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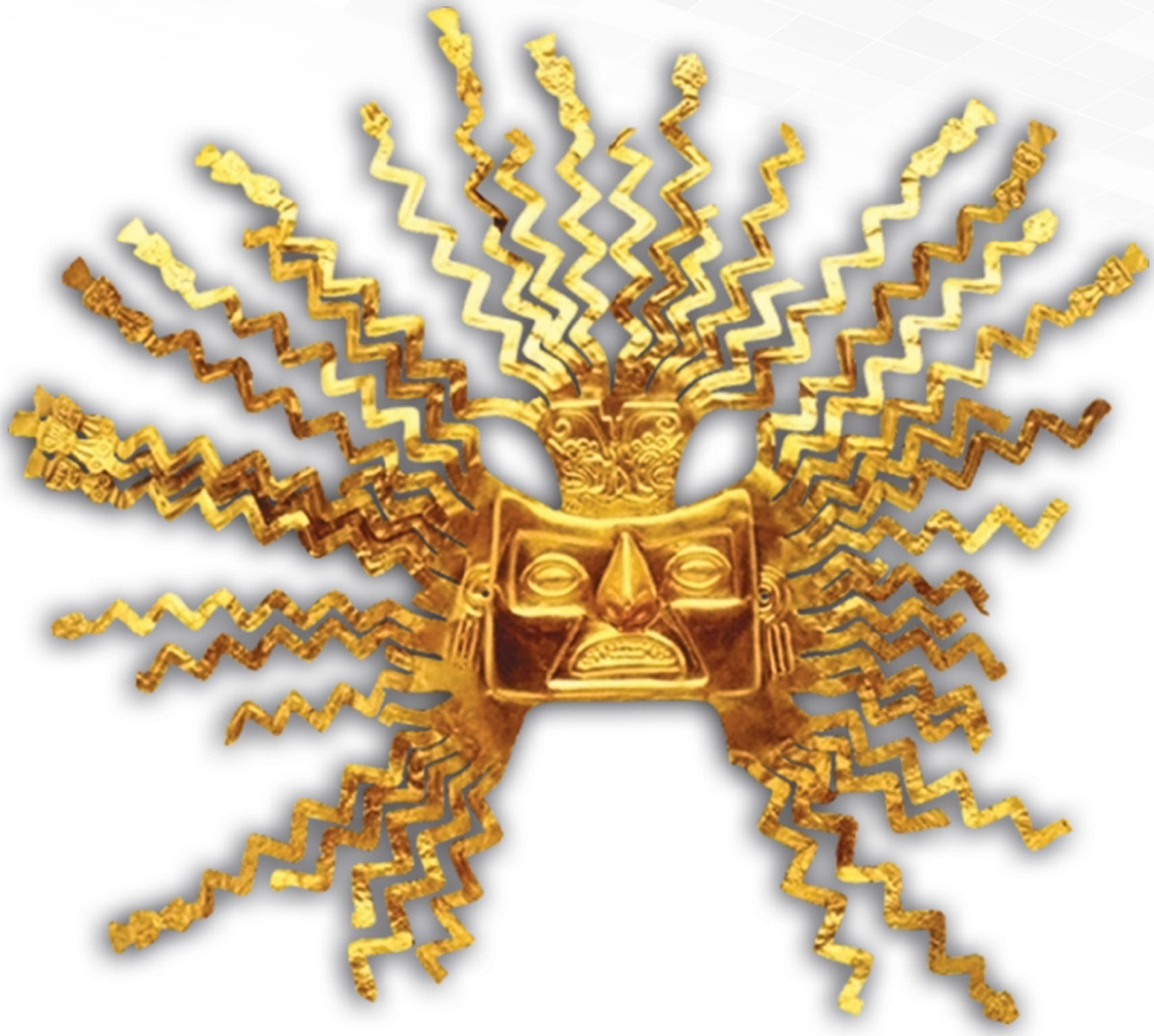

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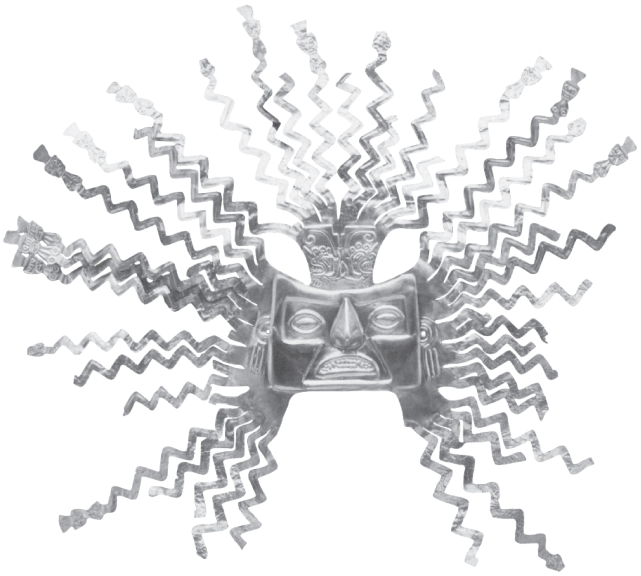

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Implicaciones macroeconómicas de la pandemia de COVID-19: un análisis de la producción académica temprana

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Resumen

Este artículo consiste en un estudio exhaustivo de literatura académica sobre Macroeconomía y COVID-19. Para este fin, se revisa treinta y cuatro artículos publicados por la Serie de Working Papers del National Bureau of Economic Research (NBER) de Estados Unidos durante los cuatro meses que siguieron al inicio de la pandemia (de mediados de marzo de 2020 hasta mediados de julio de 2020), bajo la categoría de "Efectos Macroeconómicos Agregados". El presente análisis está principalmente enfocado en comprender la evolución conceptual que ha sido alimentada por la conciliación entre macroeconomía y epidemiología, y cómo ciertas herramientas del análisis macroeconómico contemporáneo han permitido construir una mejor comprensión del proceso epidemiológico y sus efectos sobre resultados macroeconómicos agregados. También se analiza algunas de las discusiones sobre políticas de contención óptima más importantes que han sido obtenidas de dicha evolución, en coherencia con las características metodológicas particulares incluidas por cada autor en su modelo, así como los hallazgos más relevantes obtenidos.

