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The Pandemic, The Climate, and Productivity

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Abstract

The pandemic depression and climate change have buffeted the global economy and more. The pandemic has caused the deepest depression in a century, has had a devastating impact on human health and morbidity, and has exacerbated global inequalities. Climate change has exacted its own economic toll, has had its own adverse impacts on human health and global inequalities, and continues to wreak havoc on the global environment. I survey the literatures exploring the two challenges as at mid-2021, separately and jointly because they interact. I survey the impacts of the pandemic on global value chains, on aggregate and business output and employment, and on productivity. I survey the impacts of climate change on aggregate and business adaptation, the last line of defence, on agriculture, where the impacts are particularly severe, on business, and on productivity. I continue with an exploration into the linkages between the two challenges, and efforts to decouple them through a wide range of green growth policies. Throughout I emphasise the important role played by management, at business, national and global levels, in allocating resources to counter the impacts of both challenges. I acknowledge that the pandemic and climate change are evolving, the former encouragingly rapidly until the unwelcome arrival of the Delta variant, and the latter depressingly slowly, and consequently this survey is aiming at a pair of moving targets.

Keywords: pandemic, climate change, green growth, productivity, management

JEL codes: O44, Q54, Q58

The Pandemic, The Climate, and Productivity

1. Introduction

The productivity community has amassed data, has developed analytical and empirical techniques, and has experience gained from applying theory-driven techniques to data to obtain estimates of productivity in a rich variety of environments and circumstances over at least the past century. However, the community has not previously encountered a pair of circumstances quite like those of the early 2020s, a sharp depression brought on by the covid-19 pandemic in the midst of climate change largely brought on by a reliance on fossil fuels to power past economic growth. The IMF (2020) has called the pandemic depression "A Crisis Like No Other", with an uncertain recovery from what the World Bank Group (WB) (2020) has described as the deepest global decline in economic activity in eight decades. Tol (2009;29) has characterised climate change as "…the mother of all externalities…". The OECD (2020e) has called it "an existential threat", and Secretary-General of the OECD Angel Gurría (2021) has characterised efforts to deal with it as "[o]ur single most important intergenerational responsibility".

The pandemic depression began in 2020 and, depending on the efficacy of public policies and the development, distribution, and take-up of vaccines, may well be relatively short-lived. In contrast, climate change has been occurring for centuries, with modest policies designed to slow or halt its growth, and consequently with no end in sight. Generic policies to combat the two phenomena include mitigation and adaptation, and in some instances, these policies are complementary. These two generic policies are popular in the climate change literature, but rarely mentioned in the pandemic depression literature, although they are equally applicable to both scourges.

I base the analysis on the academic, business, and other relevant literatures, with an objective of uncovering conjectures and evidence that may contribute to our understanding of the separate and combined impacts of the pandemic depression and climate change, and policies designed to ameliorate both, on various indicators of economic activity, including productivity. In Section **2** I briefly survey the status quo as at mid-2021. In Section **3** I consider the potential impacts of the pandemic and its associated economic depression on productivity. Much of the literature on this topic exploits what we have learned from past diseases, the 1918 influenza pandemic in particular, and from past depressions, the Great Depression of the 1920s and 1930s in particular. In Section **4** I consider the potential impacts of climate change on productivity, an event that has no precursor from which to learn. The two phenomena are related; after trending upward together for generations, greenhouse gas emissions declined during the pandemic-induced depression as business activity slowed. Accordingly, in Section **5** I consider the potential impacts on productivity of interactions between the two, the research question being whether, and if so how, a return to economic growth can be achieved while slowing or halting or even reversing the growth of greenhouse gases, even as world leaders proclaim to be pursuing net zero

by 2050. I take stock of the pandemic depression and climate change as at mid-2021 in Section **6**.

I acknowledge that the status of both the pandemic depression and climate change are evolving, the former encouragingly rapidly (until the unwelcome arrival of the Delta variant) and the latter depressingly slowly, and consequently this survey is aiming at a pair of moving targets. By the time most peer-reviewed journal articles have appeared, the targets have moved even further, and so I rely more heavily than usual on working papers, which are relatively timely, and the business press, which is even more timely and offers a fresh perspective on the two challenges. Consequently, I offer a stocktake in lieu of the traditional conclusions in Section **6**.

