = \frac{\rho}{\theta} + \frac{\theta - 1}{\theta}\left(A - \sum_{i=1}^{n}\frac{1 - {\omega_i}^{1-\gamma}}{1 - \gamma}\lambda_i\right) \tag{4}$$

The impact of risk and risk aversion over the consumption-capital ratio is contingent on the value of the elasticity of intertemporal substitution, θ^{-1}. If $\theta^{-1} < 1$, then the consumption-capital ratio decreases with risk (with a higher probability of disasters - higher λ_i - and with a higher intensity of disasters – lower ω_i), and with risk aversion (higher γ). The opposite results are obtained for $\theta^{-1} > 1$. If $\theta = 1$, then the consumption-capital ratio is equal to the rate of time preference. When $\theta^{-1} < 1$, people increase savings in face of a given risk; this is a scenario of precautionary savings. When $\theta^{-1} > 1$, people prefer to increase consumption when confronted with higher uncertainty, a phenomenon that can be designated as precautionary consumption.

Substituting the optimal consumption-capital ratio in (4) into (3), one obtains the expected growth rate or the average long-run growth rate (of capital, consumption, and income),

$$\bar{g} \equiv \mathbb{E}\left[\frac{dK(t)/dt}{K(t)}\right] = \mathbb{E}\left[\frac{dC(t)/dt}{C(t)}\right] = \mathbb{E}\left[\frac{dY(t)/dt}{Y(t)}\right]$$

$$= \frac{1}{\theta}(A-\rho) + \frac{\theta-1}{\theta}\sum_{i=1}^{n}\frac{1-{\omega_i}^{1-\gamma}}{1-\gamma}\lambda_i - \sum_{i=1}^{n}(1-\omega_i)\,\lambda_i \qquad (5)$$

The growth rate in expression (5) involves three terms with different meanings. The first term corresponds to the no risk outcome, the well-known Euler equation result, according to which the pace of growth is essentially determined by the difference between the marginal return on capital and the rate of time preference. The second term represents the impact of risks over growth; the risk may increase the pace of growth if $\theta^{-1} < 1$ (precautionary savings trigger higher long-term growth). The third term is the impact of the actual occurrence of the disaster, which is necessarily negative. Hence, the proposed framework has the merit of separating the consequences of the threat from those of the disaster itself; they will both negatively influence welfare, but their joint effect on growth might not be negative if the risk induces, in a large extent, precautionary savings.

The above reasoning considers multiple risks (n risks, to be precise) but no association between them. As mentioned in the introduction, the threat of a large-scale nefarious event (e.g., a pandemic or a war) is just a probable seed of dystopia that easily spreads to many other areas of society or the economy. Hence, one may conceive a scenario in which an initial high probability – high intensity risk is just the first step in a chain of foreseeable events with progressively lower intensity and probability of occurring. A stylized form of representing the above reasoning consists in taking a first risk of probability $\lambda_1 = \lambda$ and intensity $\omega_1 = \omega$, and a series of subsequent risks obeying conditions $\lambda_{i+1} = \phi\lambda_i,\ \phi \in (0,1)$ and $\omega_{i+1} = \delta\omega_i,\ \delta \in (0,1)$.

Taking $n \to \infty$ (i.e., an infinite series of progressively lower probability – lower intensity potential disasters), the growth rate in expression (5) is presentable as a function of the eight relevant parameters of the model $(A, \rho, \theta, \gamma, \lambda, \omega, \phi, \delta)$,

$$\bar{g} = \frac{1}{\theta}(A-\rho) + \frac{\theta-1}{\theta}\frac{\lambda}{1-\gamma}\frac{1-\phi\delta^{1-\gamma}-(1-\phi)\omega^{1-\gamma}}{(1-\phi)(1-\phi\delta^{1-\gamma})} - \lambda\frac{1-\phi\delta-(1-\phi)\omega}{(1-\phi)(1-\phi\delta)} \quad (6)$$

If risks following the initial threat are of some significance, meaning that the values of ϕ and δ are relatively high, then the initial effect of the seed of dystopia is prolonged in time. This effect is clearly negative in what respect the impact of the disaster. However, as remarked above, it can be either positive or negative regarding the risk itself, given the value of parameter θ.

Douenne (2020) introduces an additional relevant topic, namely the possibility of deliberate risk mitigation. In what respects global risks, the effort in lowering them requires an international coordination of efforts, because the large majority of the already highlighted risks is associated with global commons (e.g., the preservation of the environment, peacekeeping, or the prevention of infectious diseases). Because free riding is unavoidable, the international community should at least guarantee a *coalition of the willing*.