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Macroeconomic Implications of the COVID-19 Pandemic: An Analysis of Early Academic Production

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Abstract

This paper consists of a comprehensive literature survey on Macroeconomics and COVID-19. For this, I revise thirty-four papers published by the Working Paper Series of the National Bureau of Economic Research (NBER) of the United States during the four months that followed the pandemic's outbreak (from mid-March to mid-July 2020), under the Aggregate Macroeconomic Effects category. The present analysis is primarily focused on understanding the conceptual evolution that has been driven by the conciliation between macroeconomics and epidemiology, and how certain tools of contemporary macroeconomic analysis have helped at better understanding the epidemiological process and its effects over aggregate macroeconomic outcomes. I also analyze some of the most important optimal containment policy discussions that have been drawn from such evolution, in coherence with the particular methodological characteristics that each researcher included in their model, as well as the most relevant findings obtained.

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1. INTRODUCTION

The unfold of the COVID-19 pandemic has brought the worst economic crisis since the times of The Great Depression, more than 90 years ago (Gopinath, 2020). Ever since this disease reached *pandemic* status, the entire scientific community turned its attention into what became an evident threat for humanity. In the case of the economics discipline, these efforts have brought an extensive interest into trying to understand the several different faces of the crisis and identify where the consequences are prone to be seen, both at a micro and at a macro level; from the households', the firms', or the governments' perspective, and either in the short or the long run.

Noteworthy, there has been an intensive use of elements from epidemiology in a way that, combined with modern tools of macroeconomic theory, has provided important results defying the previous standard in epidemiological modelling. In this context, this paper responds the question of: What kind of conceptual evolution in the way a pandemic is understood has been provided by the combination of macroeconomic with epidemiological models, and what are some relevant results, both in economic and epidemiological terms, that may be provided by such a fusion?

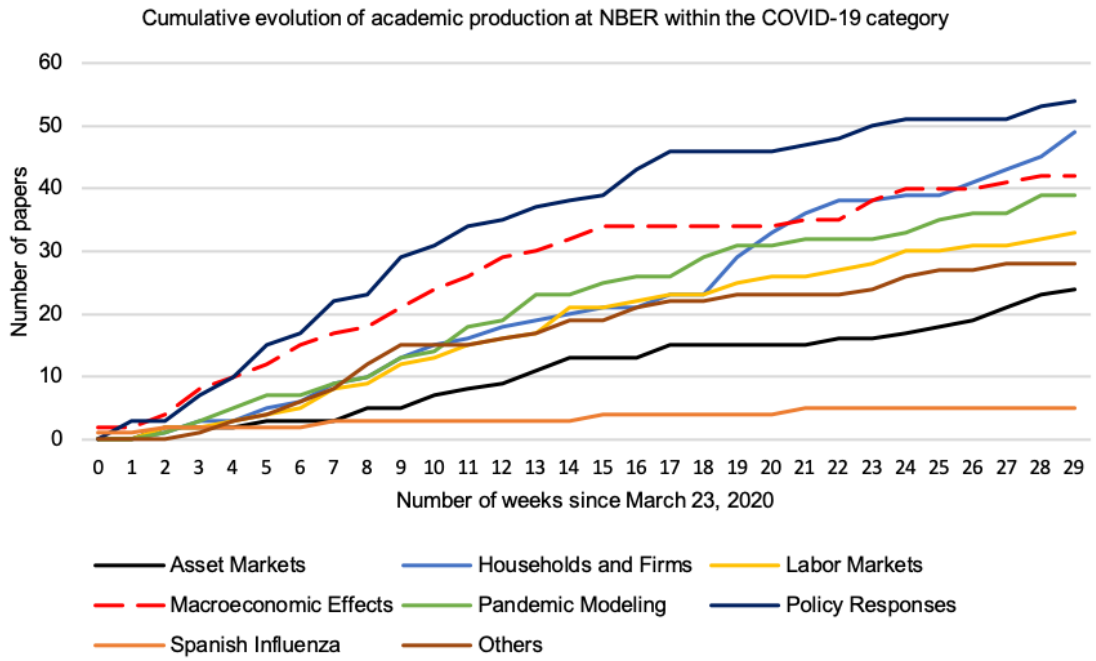
To answer the question posed, in this paper I perform a critical literature review focused on the main theoretical findings that early academic production brought into discussion on Macroeconomics and COVID-19. The totality of the referenced material has been taken from the National Bureau of Economic Research (NBER) Working Paper Series, published on a weekly basis, contained within the COVID-19 catalog. The published material was taken from series ranging from the week of March 23rd to the week of July 13th, for a total of sixteen weeks and 185 papers. The classification applied by NBER includes eight broad topics related to COVID-19. This review exclusively analyzes the production categorized under the "Macroeconomic Effects" label within the indicated period, for a total of 34 academic papers. This selection has been made considering the NBER catalog as a consistent and powerful sample of high quality, periodically published, economic research.

The academic production of COVID-related papers within the NBER series started on the third week of March 2020 and until October 12th, 2020, it followed an evolution as the one seen in Figure 1. The most investigated COVID-related topics included at NBER as of October 12th, 2020, were the *Policy Responses* to the pandemic, the effects of the pandemic for *Households and Firms* and the *Aggregate Macroeconomic Effects*. Once again, the focus of this paper is to analyze the production within the latter category. It is important to state, considering the fact that chapter 3 extensively analyzes the policy recommendations derived from the material involved, that the *Policy Responses* category has not been analyzed since the aim of this research is to synthesize the material that has specifically treated the evolution of macroeconomic estimations and modelling and, therefore, the policy recommendations that have been drawn from this particular approach.

The justification of this election relies on my belief that macroeconomic theory provides an integral perspective for the understanding of economic and social phenomena from an aggregate approach. This leads to concise forms of estimating the

diverse ways on which the pandemic and the consequences of its propagation affect aggregate social welfare, as represented by the macroeconomy. Complementary, I seek to identify some research gaps in this academic literature and propose potential paths for future research.

Figure 1.
Cumulative evolution of the NBER publications within the COVID-19 category until October 12th, 2020 (by topic)



Source: Elaborated by the author based on information available at NBER (NBER, 2020).

The paper is organized as follows: section 2 provides a synthesized generalization of the theoretical models applied in many of the papers studied in the form of a workhorse model. Section 3 contains an analysis of the main results drawn by the mentioned papers, while providing an insight into the optimal containment policy recommendations derived from such results from both a macroeconomic and epidemiological basis. Finally, section 4 provides some concluding remarks, including the identification of research gaps and important results drawn during the period of study, specially concerning the optimal policy dilemma.