2. Two Challenges of Transcendent Significance

The pandemic depression has been steep, shrinking 2020 global output by almost 5%, by over 8% in some countries, and by much more in some sectors---airline passenger revenues declined by USD 370 billion during 2020 and tourism revenues declined by USD 935 billion during the first ten months of 2020. Looking forward, macroeconomic growth projections for 2021 and beyond are optimistic and continue to improve, due primarily to policy support and vaccine developments, but subject to considerable uncertainty reflected in downside and upside risk scenarios. At the same time, global greenhouse gas emissions declined by 6% during 2020, although they nearly recovered by mid-2021 and are expected to revert to trend as the economic recovery progresses. Unfortunately, conventional measures of global output fail to capture these and other environmental effects.

2.1 The Pandemic Depression

The International Monetary Fund (IMF), the Organisation for Economic Co-operation and Development (OECD), and the World Bank Group (WB) all track trends in the global economy. Projections of all three organisations have improved throughout 2020 and into 2021. The IMF projections for global economic growth have improved from a range of -4.9% to -3.5% for 2020 and from 5.4% to 5.5% for 2021. The OECD projections have improved from -6.0% to -3.4% for 2020 and from 5.2% to 5.6% for 2021. The WB projections have improved from -5.2% to -4.3% for 2020 but declined from 4.2% to 4.0% for 2021. All three organisations project similar trends with stronger recoveries for advanced or OECD countries, and similar trends with weaker recoveries for emerging market and developing economies or non-OECD countries.

The IMF (2021) attributes its improving outlook to expectations of a vaccine-powered strengthening of activity beginning in late 2021, bolstered by additional policy support in a few large economies. It also expects the strength of the recovery to vary significantly across countries, creating a need for strong multilateral cooperation. It stresses the need for policy support that emphasises inclusive growth and accelerates the transition to lower carbon dependence, and it favours a green investment push

coupled with initially moderate but steadily rising carbon prices that would support recovery from the pandemic depression and reduce emissions.

The OECD (2021a) identified the same drivers of its improving outlook, to which it added recovering global merchandise trade. However, it cited signs of increasing and persistent divergences, in the development of vaccination deployment, labour market conditions, and rates of recovery across sectors and economies. Like the IMF, the OECD emphasised the need for policy support for health care sectors, and the need for structural reforms that foster resource reallocation toward sectors and activities that improve labour market outcomes, reduce inequalities, exploit digital technologies, strengthen economic growth, and contribute to environmental sustainability.

The WB (2021) identified the same drivers and foresaw continuing exceptional monetary policy accommodation combined with an expanding role for targeted fiscal policies. The WB noted several downside risks to its projection, including possible delays in vaccine procurement and distribution, surging debt, and weaknesses in international travel and related services. It stressed the need for improved governance, the enactment of structural reforms to reduce the long-term effects of scarring, implementing sectoral reallocations and harnessing digital technologies to enhance productivity, all with an emphasis on green infrastructure projects that can increase resilience to climate risks. Like the IMF and the OECD, the WB predicted wide international variation in the depth of the depression and the speed and extent of recovery, and a concomitant increase in inequality and poverty. Unlike the IMF and the OECD, the WB predicted a negative impact of the pandemic on productivity, by exacerbating its long run slowdown through its scarring effects on the accumulation of physical and human capital.

Many issues raised by the three organisations, and other issues raised in the academic literature, have formed the basis for subsequent research, which I survey in Sections **3** and **5**.

2.2 Climate Change

In its Fifth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) (2014) stated that warming of the climate system is “unequivocal”, and human influence on the climate system is “clear”, with greenhouse gas emissions driven largely by economic and population growth. Among its four representative greenhouse gas pathways, only the most stringent is projected to keep global warming *likely* below the 2015 Paris Agreement 21st century target level of 2°C above pre-industrial levels, a target originally proposed by William Nordhaus (1976, 1977), co-recipient of the 2018 Nobel Prize in Economic Sciences.