Analytically, in the context of the model, risk mitigation consists in diverting a share of income, $\tau \in (0,1)$, to reduce the probability of the disaster. Under risk alleviation, the probability of a disaster falls from λ to $\lambda(1-\tau^{\alpha})$, $0<\alpha<1$. Solving the model in this scenario yields an optimal result for share τ,

$$\tau = \left[\frac{(1-\omega^{1-\gamma})\lambda\alpha}{A(1-\gamma)}\right]^{\frac{1}{1-\alpha}} \quad (7)$$

One considers that the risk reduction effort is exerted only upon the first risk (the seed of dystopia). Because all other risks depend on the first, the risk reduction spreads over all potential subsequent disasters. In this case, the optimal consumption-capital ratio is

$$\frac{C(t)}{K(t)} = \frac{\rho}{\theta} + \frac{\theta-1}{\theta}\left[(1-\tau)A - (1-\tau^{\alpha})\frac{\lambda}{1-\gamma}\frac{1-\phi\delta^{1-\gamma}-(1-\phi)\omega^{1-\gamma}}{(1-\phi)(1-\phi\delta^{1-\gamma})}\right] \quad (8)$$

and the expected growth rate comes,

$$\bar{g} = \frac{1}{\theta}[(1-\tau)A-\rho] + \frac{\theta-1}{\theta}(1-\tau^{\alpha})\frac{\lambda}{1-\gamma}\frac{1-\phi\delta^{1-\gamma}-(1-\phi)\omega^{1-\gamma}}{(1-\phi)(1-\phi\delta^{1-\gamma})} - \lambda(1-\tau^{\alpha})\frac{1-\phi\delta-(1-\phi)\omega}{(1-\phi)(1-\phi\delta)} \quad (9)$$

The prevention of disasters has a negative direct impact on growth because it diverts resources from capital accumulation, but it has a positive effect via disaster avoidance. The growth effect via risk is, again, dependent on the intertemporal elasticity of substitution.

The characterized model is general enough to be applicable to any kind of global risk. However, different types of risks have specificities, concerning growth, that are worth exploring. This exploration begins in the following section, with a discussion about threats of a technological nature.

3. The Wonders of Automation and Artificial Intelligence: What Can Go Wrong?

The progress associated with computational capabilities and artificial intelligence opens new significant promising prospects regarding long-term growth. At this respect, a pertinent question is raised by Nordhaus (2021): are we heading towards a singularity point, i.e., towards a moment in history in which, without much human intervention, growth could accelerate further and further? This idyllic scenario is rapidly discarded by the author, based on empirical estimates and on the use of a few logical arguments. The strong idea is that technological wonders are necessarily accompanied by relevant technological risks that must be accounted for in order to prevent major technological disasters.

Technological risks are an unavoidable side-effect of the progressive sophistication of digital tools and other technical novelties. Such tools rely on increasingly high levels of connectivity and integration, what is necessarily accompanied by rising vulnerabilities. One must not forget that the technologies that foster growth are the same technologies that can be used for criminal activities, espionage, and other fraudulent and destructive activities. Moreover, the eventual path towards the creation of super intelligent machines can be a threat on its own, because with intelligence comes the ability to reason and to create and frame moral norms. For these reasons, and others (namely, the scarcity and non-renewable nature of most physical resources), it is safe to assert that we are not adding towards a singularity.

Most of the endogenous growth literature that equates the role of automation and artificial intelligence is a little bit more down to earth than what the above paragraphs might suggest. The main concern that transpires from such literature respects to the short and medium-term impact of the new technologies over employment and income distribution. These new technologies support a new form of capital that, unlike physical capital, is a substitute and not a complement for labor. Recent studies addressing automation and growth include Prettner and Strulik (2020), Irmen (2021), Lu (2021, 2022), Acemoglu and Restrepo (2022), Gasteiger and Prettner (2022), Hémous and Olsen (2022), Klarl (2022), Moll *et al.* (2022), Ray and Mookherjee (2022), Abeliansky and Prettner (2023), and Sasaki (2023).

The above-mentioned research proposes a wide variety of models and frameworks that are distinct in their structure and approach, but that share some common ground: in any case, automation replaces labor (at least low-skilled labor), and it allows to enhance productivity. In the end of the day, the new production capabilities are likely to foster growth, but one should not jump immediately to this conclusion. With automation comes the polarization of jobs and wages and the concomitant increase in income inequality (low-skilled workers lose for high-skilled workers and capital owners). As a significant part of the population loses income, two potentially damaging consequences emerge: a fall in aggregate demand and an increase in social discontentment. These collateral effects might overcome the productivity gains from automation, in what respects growth and, most evidently, in what concerns social welfare.

Accounting for automation in standard growth analysis requires adding a new input to the short list of production factors that are typically assumed. This new input is robotic capital (automated machines and processes, and artificial intelligence algorithms). As highlighted by Abeliansky and Prettner (2023), robotic capital mixes features of both traditional inputs: it is like labor, because it occupies the same role as human labor in the production process, and it is like capital, because it can be accumulated and it represents the non-human contribution to production. In Lu (2021), the automation input is directly interpreted as artificial intelligence. This is a special form of capital, with singular and non-trivial properties. It has similarities with human capital, because it can learn and accumulate knowledge by itself; it has similarities with ideas, because they are both nonrival.