2. A WORKHORSE MODEL

In this section, I provide a general idea of the common underlying theoretical structure implied by an important share of the referenced material. Most of the theoretical

works in the "Macroeconomic Effects" category consist of variations to the classical SIR Epidemiological Model proposed by Kermack and McKendrick (1927) incorporated within a typical Dynamic Stochastic General Equilibrium (DSGE) setting. The model specifically presented here has been inspired by the seminal work within the mentioned series (Eichenbaum, Rebelo, & Trabandt, The Macroeconomics of Epidemics, 2020) the models subsequently derived from such approach and presented in the literature cited at this paper.

While incorporating DSGE modelling within an SIR framework in coherence with the set of papers cited, the model I propose, unlike most of such papers, presents the epidemiological dynamic rates as constant through time and no explicit endogenous containment choice is drawn from the household's decision. I have made this with the aim of guaranteeing clarity in the exposition. To give a general idea of the mechanisms in place, consider a simple version of the SIR model in which an infection propagates over a population whose size remains constant through time. I consider only three compartments in this model, so each individual can be in one of three possible states: susceptible, infected, or recovered. Formally, we have that $S_t + I_t + R_t = N$, and:

$$S_{t+1} = \psi(S_t, I_t, \beta) \tag{1}$$

$$I_{t+1} = \iota(I_t, S_t, \beta, \gamma) \tag{2}$$

$$R_{t+1} = \rho(R_t, I_t, \gamma) \tag{3}$$

This system of dynamic equations is drawn considering an economy composed by J bachelor households which, in the spirit of Aiyagari (1994), may hold diverse forms of heterogeneity. Notice that $\beta, \gamma \in [0, 1]$ are the infection and recovery rates, respectively, for the classic SIR model.

The decentralized macroeconomic model involves a dynamic optimization problem for the J bachelor households in the economy, perceiving utility from a single numeraire good defined as *consumption*, and from *leisure* (defined as $l_t = 1 - n_t$, such that the agent counts with one unit of time at each period t and n_t is defined as *labor*). The household solves one of the optimization problems denoted in equations (4), (5), and (6) below, conditional on belonging to one of the epidemiological states $m = \{s, i, r\}$. Therefore, conditional on being at a susceptible state (s), the household can consume and work but faces the probability β of becoming infected. Thus, a susceptible household solves (4). (Please notice the subscript $j \in J$ has been deliberately omitted in order to avoid abusing on notation):

$$\begin{aligned} V_t(a_t, \zeta_t, \ldots, s) = \max_{c_t, l_t, a_{t+1}} u(c_t, l_t) + \\ \delta \mathbb{E}_t[\beta V_{t+1}(a_{t+1}, \zeta_t, \ldots, i) + \ldots + \beta V_{t+1}(a_{t+1}, \zeta_t, \ldots, s)], \\ s.t. \\ c_t + a_{t+1} = \zeta_t (1 - l_t) w_t + (1 + r_t) a_t \end{aligned} \tag{4}$$

where $\delta \in [0,1]$ is the discount factor and ζ_t represents a pandemic-related exogenous shock in the households' labor income that is independent to the agents' epidemiological state.

Afterwards, the optimal control problem of each agent j, conditional on her epidemiological state, would lead to a system of difference equations relating consumption, assets, and labor.

Now, suppose a susceptible agent becomes infected. Then, as I have assumed the infected are not able to work, utility is defined only over consumption and that agent is forced to live off her savings. The only source of uncertainty for this household is how long it would take to recover. In the case of being infected, the agent faces the probability γ of being removed from the infected group (i.e., by recovering). Formally, the infected agent solves:

$$V_t(a_t, \ldots, i) = \max_{c_t, a_{t+1}} u(c_t) + \delta[\gamma V_{t+1}(a_{t+1}, \ldots, r) + (1-\gamma)V_{t+1}(a_{t+1}, \ldots, i)]$$
$$s.t. \qquad (5)$$
$$c_t + a_{t+1} = (1 + r_t)a_t$$

The recovered population is assumed as belonging to the final possible stage (I assume there is no chance for reinfection) and so it does not face any probability of transition on the epidemiological state m (i.e., there is no epidemiological rate in the household's problem). Notice that such an agent returns to the working population. By this way, the problem faced by the recovered is:

$$V_t(a_t, \zeta_t, \ldots, r) = \max_{c_t, l_t, a_{t+1}} u(c_t, l_t) + \delta \mathbb{E}_t[V_{t+1}(a_{t+1}, \zeta_t, \ldots, r)]$$
$$s.t. \qquad (6)$$
$$c_t + a_{t+1} = \zeta_t(1 - l_t)w_t + (1 + r_t)a_t$$

In this case, the agent faces no uncertainty with respect to possible changes regarding her epidemiological status. A solution to each of these problems, as previously stated for the susceptible, would lead to a system of equations portraying the dynamic structure of the agents' choice. Generally, straightforward analytical solutions will not be feasible in this environment.

On the production side of the economy, I assume that there is a representative firm that sells its output and hires inputs in competitive markets to maximize its profits. Formally, the firm solves:

$$\max_{k_t, n_t} \prod(n_t, k_t, w_t, r_t) \qquad (7)$$

This problem leads to the demand for capital and labor at their correspondent market-determined prices: $k_t^*(r_t, w_t)$ and $n_t^*(w_t, r_t)$.

The general equilibrium in this family of models is included in Definition 1.1:

Definition 1.1.: General Equilibrium*: A general equilibrium occurs when, at every period* t*, conditions (4), (5), and (6) are met (households maximize their utility given their budget constraints), equation (7) holds (firms maximize their profits), and markets clear, that is, there exists a group of successions* $\{c_t, l_t, k_t\}_{t=0}^{\infty}$ *defined, respectively, as the optimal paths for the economy's aggregate consumption, labor, and capital; and of successions* $\{w_t, r_t\}_{t=0}^{\infty}$ *defined as the market prices at each period* t*.*

Dislike the model presented here, most of the papers in the literature implement an explicit containment plan for each household, affecting its consumption and labor activities as a way of avoiding getting infected and moving from state s to i. This plan may often be modelled as an endogenous choice of the household that eventually affects the infection rate that each particular household may face. However, such modelling has not being considered within this paper's approach in order to avoid unnecessary confusions.

An endogenous containment plan implies that the effective degree of exposure carried by the agent ultimately depends on individual choice. In theory, any rational and perfectly informed susceptible agent would choose a containment plan according to a series of factors associated with personal economic valuation of the trade-off implied at each moment t. For example, in a low exposure environment, the agent can minimize her risk of getting infected but faces the cost of undertaking other valuable activities that enable labor and consumption. This may translate into a function reflecting an optimal containment plan at each moment t given each household's preferences, that in the aggregate implicitly affects the general equilibrium. Different possible equilibria, both at the individual and the central planner's level may not actually be socially optimal. The optimal containment choice is rarely specified explicitly, but rather represents an abstraction about the way in which each agent faces this hazard.