The Panel noted variation in vulnerability to climate change across nations, and across regions and sectors within nations, and stressed the need for complementary policies and actions to promote mitigation of and adaptation to the impacts of climate change. Mitigation involves limiting or reducing emissions of greenhouse gases, and

confronts substantial technological, economic, social, and institutional challenges. Adaptation options include built-environment, technological, ecological, economic, and legal opportunities. The Panel warned, however, of constraints, or barriers, to implementation of mitigation and adaptation policies, among them limited human and financial resources, limited monitoring abilities, an absence of leaders and advocates, and uncertainty about the projected impacts. These mitigation and adaptation policies, and their constraints, emerge frequently in the literature and apply with equal force to policies intended to combat the pandemic depression.

In its interim Special Report, the IPCC (2018) asserted, with high confidence, that global warming is likely to reach the 2015 Paris Agreement 21st century aspirational level of 1.5°C above pre-industrial levels between 2030 and 2052 if it continues to increase at the current rate. The Report identified climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth, and noted that these risks depend on the magnitude and rate of warming, geographic location, levels of development and vulnerability, and on the choices and implementation of mitigation and adaptation strategies. It also identified policy tools to enhance mitigation and adaptation, including the use of market- and nonmarket-based instruments (for which read carbon pricing) and the adoption of new and possibly disruptive technologies. The Report has served to heighten research interest in the role of economic analysis in identifying the sources of and remedies for climate change.

The IPCC (2021) physical science assessment of climate change, released just three months prior to the November 2021 UN Climate Change Conference COP 26 in Glasgow, stated bluntly that "It is unequivocal that human influence has warmed the atmosphere, ocean and land…at a rate that is unprecedented in at least the last 2000 years". It also asserted that climate change is already affecting many weather and climate extremes such as heatwaves, heavy precipitation, droughts, and tropical cyclones, and that their attribution to human influence has strengthened since the IPCC (2014) assessment. Mean global surface temperatures have reached 1.1°C above pre-industrial levels, with larger increases over land than over oceans. Looking ahead, of five illustrative climate change scenarios, "best estimate" temperature increases range from 1.6°C to 2.4°C by 2041-2060, and from 1.4°C to 4.4°C by 2081-2100. UN Secretary-General António Guterres called the report a "code red for humanity".

The pandemic-delayed IPCC Sixth Assessment Report, *AR6 Climate Change 2022: Impacts, Adaptation, and Vulnerability*, is scheduled for release in February 2022.

Most of the issues raised by the Panel throughout its Assessment Reports, including the impact of climate change on the allocation of resources, the potential for mitigation and adaptation strategies, and some related issues the Panel did not raise, have motivated the ensuing economic research agenda, which I survey in Sections **4** and **5**.

2.3 Addressing the Two Challenges

The two challenges differ in their timescales but share some important features that motivate addressing them together. Both can be traced directly or indirectly to human activity, and the ultimate impacts of both influence human health and well-being, mostly adversely. The two are systemic, with their impacts felt throughout an interconnected world. The impacts of both vary across nations, across regions and sectors within nations, and among socioeconomic groups. The impacts of both are regressive, with particularly adverse impacts on vulnerable groups, raising the spectre of rising inequality and poverty. Macroeconomic and business policies designed to address both challenges require a refocus from short-term strategies to long-term resilience involving mitigation and adaptation, and both strategies face numerous organisational and institutional constraints to effective implementation. It is useful to view the current situation as one of managerial optimisation subject to constraints.

Our ability to overcome these two challenges with minimal adverse health, economic, and environmental consequences depends critically on the quality of management at two levels: as with most business and economic challenges, management matters. At the level of the individual business, the distinguished management consultant Drucker (1954; 71) claimed that "…the only thing that differentiates one business from another…is the quality of its management…", and the only way to measure managerial quality is by measuring "…how well resources are utilized and how much they yield". In the present context managers need to adapt business models and adopt innovative technologies and human resource strategies to deal with dramatically changing operating environments that bring stakeholders in addition to shareholders into play. At the level of the aggregate economy, Tjalling Koopmans (1951), co-recipient of the 1975 Nobel Prize in Economic Sciences, introduced the helmsman, whose task also was to allocate resources efficiently. In the present context the helmsmen (in 2021 some of the most prominent are women) are responsible for aggregate fiscal, monetary and regulatory policies intended to minimise the adverse health consequences of the pandemic and foster economic growth, preferably targeted in a green direction. Even a casual reading of the international press reveals wide variation in the performance of countries' helmsmen in confronting the two challenges. The significance of management practices and policies at both levels appears frequently in the literature. For example, McKinsey & Company and the OECD have released a stream of studies outlining new business and macroeconomic strategies required to survive the pandemic recession and climate change.