In the same vein, yet another novel input might be considered to compose the aggregate production function that underlies growth analyses. This input is big data (Cong *et al.,* 2022) and it differs from robotic capital in the sense that it is not a substitute for labor. However, these factors also share some properties: they are nonrival and, unlike human capital, they can be detached from people and concentrated in the hands of a few, thus contributing to strong levels of income and wealth inequality. Besides this, the use of data raises another relevant risk for people, namely the risk associated with their privacy.

Based on the mentioned literature, a synthesis model can be compiled. Start by assuming a Cobb-Douglas production function, with robotic capital / artificial intelligence denoted by $R(t)$,

$$Y(t) = AK(t)^{\alpha}[L(t) + R(t)]^{1-\alpha}, \qquad A > 0, \alpha \in (0,1) \tag{10}$$

In equation (1), standard notation is adopted: $Y(t)$, $K(t)$, and $L(t)$ represent, respectively, output, physical capital, and labor (for the sake of the exposition let this last variable be constant over time, $L(t) = L$); A is the productivity index and α the output-capital elasticity. The substitutability between labor and robotic capital is evident from the expression; in the limit, if all labor is replaced by machines, production is still possible.

Define $\varrho(t) \equiv R(t)/L$ and assume the commonly used notations for per capita income and capital. Equation (10) is equivalent to its intensive form counterpart,

$$y(t) = Ak(t)^{\alpha}[1 + \varrho(t)]^{1-\alpha} \tag{11}$$

In a competitive economy, factor returns have correspondence in their respective marginal products. In the devised scenario, the wage rate is identical to the rate of return on robotic capital,

$$w(t) = r_R(t) = (1-\alpha)A\left[\frac{k(t)}{1+\varrho(t)}\right]^{\alpha} \tag{12}$$

The rate of return on physical capital is:

$$r(t) = \alpha A\left[\frac{1+\varrho(t)}{k(t)}\right]^{1-\alpha} \tag{13}$$

Under this simple formulation, it is straightforward to observe that the labor income share falls with an increase in the employment of robotic capital:

$$\frac{w(t)}{y(t)} = \frac{1-\alpha}{1+\varrho(t)} \tag{14}$$

In contrast, if one defines capitalists as the agents who hold any form of capital (physical and robotic), their income share is:

$$\frac{r(t)k(t) + r_R(t)\varrho(t)}{y(t)} = \frac{\alpha + \varrho(t)}{1 + \varrho(t)} \qquad (15)$$

From expression (15), one concludes that as the participation of robotic capital in production increases, the income share of capitalists increases as well.

To associate the above reasoning to a growth model, one would need to consider a standard physical capital accumulation equation and an intertemporal felicity function. Then, it would be necessary to add a robotic capital sector to the analysis: the self-replicating feature of artificial intelligence makes it reasonable to consider that no other input is required for its generation and that, probably, in the current stage of development, this input would escape the prevalence of diminishing marginal returns. As a result, in this framework, robotic capital becomes the driver of endogenous growth. However, this is a different type of growth; it is a growth process that largely amplifies inequalities and that changes the structure of demand in the economy.

Hence, the analysis of growth in the automated economy clearly requires a modelling framework with heterogeneous agents: by separating workers from capital owners one will be able to discern how the ongoing unconstrained evolution of technology represents a risk, not only for those who directly suffer with the loss of jobs, but to all people that may end up living in a dystopian world populated by an ever-increasing army of excluded.

4. Lessons from the Pandemic

The ravaging global pandemic of the early 2020s raised disquieting interrogations about the reality that we had taken for granted concerning world prosperity and growth. It revealed how a low risk – huge impact event may suddenly affect the lives of everyone in this planet. It also showed that accounting for growth is not just an exercise of measuring the quantity and quality of inputs and the efficiency in their use; there are relevant societal issues, in this case about public health, that must be accounted for. As it is evident, the COVID pandemic led to a rethinking of growth theory in the presence of health emergences and disasters. Meaningful recent work on the macroeconomic consequences of the spread of infectious diseases comprehends the work of Fogli and Veldkamp (2021), Carmona and León (2023), Hao *et al.* (2023), Lu (2023), and Shi (2023).

The most common strategy in assessing the growth implications of the propagation of infectious diseases, followed by most of the above-mentioned literature, consists in merging benchmark optimal growth models with standard epidemiological analytical frameworks of the SIR (susceptible-infectious-recovered) type. As individuals pass from each epidemiological state to the next, the economy also evolves from one growth stage to another. Evidently, periods in which a significant percentage of the population is in the infectious state are periods of slower growth. The channels from disease to growth are essentially three: labor productivity, human capital accumulation, and population growth. Combined, the various negative effects might have devastating consequences for the world economy and the living standards of people around the world.

Some of the work on the impact of infectious diseases on growth, most noticeably Fogli and Veldkamp (2021), establish a link between the spread of diseases and the diffusion of ideas and technology. The argument is that interaction among people diffuse both ideas and diseases. Therefore, given their health conditions and systems, countries must choose the adequate balance between knowledge diffusion and the risk of the transmission of infirmities. Knowledge and infectious pathogens have one characteristic in common: they are both nonrival; however, they have an antagonistic nature in the sense that the first is a global good, while the second is a global bad. The assessment of externalities must be pondered: the positive externalities originating in knowledge diffusion have to be weighed against the negative externalities that the diffusion of virus and germs brings.