Another common feature of the literature featuring models under a similar framework include extensions to the standard SIR model to account for other possible epidemiological states that a given agent may be in at some point (e.g., deceased state). Some further extensions to this general model (as have been applied to some of the referenced material) would be to consider firm heterogeneity and a strategic equilibrium being drawn by the agents' uncertainty. Yet another interesting generalization would be to try and draw on the network effects implied by the relations among the various different agents within the economy and the potential outcomes of such interdependent interactions (i.e., Akbarpour (2020)).

3. A LITERATURE SURVEY OF MACROECONOMICS AND COVID-19

This section provides an analysis of the scientific production published at the NBER Working Paper Series on the category of *Aggregate Macroeconomic Effects* from the group of papers related to COVID-19. This compilation includes material published four months after the pandemic's outbreak in the U.S. The start of this period matches what I have considered as the seminal publication within this group, Eichenbaum, Rebelo, and Trabandt's *The Macroeconomics of Epidemics* (2020).

Specifically, I analyze the main theoretical results provided by these various research papers in the light of the different methodologies that have been applied. Furthermore, I consider optimal containment policy recommendations derived from this research to be an extremely valuable element, as they are one of the most important links through which macroeconomics has been tied to epidemiology. Such recommendations emerge from theoretical structures that understand the epidemiological process in new, and different ways. A set of recommendations taken from estimations based on purely exogenous epidemiological models, as has been the case for policymaking in certain scenarios, will not be the same as the ones provided by models that consider factors from macroeconomic theory, such as endogenous choice, heterogeneous agents, information constraints, among others.

I start detailing the set of papers that I consider to be seminal works within this series, and then continue with the rest of the material, ordered according to their most general thematic characteristics.

3.1. Seminal Works

An early example of the treatment of SIR modeling at an economic scheme was brought via Atkeson's (2020) presentation of an exogenous SIR process, which aimed at serving as a brief introductory guide for economists to the standard epidemiological model and its potential extensions. A similar perspective was taken by Pindyck (2020), who analyzed the broad insights of a simple SIRD model in terms of general, potential policy design and welfare implications. Both early approaches, however, relied on the implicit assumption that economic choices and the pandemic's containment decisions where rather independent from each other.

The seminal treatment of the epidemiological process within a macroeconomic model (that is, within a single theoretical structure) was presented by *The Macroeconomics of Epidemics* (Eichenbaum, Rebelo, & Trabandt, The Macroeconomics of Epidemics, 2020) in early March 2020. This publication set the precedent for endogenous modelling of the pandemic's evolution within a macroeconomic environment. It did so by considering the households' optimal choice of consumption and labor simultaneously with the containment measures in a way that both kind of variables (economic and epidemiological) were interdependent and controlling for the probability of treatment and vaccine development, as well as medical preparedness. This

allowed the provision of multiple extensions to the basic problem where labor and consumption decisions of the different epidemiological agents played key roles in the economy. Under their benchmark formulation, the authors estimated alternative possible effects considering the potential of different policies, ranging from a 7 % (with no containment measures) to a 22 % contraction (under optimal containment) of consumption in the first year. Such an optimal containment policy scenario implies saving about half a million lives (p. 5).

In the next few months that followed, Eichenbaum, Rebelo, and Trabandt provided a bi-dimensional extension to their basic model in order to explain the positive comovement observed between consumption and investment during the pandemic's crisis (Epidemics in the Neoclassical and New Keynesian Models, 2020). In the first case, they extended the standard neoclassical model previously presented as their seminal work in order to account for monopolistic structures. In this case, they found that recessive comovement among consumption and investment is able to be explained within the neoclassical framework only when accounting for such monopolistic competition. This is because of the differential trade-off that both labor and consumption activities that are defined as risky in terms of contagion exposure, have over the recessive outcomes when accounting for the real wage contraction implied by monopolies as compared to perfect competition: "A lower wage means that the compensation to a worker for being exposed to the virus is lower" (p. 2). This is argued to be causal mechanism that leads to a sharper decline in labor supply compared to the decline in consumption, that subsequently induces the attained comovement between consumption and investment. This happens in opposition to the seminal model, where the contraction in consumption outweighed the labor supply shift, On the other hand, the New Keynesian model extension with sticky prices, while also explaining the comovement, induces a marginally deeper recession explained by the model's tendency to "exacerbate negative demand shifts" while minimizing the effects of negative shifts over supply. The authors remark on the need to keep on accounting for other factors, such as financial frictions, in order to further improve the SIR-Macro model.

3.2. Centralized vs. Decentralized Containment Policies, Market Imperfectness, and the Role of Information

A frequently cited concern among diverse authors in the literature is the efficiency difference that a centralized containment policy poses with respect to a decentralized strategy, in terms of the externalities implied by imperfect information and differential levels of subjective life-valuation and risk aversion. Álvarez, Argente, and Lippi (2020) estimate a centralized containment solution in an endogenous SIR environment. In this model, the central planner seeks to simultaneously minimize fatalities and the aggregate economic costs associated with achieving that first goal. In their baseline simulation, they estimate an 8 % yearly GDP contraction under lockdown policies. Interestingly, fixing a fatality rate at a 1 % (theoretically never

letting a healthcare system collapse) leads to an optimal policy that converges to zero lockdown.

Guerrieri, Lorenzoni, Straub, and Werning (2020) consider the possibility of "Keynesian supply shocks" (that is, aggregate demand shortages caused by negative supply shocks), under the context of imperfect markets and multiple sectors. They show that the effect induced by the aggregate supply shock over labor could be so large that it may ultimately generate an aggregate demand contraction that comparatively overpasses the magnitude of the initial supply shock. By doing so, they neglect the efficacy of expansionary fiscal policy amid the pandemic, and rather aim at a reduction in payroll taxes. Furthermore, the authors claim the need for monetary mechanisms focused on lowering debt obligations for firms, while strengthening certain social insurance mechanisms. Complementary, they remark on an optimal policy consisting of "closing down contact-intense sectors and insurance payments to affected workers" (p. 5).

Bethune and Korinek (2020) estimate the aggregate social cost posed by the agents not internalizing the effect of their behavior amid the pandemic. They find that the marginal valuation agents hold regarding an infection is just about a third of the actual social cost associated to it. This leads them to study the different outcomes that a real economy with imperfect information and the limited role of a central planner may ultimately suffer with respect to a theoretical state where policy designs may be rigorously treated among different population groups. They consider imperfect and incomplete information at the policymaking level to study the contrast of its associated solution with a decentralized scheme, implying that the pandemic is impossible to fully overcome until herd immunity is achieved.