3. The Pandemic and Productivity

Not all depressions are caused by pandemics. Prior to considering the 2020 pandemic depression I briefly consider two that were, the cholera pandemic of the 1830s (which I consider for a reason unrelated to the 2020 pandemic depression) and the 1918 influenza pandemic, and one that was not, the 2008 financial crisis. The

distinction matters, because the health effects of a pandemic have short- and long-run effects on labour markets, output, and productivity not encountered in other depressions.

Interest in the economic effects of pandemics and depressions is not new. Fourastié (1951; Chapter IV) wrote of the impact of the economic crisis brought on by the cholera pandemic of the 1830s on the level of living in France. He observed that a quantity-based measure of the level of living, the average real income of the whole population, declined appreciably, while a price-based measure, the purchasing power of wages, varied little. He attributed the apparent inconsistency to a decline in output that exceeded the decline in employment and other resource use, combined with a decline in wages that was approximately matched by a decline in prices. Fourastié devoted much of his book to the development of a price-based approach to productivity analysis that Siegel (1955) extended theoretically, and Kendrick (1961), the father of modern productivity analysis, found very useful in his empirical exploration into the distribution of a nation's productivity bonus. Only under restrictive conditions are price-based and quantity-based productivity measures equal, however, and Hsieh (2002), Fernald and Neiman (2011) and Grifell-Tatjé and Lovell (2021) have explored alternative strategies when they are not equal.

The 1918 influenza pandemic has attracted considerable economic research, much of it inspired by the 2020 pandemic depression. Barro et al. (2020), Beach et al. (in press) and Arthi and Parman (2021) have studied the global impacts of the 1918 influenza pandemic (unfairly named the Spanish Flu), a virus that caused tens of millions of deaths, or 2% of the global population, during 1918-1920, and their relevance for those of the 2020 pandemic. Barro et al. examined the *short-term* economic impacts across 48 countries and estimated a statistically significant decline in real per capita GDP of 6%, and of 8% in real per capita consumption. These estimated economic impacts are marginally higher than the predictions of the IMF, the OECD, and the WB for the current pandemic. Beach et al. surveyed the literature on the *short- and medium-term* health and economic effects of the 1918 pandemic and their potential relevance for the 2020 pandemic and found limited help on the economic front. The main difference between the two impacts is that the former was driven largely by a negative supply shock, as many prime-age workers died, whereas this group is among the least likely to contract the current virus. Among the similarities were the predicted adverse short- and medium-term effects on economic growth and employment attributable to the effect of scarring on human capital accumulation through education. Arthi and Parman studied the *long-run* economic impacts of the 1918 pandemic on health, labour, and human capital in the US. They found evidence of substantial scarring effects, including reductions in educational attainment and wages, and increases in the probability of living in poverty, receiving welfare support, and physical disability. These scarring effects were magnified for people with lower socioeconomic status.

These and many other studies tend to agree on effects of the 1918 pandemic: brief sharp reductions in output and either population or employment, followed by quick recovery, and eventual adverse scarring effects on human capital development. They also are consistent in their provision of weak evidence on changes in productivity and on the nature of the cyclicality of productivity. Significantly for inferential purposes, they each encountered an external event, the Armistice that ended World War I, which extended the depression and complicated analysis of the health and economic effects of the pandemic.