As an illustration of the growth implications of disease propagation, consider the following straightforward reasoning. Imagine a standard growth model, with physical and human capital as production inputs. In this setup, the driver of growth is human capital accumulation; thus, let us concentrate in the motion of this input, represented in what follows by variable $H(t)$. Human capital is subject to obsolescence at rate $\delta_h \in (0,1)$ and its production is subject to constant returns; however, there is a productivity loss in the education sector directly attributable to illness. Let variable $\phi(t)$ represent the prevalence of an infectious disease and let $x(t)$ be the productivity loss directly attributable to the disease.

With the above information, one can display the growth rate of human capital (which will also be the growth rate of the economy under a trivial two-sector optimal growth setup) in the following terms:

$$\frac{\dot{H}(t)}{H(t)} = B[1-\phi(t)x(t)] - \delta_h, \qquad B>0 \tag{16}$$

Assume that $x(t)$ is time invariant and that the prevalence rate evolves, as in Hao *et al.* (2023), following a double-logistic rule, i.e.,

$$\phi(t) = \phi_0\left(\frac{1}{1+e^{-a_1 t}} - \frac{1}{1+e^{-a_2 t}}\right) \tag{17}$$

All parameters in equation (17) are positive values. Fig.1 illustrates the evolution of the infection rate for $\phi_0 = 2.5$, $a_1 = 1$, and $a_2 = 0.4$. After a first phase of fast increase in the share of infected in the population, this value gradually falls to zero.

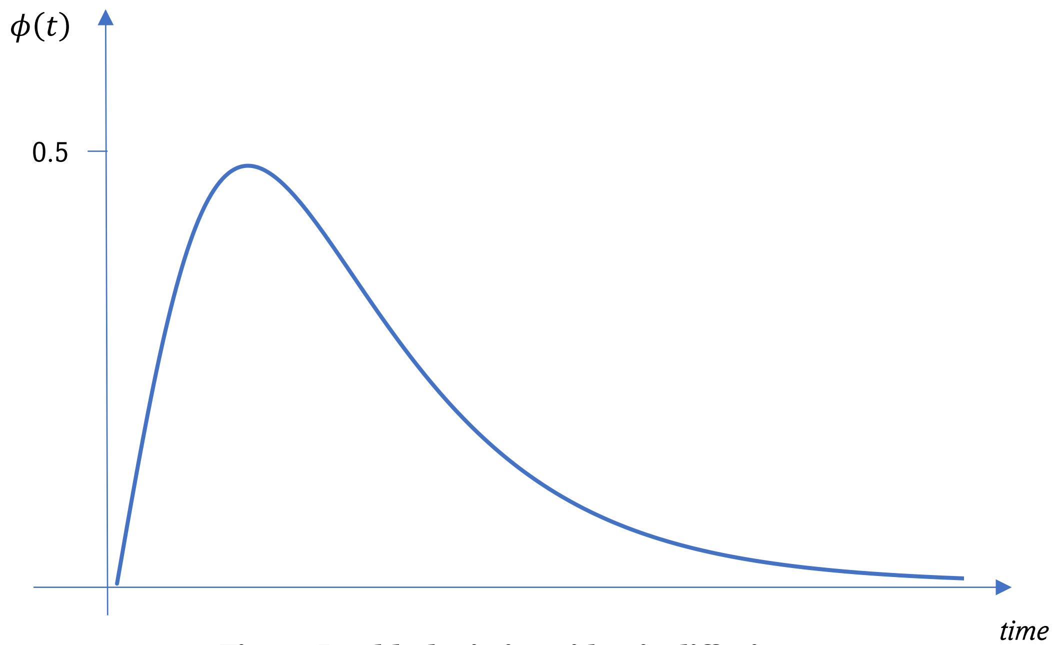

Fig.1 – Double-logistic epidemic diffusion.

In this simple framework, given equation (16), in the absence of the disease the economy grows at a constant rate. The effect of the epidemic is to provoke a transient fall in the growth rate. Fig.2 illustrates this effect for the spreading mechanism displayed in Fig.1 and characterized through equation (17).