Chang and Velasco (2020) face a similar problem given certain information constraints among differentiated actors from the perspective of Pareto optimality. They argue that an economic transfers policy should not only be an incentive for individuals to contribute to the virus' containment, but it should also make it feasible for agents to expect that other agents will follow the optimal policy's measures. This argument, while providing evidence in support for expansionary policies at the peak of the epidemic, may imply that an optimal policy would actually reduce the aggregate fiscal cost associated to the containment.

They argue, as well, that a decentralized containment strategy would lead to a suboptimal solution (due to the externalities each agent creates over others via their decisions and their choices' incidence over the pandemic's transmission). Actually, there may be a suboptimal level of risk-aversion behavior under which the extensive existence of locked-down workers may be excessive, causing that "having one more person go to work could in fact reduce the share of infected people in the workforce, and therefore cut back on the risk of infection" (Chang & Velasco, p. 2). These authors included in their discussion what eventually became a central debate topic among researchers: first, if whether there is an effective (linear) trade-off between health and economic outcomes, and second, if optimal testing policies should be massive or not. Chang and Velasco imply a "no" response to the first question but a "yes" to

the latter. Furthermore, this approach remarks the fundamental role that information imperfection plays in the aggregate, even during processes of contagion.

3.3. Further Forms of Agents' Heterogeneity, Network Effects, and Targeted Policies.

Further applications of models based on heterogeneous agents provide important insights into diverse factors such as the labor market dynamics amid the pandemic. Gregory, Menzio, and Wiczer (2020) consider diverse worker types whose heterogeneity is determined ex-ante according to their productivity level and labor stability conditions. They subsequently simulate the pandemic shock as faced by the workers, given the implied costs to the firm. Using U.S. data for providing a long-run estimation, they argue that recessive consequences via unemployment are expected to follow an "L-shape". These results imply up to 35 % of workers would permanently terminate their contractual relationship with workers in the low productivity range taking some years to re-establish stable labor contracts (simulated with a 3-month lockdown which marginally decreases in time thereafter).

Another methodological extension to the modeling of the epidemiological process and its consequences in a macroeconomic context consists of the use of models with an implied network scheme. Such applications have provided yet more results that are important to consider.

Baqaee and Farhi (2020) base their research on a disaggregated macro model that allows for diverse factors and economic sectors, as well as input-output interdependent relationships in elasticities of substitution and downward nominal wage rigidities. They simulate a network effect that implies the negative shocks get dispersed across sectors in productive relations of dependence. Negative shocks (both at the side of demand and of supply) are simulated in order to estimate effects over output, inflation, and unemployment, and to propose subsequent policy recommendations. Negative supply shocks are found to be stagflationary and negative intertemporal demand shocks are found to be deflationary.

By calibrating the model to the U.S. data, it is found that both demand and supply shocks are simultaneously needed to explain the real phenomenon, by jointly creating an impact of inter-dependence among sectors. They also study differences within labor markets among those which are supply-constrained ("tight") and those demand-constrained ("slack"). Both market types are later modelled as endogenously affecting the scope of the shock via credit constraints (and acting as negative multipliers). In this way, the authors assert the fact that regular, untargeted economic policy amid the pandemic would be considerably more inefficient than at regular times (Baqaee & Farhi, Supply and Demand in Disaggregated Keynesian Economies with an Application to the COVID-19 crisis). Furthermore, they expand this modelling approach (Baqaee & Farhi, Nonlinear Production Networks with an Application to the COVID-19 Crisis, 2020) in order to account for the effect that heterogeneity plays over recessive supply outcomes when consumption and production phenomena are explained as structured, non-linear, networks of systematic co-dependence.

When considering these conditions, the shocks amplification range from between a 10 % to 100 % (as attributed to nonlinearities) of the initial shock, depending on the calibration settings.

Akbarpour, et al. (2020) build a network model based on agents who differ by age, industry, and location, and whose interaction mechanisms boil down to contact matrices built for specific spatiotemporal characteristics from where a sub-graph of counterfactuals is drawn for each alternative containment policy. The data is taken from various, real-activity sources and considered within an expansion to the standard epidemiological model designed to control for exposed and deceased individuals, as well as some subsets to the infected and recovered groups (namely, a "θ – SEIIIRRD Model"). Their research subsequently rests on finding dynamic successions of optimal containment policies given certain situations, as based on what real data can tell from an expanded and endogenous version of the epidemiological model. They find that geographical locations that were hit early and strongly by the pandemic are less likely to suffer a strong contagion growth after measures are relaxed (as estimated in June 2020). Concerning optimal policy, they argue for measures such as alternated schedules at work and school as ways of, not only reducing cumulative deaths (40 % in Chicago and 17 % in New York) but also reducing expected unemployment against other alternatives.

In this way, Akbarpour, et al. (2020) remark once again a crucial element common to many papers: the need for targeted containment policies. This is, certainly, something that became quantitatively approachable under the novel framework provided by macroeconomics, and particularly, the seminal paper within this research. In this manner, Baqaee, Farhi, Mina, and Stock (Reopening Scenarios, 2020), expanded the standard SIR model to consider the exposed, the quarantined and those that die (SEIQRD model) and classify each group as a vector containing five different age groups that among the population may be within a certain epidemiological category at a given time. They combine this with a sectorial economics model and build a GDP-to-Risk index by sector in order to measure the marginal impact of each additional worker (for a certain sector) on GDP.

The authors subsequently study optimal policies concerning back-to-work policies and Nonpharmaceutical Interventions (NPIs) (for example, the allowance for regular consumption activities). They find three main results. First, that age-based, back-to-work policies have little impact over death reduction but rather significantly impact economic recovery. Second, that a deregularized "back to normal" policy potentially leads to a strong resurgence in cases. Third, that strong testing, tracing, and quarantine policies are efficient at leading economic recovery (conditional on the previous recommendations holding). They reinforce that "smart" reopening plans (mostly age-based targeted policies) by the labor side, "can lead to modest but worthwhile improvements in economic and/or public health metrics" (Baqaee, Farhi, Mina, & Stock, p. 3).