Pro-cyclicality of productivity has long been conventional wisdom, at least since the Great Depression of 1929. To cite a prominent example, Basu and Fernald (2001) bluntly asserted that "[p]roductivity is pro-cyclical" and examined four explanatory hypotheses for this stylized fact: technology is pro-cyclical; imperfect competition and increasing returns cause productivity to rise when input usage rises; utilization of inputs itself varies over the cycle; and reallocation of inputs across uses is pro-cyclical. Using aggregate US data over 1950-1989, thereby excluding the two aforementioned depressions, they found support for cyclical input utilization rates and cyclical input reallocation. However, conventional wisdom has been called into question recently.

The global financial crisis (aka the great recession) of 2008 has changed the prevailing productivity story to one of neither pro-cyclicality nor counter-cyclicality, but to one of a rather different type. Fernald (2015) studied the US economy before, during & after the financial crisis. He found exceptionally strong growth in total and labour productivity from 1995 through 2003, followed by much weaker growth beginning in 2003 and lasting through 2013. Thus, slower productivity growth preceded and followed, rather than coincided with, the financial crisis. Fernald attributed the pre-crisis productivity slowdown to the waning of the rapid pace of IT investment and complementary innovations such as business reorganization that boosted productivity growth beginning in the mid-1990s. Fernald and Wang (2016) argued that the pro-cyclical pattern of productivity has waned, with total productivity becoming a-cyclical and labour productivity becoming counter-cyclical, with both changes robust to alternative measures of output and input. In their study of the US economy during 1955-2015, they considered four potential sources of reduced pro-cyclicality. Increased labour market flexibility has reduced the need to adjust capacity utilization. Pro-cyclical reallocations within and across production units have declined. A shift in the structure of the economy from manufacturing to services has reduced cyclicality. The growing importance of intangible investments in R&D, IT and other hard-to-measure outputs also has reduced cyclicality. They cited increased flexibility in labour markets as having been the most likely source, although they were unable to dismiss the other potential sources. Galí and van Rens (2021) also claimed pro-cyclicality of labour productivity in the US has vanished, and its disappearance has not been driven solely by shifts in the structure of the economy since it occurs within as well as among industries. Rather it has been driven by an influence Fernald and Wang considered, increased flexibility in labour markets resulting from innovations in job search technology and improvements in information about the quality of job matches. This

has reduced hiring and firing frictions, allowing firms to adjust their work force in response to shocks.

Away from the US, Oulton (2018) studied 23 countries before, during and after the financial crisis, and obtained a similar result. He compared growth rates of GDP, GDP per hour and total productivity from 2007-2015 relative to 2000-2007. He found that the fading effects of the IT revolution and weaknesses in the competitive process both predated the crisis, and he found evidence of a declining productivity growth rate in the US and a few other countries that predated the crisis. He also found that the reduced growth rates of the two productivity measures lasted well beyond 2008. Across all 23 countries, he found labour productivity 1.3% lower and total productivity 0.9% lower, through the post-crisis period, a finding he attributed in part to labour market rigidities and stringent immigration policies.

Casual empiricism suggests that the observed inter-country variation in success in dealing with the financial crisis may have been driven in part by variation in the performance of countries' helmsmen, in their ability to manage and regulate the economic fallout. With this hypothesis in mind, Cette et al. (2020) explored how *managerial* practices affected economic adjustments during the 2008 financial crisis. They constructed a country by industry panel during 2007-2015 for 18 industries in 10 OECD countries, augmented by a matching indicator of management quality from the World Management Survey (https://worldmanagementsurvey.org/). They found that the quality of management practices was significantly associated with employment dynamics, with countries having higher management quality experiencing smaller output and employment losses than other countries and suffering no decline in labour productivity. Looking ahead, with evidence from the financial crisis that the impact of the pandemic depression depends on the magnitude of the shock and the quality of a country's management, they predicted that Japan would suffer less, and Spain more, than other countries. Management continues to matter. In a complementary study, Chari et al. (2021) studied the role of *regulatory* practices during India's efforts to deal with the financial crisis. They found the "unholy trinity" of regulatory forbearance at the Reserve Bank of India, stressed state-owned banks, and zombie firms created a significant credit misallocation, with regulatory forbearance allowing stressed banks to support low-liquidity and low-solvency zombie firms, thereby crowding out healthy firms, a practice that hindered the process of creative destruction, and retarded India's recovery from the crisis. They concluded, presciently, that their findings have relevance for the quality of temporary forbearance policies widely adopted to deal with the 2020 pandemic and equally widely reported in the media.