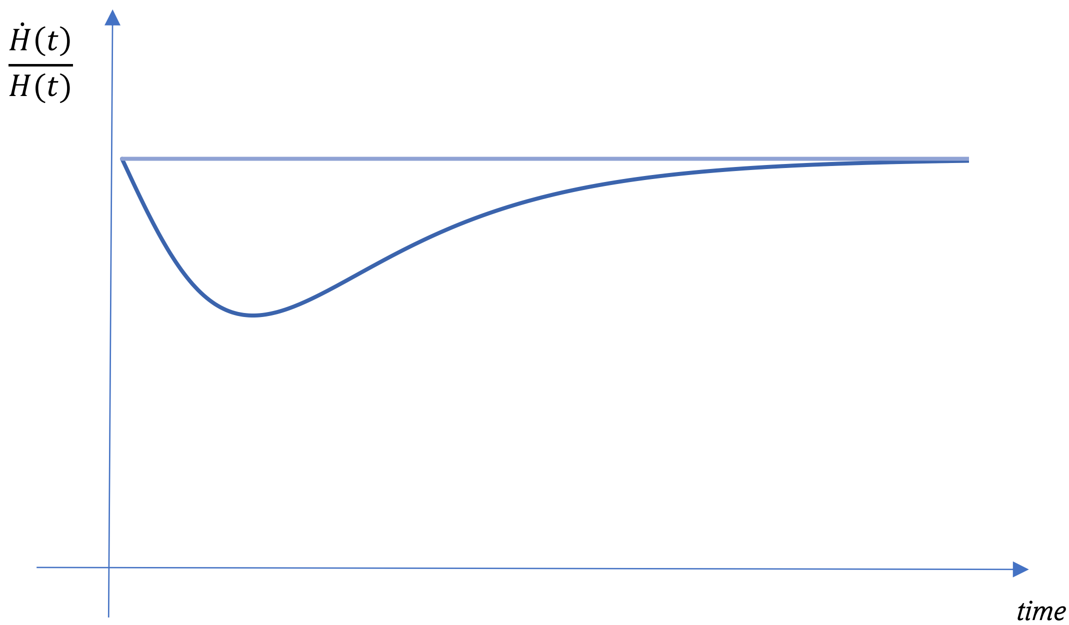

Fig.2 – Transitional path implied by the spread of an infectious disease.

The above reasoning directly applies to the dissemination of a disease but, in fact, it is adaptable to many other societal threats. Any event leading to social distrust or the breakdown of social ties (e.g., the growing youth disillusionment mentioned in the introduction) may cause a negative impact on the accumulation of human capital. In the sketched framework, the impact is transitory, in the sense that it is expected that the health issue is resolved sooner or later. Some societal problems might be more profound and eventually trigger a growth slowdown of a more permanent nature.

5. The Greatest of Them All: the Environmental Externality

As remarked in the latest editions of the *Global Risks Report*, environmental threats (climate change, extreme weather episodes, biodiversity losses, depletion of natural resources, man-made disasters) occupy the first places in the ranking of global risks, both in terms of likelihood and expected damaging impact. Due to their catastrophic nature, environmental risks are hard to reconcile with economic theory and, in particular, with growth theory, which privileges 'business as usual'. None the less, there is a voluminous new literature searching for a coherent integration between the two. It is safe to say that environmental concerns have become an increasingly relevant part of the theory of economic growth.

Contributions are dispersed and approach diverse aspects of the environmental menace. One of the most prominent topics concerns the impact of pollution or, more precisely, of carbon emissions (Bremer and Ploeg, 2021; Oliveira and Lima, 2022; Olijslagers *et al.*, 2023). Measuring the social cost of carbon is a complicated task, given the inherent long-term uncertainty that makes it unfeasible to compute undisputable discount rates to quantify the current value of future damages. In growth models, the environment is frequently added to the analysis through the exploration of the pollution-growth trade-off: pollution is a by-product of production, while environmental quality is an argument of the utility function. The solution for the underlying conundrum consists in promoting the transition to clean production technologies (Hart, 2020).

Hassler *et al.* (2021) and Casey (2023) develop growth models in which technical change endogenously evolves to increase energy efficiency and to adapt to environmental changes. Energy dependence will then determine the structure of production and the pace of growth. Fabozzi *et al.* (2022) look at the economy from the perspective of green growth. Green growth is associated with the notion of putting science and technology at the service of environmental preservation, at the same time they facilitate growth. This requires rethinking technological change and, also, the very own concept of growth. One way of following such path is to recenter attention in the ideas of recycling, reusing, and refurbishing (i.e., to adopt a circular economy worldview). However, as Zhou and Smulders (2021) highlight, the conversion to a circular economy also has its perils: excessive resource savings may hamper innovation and, consequently, have detrimental growth effects.

Addressing environmental issues in the context of growth theory requires, as well, assembling models capable of integrating, in a single framework, the management of scarce and non-renewable resources, population dynamics, innovation and the accumulation of knowledge, in order to search for the most likely drivers of sustained growth in a world of finite physical resources (Peretto, 2021; Sriket and Suen, 2022). Other ingredients can be added as well, namely health (Wei and Aadland, 2022): environmental degradation is detrimental for human health, what can compromise productivity and human capital accumulation.

To exemplify how environmental risks can be associated with the analytics of growth, a simple model of climate change, based on Cruz and Rossi-Hansberg (2023), is now devised. The framework is a typical optimal growth model, where the consumption – capital accumulation trade-off is complemented by a series of considerations regarding energy use, carbon dioxide emissions, local amenities, and climate change.