Rampini (2020) worked on other variations to the workhorse model. He studied economic and containment outcomes by expanding the diversity of the groups' characteristics, namely by age groups and workforce characteristics. Sequential lifting

is promoted in coherence with age differences. As the young get back to work (to avoid a more severe economic contraction), the healthcare system is alleviated, being allowed to develop more capacity and potential treatments by the time the elder are slowly allowed back to normal. Remarkably, mortality is reduced because by the time that the elder are allowed back to work, the level of contagion is expected to have been significantly reduced. Rampini's baseline specification for containment policy, implies mortality is reduced by 40 %, while peak load hospitalizations, by 75 %, and critical care demand by approximately 80 %. Noteworthy, "herd immunity is achieved with a lower fraction of the population ever infected" (Rampini, p. 3).

3.4. Welfare Implications, a Controversial Trade-Off, and Other Extensions.

As discussed with externalities, a crucial factor in this context is the diversity of preferences and relative trade-offs faced by different agents when contrasting economic activities with certain degrees of containment. This is what, at the policy level, Glover, Heathcote, Krueger, and Ríos-Rull (2020) call "distributional effects" of the welfare compensation mechanisms to be considered. Noteworthy, they consider heterogeneity, besides by age, in terms of economic sectors (luxury and non-luxury) and by state of health. The central planner's problem is to optimally choose both the fraction of economic activity in the luxury sector that is to be shut down, and the level of income that is to be redistributed from those who are enabled to work to those who are not. Due to the cost associated to redistribution, there is a trade-off between distributive and mitigation costs. The optimal policy varies depending on the age group of the population at whom the planner gives its relative priority. Preferences for extensive mitigation policies among distributional groups are deepened proportionally to the certainty of a vaccine being available in the near future.

Life-valuation mechanisms are another recurrent concern among some researchers. As an example, Hall, Jones, and Klenow (2020) propose a life valuation model integrated into the household problem so that they can estimate a certain level of yearly consumption that a utilitarian agent would give up avoiding dying by COVID-19. The life valuation metric applied is weighted by life expectancy and the pandemic's death rate so that it portrays the "price of annual consumption". Considering the preferences' properties, it is found that such sacrifice would consist of a 41 % decrease in yearly consumption for a conservative estimation of the death rate, and of 28 % for an untightened one.

Until a certain moment, most authors (as in the seminal paper) had implied an evident trade-off between the pandemic's containment efforts and the economy (excluding Chang and Velasco). However, the results of other authors seriously put into doubt this intuition and the nature of such relation. Aum, Lee, and Shin (2020) question this dichotomy from the perspective of the policymaker's various tools as simulated for both South Korea and the U.K. It is found that workers in low-skilled jobs, despite suffering more from the pandemic shock, simultaneously benefit more from "virus visas" awarded for recovered people to get back to work. This implies an optimal testing policy should prioritize low-skill workers. A fundamental implication

from this research is that lockdown measures that are lifted too soon lead to a certain threshold of infection at which further countermeasures may lose potential efficacy at tackling the pandemic. Furthermore, certain containment policies regarded as "too mild" applied to minimize the economic crisis, may actually turn out to produce worse recessive effects than in a scenario with initial tighter policies (as suggested by the simulations applied for the U.K. case).

A similar finding is provided by Acemoglu, Chernozhukov, Werning, and Whinston (2020) when considering differences among agents in terms of infection, hospitalization, and fatality rates (via age groups). They establish important differences among standard uniform containment policies versus policies that differentially target individuals by risk groups, while providing a specific trade-off calculation for the U.S. by stating, for example, that a mortality rate target below 0.2 % for the adult population will necessarily demand a full or partial lockdown for at least a year and a half, leading to a GDP yearly contraction of a 38 % (a safety-focused objective). If the goal were economic (keeping a yearly contraction at less than a 10 %) the consequences would imply a mortality rate over 1 % (an economy-focused policy). With these results, they make the case once again for targeted policy implementation.

Furthermore, Acemoglu et al (2020) find that such policies follow a V-shaped trade-off relationship among output loss and deaths. This implies that in a scenario with poor spread control, not only that deaths rise, but there is an important output loss as well. An important conclusion is that "the trade-off between lives lost and economic damages improves substantially with targeted policies" (Acemoglu, Chernozhukov, Werning, & Whinston, p. 45). These findings provide yet another critical perspective to the trade-off debate and proves that evaluating policies explicitly derived from a differential focus, may significantly improve the efficiency of tackling the pandemic.

Besides household heterogeneity and the differences posed by simple epidemiological groups, some further modeling extensions involve considering different groups within each epidemiological category. As an example, Chari, Kirpalani, and Phelan (2020) consider subgroups within the infected individual's category and determine the virus' transmission via an exogenous activity-specific probability determined by the differential basis of certain economic activities (production and consumption). Testing technology is applied based on an imperfect signal about the state of the infected, and optimal containment policy is estimated by specifically targeting different population sets, leading to a comparison of the welfare gains within such approach. The welfare gains estimated from optimal containment policies will vary upon the acuteness of the signals the central planner receives, the actual capacity of testing, and the effective rate of isolation among individuals given the targeted policy.

As included in Eichenbaum, Rebelo, and Trabandt's second approach (2020), factors considered by some authors are the comparative consequences posed by the pandemic in the context of a New Keynesian environment (so that other theoretical elements can be considered). Auerbach, Gorodnichenko, and Murphy (2020) consider the dynamic heterogeneity structure of both households and firms (in terms of income

and costs' structure, respectively) from a "negligible-marginal-cost framework" (p. 1) (NMC) aiming at comparatively addressing the effects of fiscal policy against standard New Keynesian approaches. Under the framework drawn, the authors find that inequality harms the recovery effects, that is, the lower the share of wealth that the bottom percentiles of the income distribution possess, the less marginally efficient the households' transfers are. Furthermore, they find that more inequality may contract output in both present and future states of the economy. Also, the recessive (restriction) multiplier of firm exits in this context would be significantly large and proportional to the firms' capital cost rigidity and profitability.

3.5. Financial, Cross-Country, and International Frameworks

There has been some focus on the role of international financial institutions for achieving economic stability. Céspedes, Chang, and Velasco (2020) develop a minimalist macroeconomic model from the perspective of credit constraints. The situation is modelled, first, as a productivity crisis dependent on a certain threshold determined by labor allowances, and second, as an imperfection in credit markets where lenders are uncertain about repayment. Both factors interact in what the authors quote as an "unemployment and asset price deflation doom loop" (p. 2) which works as a negative multiplier, upon which they justify their call for unconventional economic policy. For instance, they propose mechanisms such as "helicopter drops" of liquid assets, wage subsidies, loan guarantees, and equity injections to match the uncertainty among lenders and the firms' demand for credit. The authors remark upon the importance of government control in order to generate adequate incentives, as well as the need for multilateral institutions to provide suitable conditions among developing nations.