Looking forward with the benefit of hindsight gained from analysing previous economic downturns, a large and growing number of studies of the 2020 pandemic depression have appeared: the more recent the depression, the better the data and the more sophisticated the toolkit. For convenience, I allocate these studies to five issues, an admittedly arbitrary allocation since the issues overlap, but one with a logic: disruptions to global trade and value chains adversely affect national output, and

therefore resource allocation and employment, and potentially productivity, increasing the need for policy intervention and highlighting the importance of good management.

Global Trade and Value Chains

Global value chains (GVCs) are organised to maximise efficiency; vaccine producer Pfizer has thousands of suppliers and Taiwan Semiconductor Manufacturing Company has many customers and a large and growing market share. However, the pandemic and related geopolitical tensions have led to a transformation of value chains in pursuit of resilience and self-reliance at the expense of efficiency. The literature has investigated the trade-offs involved.

Criscuolo and Timmis (2017) stated the case for GVCs, acknowledging that most value chains are regional. Participation can stimulate productivity through several channels, including firm specialisation in core tasks, access to imported inputs, and knowledge spillovers from foreign firms, a list similar to one compiled for a somewhat different purpose by Adam Smith over two centuries ago. However, participation also exposes firms to various risks, among them supply monopolisation, border bottlenecks, coordination of standards, and hostile trade practices. These risks have been magnified, by lockdowns and border closures brought on by the pandemic depression, leading to shortening and fragmentation of value chains, as The *Economist* has frequently observed. The 2021 semiconductor shortage, widely attributed to the pandemic and extreme weather in Taiwan, provides a good example of the consequences for over 100 industries ranging from automobiles to smartphones of reliance on a single supplier.

The impact of the pandemic on global trade and supply chains has affected both output and employment. The WB (2021) data show growth in world trade volumes declined from 4.3% in 2018 to 1.1% in 2019 and are expected to decline steeply to -9.5% in 2020 before a projected recovery to 5.0% in 2021. Antràs (2020) has observed that even before the pandemic depression the growth of GVCs had been slowing, a trend he attributed to an unsustainable increase in globalisation through the early 2000s that “had run out of steam”. Other explanations attributed the slowdown to technological factors such as the rise of automation, which acts as a substitute for offshoring, and to policy factors, including Brexit, the growth in trade-induced inequalities, rising tariffs, and growing uncertainty driven by US-China trade tensions. The pandemic has reinforced the downward trend, particularly for the high-productivity participants relying on just-in-time delivery and lean inventories, for those countries most reliant on international tourism, and especially for England, where the uncertainty surrounding Brexit magnifies the impacts of both.

Baldwin and Freeman (2020a,b) documented the recent experience with GVCs, beginning with a pandemic-induced supply disruption in China in early 2020 that slashed its exports. As the pandemic spread to other nations, a demand disruption emerged, and their imports declined. Value chains have become fragmented and global trade has declined, further reducing incomes and employment. Although trade

in goods and services, but not migration, picked up in the second half of 2020, Baldwin and Freeman noted that international coordination could help soften the impacts of value chain disruptions. Yet several new protectionist initiatives have been adopted or discussed that could further disrupt GVCs; the *Economist* has described the paucity of international coordination as "the anarchy of global governance". Antràs noted additional sources of concern: the pandemic is likely to be transmitted across countries, it is likely to increase global income inequality, it will continue to disrupt global business travel, a key input in global production networks, and it will dramatically reduce international migration. Each concern has since been realised. Since globalisation enhances the efficiency of global resource allocation, productivity is likely to suffer.