Consider a world economy (*O*) with multiple locations indexed by *r*. At date *t* and location *r*, per capita consumption, income, and physical capital are represented by $c(t,r)$, $y(t,r)$, and $k(t,r)$, respectively. Material production inputs, per unit of labor, are physical capital and also energy, denoted by $e(t,r)$. Representing the productivity index by $a(t,r)$, the production function comes

$$y(t) = a(t,r)F[k(t,r),e(t,r)] \tag{18}$$

Function $F(.)$ is an ordinary neoclassical production function exhibiting constant returns to scale and diminishing marginal returns. The capital accumulation equation takes the trivial form

$$\begin{gathered}\dot{k}(t,r) = a(t,r)F[k(t,r),e(t,r)] - c(t,r) - \delta k(t,r),\\ k(0,r)\ given\end{gathered} \tag{19}$$

Parameter $\delta \in (0,1)$ represents the depreciation rate of capital. The use of fossil fuels to generate energy induces a negative externality, namely CO_2 emissions; hence, emissions grow with energy intensity in production. Emissions pose a global and not a local risk, and therefore one should account for the change in the stock of emissions, $S(t)$, in a global perspective,

$$\dot{S}(t) = \int_{O} G[e(t,r)]dr - \delta_S S(t), \qquad S(0)\text{ given} \tag{20}$$

Value $S(0)$ may be interpreted as the pre-industrial level of emissions; this is a floor value for variable $S(t)$. Function G indicates how much the level of energy contributes to emissions; obviously, $G' > 0$, but the shape of the function will depend on how much energy resources rely on fossil fuels. Parameter $\delta_S \in (0,1)$ is the pollution recovery effect from one period to the next. The stock of emissions (i.e., the stock of carbon in the atmosphere) raises what Cruz and Rossi-Hansberg (2023) designate as global radiative forcing, which, in turn, increases temperature. To simplify, one can model a direct effect of emissions over global average temperature taking a logarithmic function,

$$T(t) = T(0) + \varphi \ln\left[\frac{S(t)}{S(0)}\right], \qquad \varphi > 0 \tag{21}$$

Variable $T(t)$ translates global temperature (recall that carbon emissions are a global externality); $T(0)$ is the global average temperature in the pre-industrial era. Local temperatures vary in response to a change in global temperature, but this is not necessarily a straightforward effect; it depends on local physical characteristics $g(r)$, i.e.,

$$\dot{T}(t,r) = g(r)\dot{T}(t) \tag{22}$$

In this setting, productivity is impacted by climate change, with productivity falling as the temperature eventually departs from the optimal level at location *r*, $T^*(r)$. The optimal temperature may vary across locations because of the physiological characteristics of people inhabiting them, and because of the amenities already in place in such locations. The effect over productivity might be modeled in the following terms:

$$a(t,r) = a(r)e^{-\phi[T^*(r)-T(t,r)]^2} \tag{23}$$

In expression (23), $a(r)$ represents productivity in location *r* under perfect conditions of temperature; parameter $\phi > 0$ measures the extent in which departures from optimal temperature provoke a fall in productivity.

Concerning preferences, the utility function of the representative agent in location *r* encloses two arguments: consumption and local amenities, $b(t,r)$. The utility function is a constant intertemporal elasticity of substitution utility function for consumption with the amenities term indicating how much consumption utility is discounted when the actual temperature departs from the benchmark level,

$$u[c(t,r),b(t,r)] = \frac{c(t)^{1-\theta}-1}{1-\theta} b(t,r), \qquad \theta \in [0,+\infty)\backslash\{1\} \tag{24}$$

The amenities term takes a shape similar to productivity in (23), i.e.,

$$b(t,r) = b(r)e^{-\zeta[T^*(r)-T(t,r)]^2}, \qquad \zeta > 0 \tag{25}$$

If the temperature remains at its optimal level, the utility from consumption comes multiplied by $b(r) \geq 1$; as the temperature deviates from optimal, the amenities term converges to zero and the level of utility also falls to zero.

The above characterized growth apparatus is a Ramsey growth model involving climate change considerations. The main point to retain is that although energy is an input in production in region *r*, this contributes only partially to global emissions. A tragedy of the commons scenario clearly emerges, as in any other assessment of possible environmental damages. Therefore, the key environmental variable, $S(t)$, is exogenous to the local economy. Without a coalition of the willing focused on avoiding the increase of emissions, the temperature will continue rising, possibly making it departure further and further from the optimal benchmark. This is detrimental for the representative agent at two levels (following the logic of the model): rising temperatures penalize productivity and thus the ability to generate income and grow, leading to lower long-term consumption levels. Furthermore, climate change potentially deteriorates local amenities with a direct detrimental effect on welfare.

6. A Tumultuous and Conflicted World

Politics and geostrategic interests are, on many occasions, influential contextual factors underlying growth performance. Fragile political systems and social unrest prevent the creation of a stimulating environment for the accumulation and efficient use of production inputs. Geopolitical risks embrace many different types of threats, what implies the need for a wide variety of growth frameworks to approach different topics from different perspectives.