A similar effect is implied by Arellano, Bai, and Mihalache (2020) when studying the epidemiological process within the framework of the sovereign debt situation in emerging markets. The point is that an initial default risk increases the social cost of the containment measures by limiting fiscal capacity when facing the crisis. Despite not explicitly modelling it, the authors consider the agents' externalities, via a central planner that considers agents not internalizing their behavior leading to sovereign debt crises. They find that while some policies aimed at containing the pandemic's effects (mostly transfers) may improve certain aggregate outcomes, they could simultaneously fuel a sovereign debt crisis, potentially leading to further constraints on the fiscal capacity needed to face the health hazard, subsequently demanding an easing of the containment measures, further deepening the crisis. Estimations for emerging markets imply an optimal lockdown policy that would reduce the total death toll by half but imply an output contraction on present value of 19 % and a crisis of debt lasting up to 43 months with defaults (p. 2). The authors insist on the importance of sovereign debt relief programs aimed at providing stability to these economies, finding a program costing a 10 % of output to the lender, would mean a welfare gain of 14 % of output to the borrower nation involved (Arellano, Bai, & Mihalache, p. 2).

The concern about the differential effects faced by emerging economies arises again in Alfaro, Becerra, and Eslava's work (2020) when considering the labor market consequences of the pandemic in the context of an economy full of labor informality and small-sized firms as in Colombia (a proxy for many countries in the Latin American region) and comparatively contrasting its implications to the U.S. scenario. They collect empirical data related to employment and the size of firms across industries and construct a model that estimates the mechanisms of recovery potentially available for such economic agents given their heterogeneous characteristics. They find that a wide proportion of jobs, because they belong to the informal sector or to small-sized firms, are more at risk of failing given the pandemic shock, but they are paradoxically more likely to quickly recuperate because of the lower costs associated with those firms (an implication quite aligned to the findings by Auerbach, et al.). It is found that up to 56 % of jobs and 43 % of "aggregate value added" face a strong risk as the series of shocks associated with the pandemic hit (corresponding, respectively, to a 33 % and a 30 % fall under the case of Colombian data fitted to a U.S.-like job market structure). As the situation improves, the Colombian case registers just 20 % of jobs at risk compared to the baseline amid an informality-based recovery, "while under the U.S. distribution (…) risk would remain at 40 % in the initial recovery phase" (p. 2) (keeping labor market rigidities as in Colombia).

Alon, Kim, Lagakos, and VanVuren (2020) further expand the workhorse model by considering an economy with the average characteristics of those nations at the top quartile of world income distribution and those that fall in the bottom quartile. They consider structural differences, modeling the broad fiscal constraints, labor informality, lower median age, and healthcare system's deficiencies among developing nations. By making the distinctions between the two country groups, they find differences in the way policies work, and subsequently, how the crisis should be optimally managed at each specific scenario. They find that generalized containment measures are much less efficient in developing nations than in developed nations and argue for a lockdown policy focused on the older population in developing countries (p. 32). These cross-country differences are mostly explained, among other factors, by the age structure of each group of nations, as well as by the labor markets conditions. Thus, these findings highlight the importance, once again, and in this particular case, among developing nations, of carrying out age-targeted policies (especially lockdown and transfers measures).

Another approach to understanding the impact of credit constrains implied by the crisis is modeled by Sims and Wu (2020) via the alternatives faced by the Federal Reserve of the U.S. of allocating capital through quantitative easing policies directed at firms in the financial markets or doing so via non-financial firms in the real economy. They model financial firms as leverage-constrained (binding during both the 2007-2009 Great Recession and the COVID-19 recession) and conventional firms as facing liquidity constraints generated by the consumption and labor crisis (only binding in the COVID case). The pandemic is modeled as a series of shocks to the firm's activities. They find that during this particular crisis, the reactivation

measures fueled via the support to non-financial institutions are considerably more efficient compared to a "Wall Street QE" and ultimately led to an aggregate demand expansion. The logic behind this is that a policy aimed at financial firms, despite loosening the constraint and allowing for more debt transactions, does not tackle the restrictions of agents raised by the cash flow constraint faced by regular firms (which is of itself endogenously modelled as part of the pandemic's shock). From the other angle, the "Main Street QE" policy provides a loosening of the liquidity constraint, allowing for more investment, and helping the real economy as well.

3.6. Empirical Approaches

Some other research papers consist mostly of empirical strategies of identification. Overall, these approaches rely on applying or expanding certain econometric models to fit COVID-19 data and critically assess the situation derived from it, mostly in economic terms. Some important elements within this set of papers are the evaluation of counterfactual scenarios amid the crisis, as carried out by Mulligan (2020) or, in the case of the work of Benmelech and Tzur-Ilan (2020), or Ludvigson, Ma, and Ng (2020), a search for causal economic explanations in the context of a pandemic (even on a very-long run context as with Jordà, Singh, and Taylor (2020). Noteworthy there is a remark on the need for real-time indicators, as in the research by Lewis, Mertens, and Stock (2020) and Diebold (2020), for taking into account uncertainty measures, as at the work of Baker, Bloom, Davis, and Terry (2020); or for considering both, as in the paper by Altig, et al (2020). Given the current paper is focused on analyzing the intersection of COVID-19 and macroeconomics from a theoretical modelling approach, I will not analyze the results provided by the authors previously mentioned, as they base their research on rather empirical-econometric contributions.

Nonetheless, there is one paper within this group whose consequences I consider particularly relevant to the discussion on containment policy. Goolsbee and Syverson (2020) collected county-level, cellphone "foot traffic" data from 2.25 million businesses across the U.S. They controlled the data for sectors that were legally mandated to shut down and compared it to the ones which were not (i.e., "essential businesses"). They analyzed the differential effects over consumption activities exactly during the weeks that restrictions were imposed, so that they may account for the role of legally imposed containment measures, comparatively to those effects explained by individual choice (on social distancing and voluntary behavioral change). When asking to what extent the recessive effects due to consumption were explained by legal restrictions (containment policies), they found that they account for just a small share on the behavioral change associated to consumption habits. Total foot traffic data registered amid the early imposition of lockdown measures showed that while total traffic contracted at more than 60 %, only 7 % of it is explained by legal impositions. This result poses important implications at the policy level: if the dynamics of economic activity are actually explained by personal choice mostly, how effective at changing outcomes may any containment policy, or relaxation of the same, really be at all?