Bonadio et al. (2020) and Inoue et al. (2021) argued along similar lines that the economic benefit from lifting lockdowns depends on the strategy of trading partners, making coordination mutually beneficial. Bonadio et al. studied world production and trade covering 33 sectors, including health, in 64 countries, parameterised with OECD data. They predicted a large decline in GDP in those countries, one third of which would be transmitted through GVCs, with both effects varying widely across countries. They then posed a counterfactual, asking whether a country might be better off under renationalisation. The answer depends on the severity of its planned lockdown relative to those of its trading partners, again with wide inter-country variation. With reference to the health dimension, they concluded that since the health sector is largely non-tradeable and not subject to lockdowns, increasing its size reduces the decline in GDP but does not have a consistent impact on the relative importance of international transmission. Inoue et al. tested the coordination hypothesis on firm-level data in Japan during an early 2020 lockdown period and found productivity advantages for firms linked with other firms having different lockdown strategies, which highlights the need for policy coordination noted by Baldwin and Freeman.

The evidence suggests that international firms are more exposed than their domestic counterparts to the pandemic depression. Disruptions on demand and supply sides spill over and fragment their GVCs. However, Borino et al. (2021) have studied a sample of over 4,000 firms in 133 countries and found that, while international firms are more exposed, they are also more resilient, with resilience measured by the ability to adopt remote work practices, source from new suppliers and develop new processes and products. This compensating advantage is endangered by nationalistic trade practices adopted by some governments. Arriola et al. (2020) reached a similar conclusion, that the economic case for policy-induced reshoring of GVCs is weak. They have used the OECD's computable general equilibrium trade model METRO that traces international interdependencies to create an interconnected regime incorporating fragmented production in a GVC, and a localised regime that localises value chains, both of which incorporate features of the pandemic. Their main findings are that localisation of value chains would add further economic losses to those incurred from the pandemic and, contrary to frequent claims, localised value chains are more rather than less vulnerable to shocks for most

countries. Under localisation, countries are less exposed to foreign shocks, but they are also less able to cushion shocks through trade, and the latter effect dominates.

If one considers that migrating workers are part of international supply chains, then restrictions on immigration constitute a class of protectionist initiative, with the same depressing effects on incomes and employment. The OECD (2020g) has documented two impacts of the pandemic depression on migration: a dramatic decline in permanent and temporary migration into the EU, and an increase in unemployment rates for immigrants within the EU that exceeded that of their native-born peers. The pandemic-induced decline in immigration matters for three reasons: evidence suggests that immigrants are key workers in essential services, their remittances form a vital source of income in developing countries, and immigrants, especially skilled immigrants, raise productivity in host countries. The OECD (2020j) and the EU Science Hub (2020) reckon that immigrants constitute a large share of the EU medical workforce and other key sectors such as transport, food manufacturing and IT services, making declining immigration a serious concern during the time of the pandemic. Citing a World Bank forecast, the EU Science Hub projects a 7% decline in remittances in 2020 and an even larger decline in 2021, thereby magnifying structural fragilities in developing countries.

The evidence linking immigration and host country productivity takes indirect and direct forms. Indirect evidence concerns the effect of immigration on internationalisation and innovative activity, both of which have been directly linked to productivity gains. Hatzigeorgiou and Lodefalk (2021) surveyed the evidence at national, sub-national and firm levels exploring the nexus between migration and internationalisation. They found immigration and host country trade to be complements rather than the long-assumed substitutes, with the same complementarity holding for inter-regional migration within countries. The firm-level evidence suggests that the strength of complementarity varies directly with immigrants' skill level. In an environment of hybrid work, the authors suggested that the same technologies that boost the productivity of working from home also boost the productivity of foreign-based online work – tele-migration. In a pair of complementary studies published in a special issue of *Research Policy* devoted to STEM migration, Bahar et al. (2020) and Laursen et al. (2020) explored the contribution of skilled immigration to host country patent production and corporate innovation performance. Using two large panel data sets, both studies provided strong evidence of a statistically significant positive relationship between inventor immigration and host country innovation dynamics, yielding increased patent production. Bahar et al. used an international panel to suggest that these findings show that inventor immigration can play an important role in other economic outcomes such as productivity and economic growth. Laursen et al. used a panel of Dutch firms to reach similar conclusions but stressed that it is the cultural diversity provided by immigrant innovators that is largely responsible for increases in firm-level innovation output, since their different experience and perspectives on problem solving complement those of incumbent employees', much as some types of capital complement human capital.