The type of political regime is a relevant element. The intrinsic characteristics of freedom and participation that are typical of democratic societies contain some of the seeds that allow growth to germinate, but this effect is neither linear nor universal (Eberhardt, 2022). Paradoxically, in certain geographies, economic growth and political control appear to go hand in hand. Beraja *et al.* (2021) argue that artificial intelligence technologies and autocratic regimes might reinforce each other; autocrats benefit from the mechanisms of control that new technologies allow for (e.g., facial recognition) and, therefore, they have reasons to incentivize innovation. Obviously, this can backfire if the evolution of the technology becomes uncontrollable from the point of view of the political regime.

Another important element is conflict. Both at the national and the international levels, armed conflicts entail heavy macroeconomic costs, typically materialized on significant falls on consumption and trade (Novta and Pugacheva, 2021). In any case, conflict is a key factor in holding back economic development; it is one of the most relevant seeds of dystopia, awakening many other risks. A sound political environment is associated with the absence of conflict and with the building of trust. Bjornskov (2022) argues that social trust enhances productivity growth and has also a role in consolidating formal institutions.

The behavior and practices adopted by politicians in power convey an important sign for those who strive, in society, to accomplish better lives. The type of leadership (i.e., the personality of the leaders and their technical capabilities), or the extent in which corruption and nepotism are more or less pervasive, create the incentives (bad or good) for people to engage on activities that foster innovation, human capital accumulation, and the creation of wealth (Brown, 2020; Perez-Alvarez and Strulik, 2021; Varvarigos, 2023). Political instability can also be interpreted as an impactful force underlying growth, as in the growth model proposed by Tohmé *et al.* (2022).

Let us concentrate attention on Tohmé's model. The model (a standard neoclassical optimal growth setup) sets the stage to address the implications of political instability on growth and welfare. The baseline assumption is the heterogeneity associated with the rate of time preference. Specifically, it is assumed that the intertemporal discount rate is a decreasing function of income (agents with a low income are the most impatient agents). In this setup, a political system selects a ruler. This ruler governs the economy taking into consideration her own intertemporal preferences, which become the intertemporal preferences of the society. Political systems may vary, in the sense that the ruler might be selected by majority voting, proportional representation, or not chosen at all if a dictatorship is established.

The ruler may be overthrown. Political instability sets in whenever the deposition of the ruler in power is frequent, and the regime is characterized by short periods in office. If the probable horizon in power is shortened, then the ruler will increase the rate of time preference, with the objective of compensating for the expected loss of utility for not staying a longer period of time in power. The shorter horizon will trigger higher levels of consumption and lower levels of capital accumulation in the short run, what might compromise long-term growth, thus imposing an inferior steady state outcome.

The above logic can be analytically translated in the following terms. Let $\Omega(t)$ be the probability of remaining in power after t periods; this is a decreasing probability, i.e., $\dot{\Omega}(t) < 0$. Variable $\Omega(t)$ approximates for the degree of instability. In this case, the intertemporal objective function of the planner becomes,

$$U(0) = \int_0^\infty \Omega(t)U[c(t)]e^{-\rho t} \tag{26}$$

The maximization of objective function (26) is subject to a trivial capital accumulation differential equation,

$$\dot{k}(t) = (1-s)f[k(t)] - c(t) - \delta k(t) \tag{27}$$

Parameter $s \in (0,1)$ represents the share of resources allocated to the effort of staying in power. Under this configuration of the Ramsey growth problem, the growth rate of consumption (derived from the optimal control problem) becomes,

$$\frac{\dot{c}(t)}{c(t)} = \theta^{-1}\left[(1-s)f'(k) - (\rho + \delta + \widetilde{\Omega})\right] \tag{28}$$

In equation (28), θ^{-1} represents the elasticity of intertemporal substitution and $\widetilde{\Omega} > 0$ is the time increasing rate of the probability of losing the place in office. Comparing this with the standard version of the model ($\widetilde{\Omega} = 0$ and $s = 0$), one verifies that there is a new adjusted rate of time preference, $\rho' = \frac{\rho+\widetilde{\Omega}}{1-s}$, which is larger than ρ (and that increases with the probability of losing power and with the extent of the resources diverted to attempt to remain in power).

Therefore, the steady state will be poorer (lower levels of consumption and capital) when the instability is stronger, i.e., the effort of the government to remain in office makes growth to fall. Hence, under the simple structure of the model, there is a negative correlation between political instability and economic growth. In practice, the intuition for this outcome is obvious: unstable executives tend to be more corrupt, to suffer from myopia in fiscal policy decisions, and to spend more and contract higher levels of debt.

7. … and Much More

The discussion thus far has highlighted a large collection of risks that have the potential to disturb the world economy in a more or less persistent way. There are many other substantial risks that economists have considered in their analyses of development and growth, and that were not yet mentioned. Some of them blend in naturally in growth models, as they have an eminently economic nature. This section proceeds with a short survey of the literature dealing with some of the risks that did not deserve a particularly special attention in previous sections.