4. CONCLUSIONS

This paper has provided an analysis of the evolution experienced by macroeconomic theory in modelling the epidemiological process implied by the COVID-19 pandemic simultaneously to aggregate macroeconomic dynamics. It has been found that some fundamental tools of contemporary macroeconomics, particularly heterogeneous agents, and endogenous choice in a stochastic dynamic setting, proved to be crucial at better understanding, not only the macroeconomic effects of the pandemic, but the epidemiological process itself, while proposing refined policy recommendations. The results are contingent on the degree of scaling complexity in the models' underlying theoretical structure which increased with the ever-growing peer-learning process that the analyzed material proved to have been gone through, the process itself showing to be of high importance. This suggests that the development of economic theory relies on constantly finding mechanisms for methodological improvement in the way complex aggregate socioeconomic phenomena are described. Furthermore, and as is the case here with epidemiology, economists have applied economic tools to the study of epidemiological themes, integrating the two approaches within a single framework. The basis for such conciliation within this paper's context appears via the various uses and extensions provided by the SIR model.

The seminal work within this series introduced macroeconomic and epidemiological modelling within a single theoretical framework. The subsequent academic production in the field of macroeconomics and COVID-19 is extensively based on such approach, leaving exogenous, purely epidemiological modelling, behind. Among the studied material, there are some key recurrent interest factors among some researchers that are worth pointing out. In particular, there is an important interest in finding out the best possible optimal containment policies for certain scenarios. In this context, the information issues associated to the centralized versus decentralized solutions remain latent in coherence with the accounting of other forms of asymmetries and market imperfections.

At the specific level of policy analysis, despite the heterogeneity of the findings given the diversity of approaches and the specific moments at when any specific piece of research was published, there are some general, crucial conclusions, to be drawn from the cited material. First, there are relevant findings arguing for the need for nations to keep a differential approach within their population and with respect to other nations, with regards to the economic recovery measures and the pandemic containment policies required. This is because firms, households, governments, healthcare supply, and labor market features are fundamentally different and locally heterogeneous, that is, dependent on structural variables relative to each country's characteristics. Additionally, there does not seem to exist an absolute trade-off, or at least not a linear one, between the health of the economy and the pandemic's containment. As implied by multiple authors, it may be the case that extremely loose containment measures may ultimately lead to worsened economic consequences (Aum, Lee, & Shin, 2020).

In the months following the seminal work within this series, yet other methodologically diverse approaches were introduced within an epidemiological environment, including network effects, Neo Keynesian environments, and multi-compartment extensions to the standard SIR model. Some other forms of agents' heterogeneity, not only regarding households but also firms and entire simulated economies (e.g., Alfaro, Becerra, & Eslava (2020)) were implemented. These further expansions fueled yet some other important findings; the idea that individuals often do not fully internalize their active role as endogenous pandemic-driver agents makes their containment plans sib-optimal. Specifically, their "containment plan", even if aimed at so, is hardly ever really optimal in a decentralized equilibrium because of the externalities implied by other agents (however, a centralized equilibrium still poses important issues, mostly related to information constraints as previous authors had already implied). Yet other latent topics covered on a rather marginal basis among the studied material include life-valuation methodologies, analysis of welfare variations, and inequality (e.g., Auerbach, Gorodnichenko, & Murphy (2020)).

There is a share of the cited papers that report interesting findings on other topics such as sovereign debt, the role of key financial institutions, and cross-country differences implied by the pandemic's consequence (e.g., Alon, Kim, Lagakos, & VanVuren (2020)). Interestingly, among the studied material, there is relatively smaller share of rather empirically-intensive approaches (in the use of econometric methods). However, some of these provide important insights underlying the data. In particular, it may be the case, as implied by Goolsbee and Syverson (2020), that the containment outcomes may ultimately depend, to a very large extent, on voluntary behavioral choice, even in the presence of legally enforced measures. This particular finding, combined with the controversial "health vs. economy" tradeoff, and the information issues at the centralized vs. decentralized discussion, pose severe doubts over optimal containment policies and their effectiveness.

The COVID-19 crisis fueled an unprecedented number of academic publications in economics coming out on a periodical basis, and so the four months that I covered do not fully contemplate the further conceptual transformation that the analysis of the Macroeconomics of COVID-19 may still keep on providing during the next months with regards to epidemiological and economic modelling. That is, given the rather limited number of papers I studied compared to the potential size of existing literature on the macroeconomics of COVID-19, I could hardly even address concise limitations to this survey other than the very awareness of such incompleteness, given that the entire universe of papers on this category is hardly likely to be fully addressed. Furthermore, some other valuable material regarding the modelling of the pandemic as based on tools from modern economics may have escaped my analysis as by design I chose to focus exclusively on the direct relationship of the pandemic with macroeconomics, taking a single source (NBER Working Paper Series).

This rapid growth of research is coherent with the divergent recessive estimations that at some point certain authors posed, as the development of real-time research evolves according to the actual process carried out by the pandemic. That

is, some numerical previsions attained by the authors cited may result outdated just some months after its publication.

Despite the constrained delimitation of the papers involved, there are some important research gaps that may in fact be inferable from the cited material and that may potentially constitute important extensions to the already existent research on macroeconomics and COVID-19. Some important gaps to consider are the longer-run effects of the pandemic for income distribution or human development indicators. Another clear avenue for future research is that of investigating financial markets' outcomes amid the pandemic and the effects and consequences of public finance structures in a macroeconomic context. In addition, I believe that it would be very useful to further estimate differential policy outcomes for emerging economies considering their specific heterogeneous structure (Alfaro, Becerra, & Eslava, 2020). In terms of methodology, I believe that there is still an important tendency to base macroeconomic modelling in terms of a DSGE environment. While this has undeniably proved to be fruitful, a further integration of other methodologies and a clear contrast of possible differential findings (e.g., with Neo Keynesian approaches) would be of great value.

The material analyzed and contrasted, both in terms of topics treated, methodologies applied, and findings attained, suggest that an important conceptual evolution occurred with regards to the way some macroeconomic researchers understood an epidemiological process. This led to a change in the very way an epidemic was modelled by macroeconomists. Early approaches soon progressed into sophisticated models that learned to integrate macroeconomic and epidemiological phenomena under a single theoretical structure leading to important implications at the economic and public health policy level. The extent to which such findings eventually influenced epidemiologists and policy makers (both in the economic and public health spheres) is yet to be addressed. A further dig on this query would undeniably provide important insights on the real impact economists attain at the public realm, particularly in times of crisis.

Finally, I consider that a deeper comprehension of this conceptual transformation and its possible methodological implications should undeniably be accompanied by a rigorous epistemological analysis that may find it useful to study the foundations of such concerns from the philosophy of economics.

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