Let us begin by recovering the central role that innovation and diffusion play in framing the pace of growth. Innovation and the adoption of technologies are intrinsically associated with firm dynamics and market concentration. Hence, a relevant risk for the creation and exchange of ideas comes from rigid market structures, where incumbent firms obstruct entry and concentrate power, thus imposing low business dynamism (Akcigit and Ates, 2021; Aghion *et al.*, 2023). The diffusion of ideas and the technological interdependence are particularly relevant at the international level (Buera and Oberfield, 2020); however, one must not forget the associated perils, namely the rising inter-state inequality, the undesired migratory movements, and the hardship for developing countries that emerges from unfair trading practices (Chattopadhyay, 2020; Lindner and Strulik, 2020; Afonso and Longras, 2022; Jin and Zhou, 2022; Parello, 2022).

Bubbles, understood as strong, persistent, and pervasive deviations of asset prices from their fundamental values, are typically interpreted as a short-term macro phenomenon associated with income variations over the business cycle. However, bubbles may have long-lasting effects and constitute an effective risk for growth (Guerron-Quintana *et al.*, 2023; Xavier, 2023). Regarding growth, two mechanisms that work in opposite directions need to be considered: the bubbly episodes *per se* tend, by definition, to incentivize investment and, thus, to speed up capital accumulation, with a positive effect on growth (realized bubbles provoke a crowding-in effect). On the contrary, the expectation of future bubbles triggers a crowding-out effect, because economic agents will anticipate higher future wealth and react by increasing current consumption in detriment of savings and investment.

In general, the architecture of the financial system and how public authorities choose to regulate it, is a clear potential source of risks for the world economy. Growth models that take into account the globalization of financial markets and its underlying risks tend to admit that the straightforward impact of financial liberalization over the creation of wealth is positive. However, with global finance it comes a rise in inequality that, as insistently mentioned in this essay, may compromise growth (Heimberger, 2022; Ho, 2022; Lee, 2023; Marrero and Rodriguez, 2023).

As a final remark, let us pose the following question: is the world in risk of running out of ideas? Ideas and knowledge are fundamental growth drivers; therefore, it is not absurd to ask whether one of the risks the world economy faces is an eventual unrecoverable loss of creativity. There are two reasons to argue that the growth of ideas is in danger. On the one hand, there is evidence pointing to the fact that the current process of accumulation of ideas is subject to diminishing marginal returns. As documented in Bloom *et al.* (2020), research productivity is declining sharply, even where and when the research effort and the number of researchers is increasing. On the other hand, Jones (2022*a*) emphasizes, as the main reason for the decline in the number of new ideas, the world's lower rates of fertility. In a future with negative rates of population growth, we might be heading to an empty planet result, where the stock of knowledge and the living standards may stagnate or decline.

In counterpoint to the above arguments, Jones (2022*b*) elaborates on two lines of thought. First, the empty planet outcome can be counteracted by a better allocation of human resources: inclusive societies can discover new talents (missing Einsteins) and stimulate the creativity of more people over longer periods of time (Agénor *et al.*, 2021; Celik, 2023; Kuhn and Prettner, 2023). The second answer for the exhaustion of ideas resides on the powers of artificial intelligence; artificial intelligence can assist (or, in the limit, replace) people in research.

8. Conclusion

In his seminal work on economic growth, Robert Lucas initiates the article's introduction with the following words (Lucas, 1988, p.3),

> "By the problem of economic development I mean simply the problem of accounting for the observed pattern, across countries and across time, in levels and rates of growth of per capita income. This may seem too narrow a definition, and perhaps it is, but thinking about income patterns will necessarily involve us in thinking about many other aspects of societies too (…)"

As bluntly stated in the citation, the study of economic growth is essentially about the characterization of income patterns. To understand how income evolves, one needs to know what lies behind its replication, namely which factors need to be accumulated and how should they be combined in order to generate progressively larger levels of output. This is growth theory, or at least the growth theory that we, economists and researchers, became used to know and accept.

The current paper argues in favor of a fundamental shift in growth theory. Although models explaining the role of product and process innovation, creative destruction, basic and applied research, and dissemination of ideas, continue to populate growth literature, there is a growing concern with the large collection of real-world episodes and events that threaten our way of life and our capacity to continuously raise living standards. Such concern is, today, very much present in growth theory, as evidenced in this survey. It is no exaggeration to assert that growth theory is evolving to a theory in which challenges and menaces are an indissociable part of the way in which we think about economic progress.

Most of the risks faced by national and local economies are global risks. This essentially signifies that they are somehow associated with common goods whose management requires international coordination (e.g., the environment, geopolitical stability, or digital networks). It also implies the need for a new look over growth: first, no country or region is an island, and no growth model should envision to explain growth without embracing a global perspective; second, free-riding is a relevant issue to take into consideration in a world of common threats and private interests; third, as mentioned throughout the article, global risks are intertwined and they cannot be compartmentalized if one truly seeks an overarching understanding of their implications for growth.

Accounting for risks and threats of every sort is today a pressing task growth theory must embrace. Along the text, it became clear that most of the relevant risks are already on the radar of growth theorists. However, an integrated theory of global risks and economic growth (a GREG theory) is still missing. Developing and deepening such theory is a vital task now in the hands of those who embraced the mission of developing further this discipline.

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