Direct evidence linking immigration to productivity has been provided by Bitzer et al. (2020), who tested the hypothesis that the contribution of *skilled* immigrants to firm patent applications and total productivity depends on the technological knowledge base of their country of origin. Using a large panel of Danish firms during 2001-2011, the authors found robust, positive and significant relationships linking several measures of firm-specific absorbable foreign knowledge with both firm-level patenting activity and total productivity. In addition to the absorbable knowledge base of an immigrant's country of origin, the immigrant's educational status and occupational position within the employing firm influence firm patenting activity and total productivity. This evidence complements prior evidence of Malchow-Møller et al. (2019), who exploited an earlier panel from the same Danish database. They found evidence that firms become more productive and more profitable when hiring foreign *experts* compared to firms that hire only domestic experts, a finding they traced to complementarities between skill sets and backgrounds of immigrant and domestic employees. The authors made the important point that foreign experts differ from foreign STEM workers, who are known to increase domestic employer performance, the difference arising from the fact that expert immigrants may have non-STEM skills including managerial, professional, and technical. To this point, it is worth adding that expert, skilled and STEM immigrants constitute a subset of the set of immigrants, and there is a large body of research linking immigrant workers with domestic employer performance. Ottaviano et al. (2018) and Mitaritonna et al. (2017) provide recent evidence from the UK and France, respectively.

Output

Numerous macroeconomic studies have examined and/or predicted the impact of the pandemic on output. In many of these studies, its impact on output is indirect, influenced by its impact on health. König and Winkler (2021) noted that, while the pandemic is global, countries have been affected differently and have responded with different policies. They examined GDP trends across 42 countries in the first three quarters of 2020, with a focus on two drivers, mandatory lockdown policies and health as proxied by fatality rates leading to voluntary social distancing. They found the stringency of lockdown policies to have been the more important driver of within-country GDP trends through time, but differences in health risks expressed by fatality rates were the more important driver of cross-country variation in GDP trends. Fernández-Villaverde and Jones (2020) summarised the macroeconomic outcomes through the first three quarters of 2020, based on a novel data set including international economies, US states and key global cities. Using output loss and pandemic deaths as outcome indicators, they found New York City, Lombardy, the UK, and Madrid to have had poor outcomes, and Germany, Norway, Japan, South Korea, China, Taiwan, Kentucky, and Montana to have had good outcomes. Very few observations had one good outcome and one poor outcome. They acknowledged the difficulty in attributing outcomes to luck or management, and like König and Winkler they concluded that their findings may look quite different in six months, when the

extent to which the divergence in outcomes was driven by luck or managerial policies might become more transparent. At that point it will be worth examining the policies that may have driven the good outcomes in those locations.

De Grauwe and Ji (2020) contrasted the effects of the pandemic depression on world industrial production with those of the Great Depression of 1929 and the financial crisis of 2008. They found the 2020 depression to have been much steeper than the two previous downturns in economic activity. It also appeared to exhibit a strong short-run V-shaped rebound in output, which they attributed to improved government policies relative to the 1929 depression, and to the absence of bank failures in need of repair before a recovery could be sustained in the 2008 downturn. In contrast to the findings of De Grauwe and Ji concerning the 2020 depression, Gregory et al. (2020) found the same steep downturn in output but predicted an L-shaped rather than V-shaped recession in the US, with long-lasting negative effects on unemployment. They assumed a three-month lockdown followed by a year of uncertainty during which there is a risk of a second lockdown, with unemployment benefits augmented by federal programs. The lockdown would cause some employment relationships to be terminated, others to be suspended, and still others to continue. They calibrated their model to US unemployment data across industries in March and April 2020 and generated an L-shaped recovery in which the unemployment rate takes several years to return to its pre-lockdown level, with the recovery rate varying across industries. Admittedly, these two studies were short-term, and their findings may be overturned, but they both have the lasting value of pointing to the role of good macroeconomic management in quickly ameliorating the economic impacts of economic downturns.

Microeconomic studies are less numerous. Bartik et al. (2020) surveyed over 5,800 US members of Alignable, a small business network, in March and April 2020. Even at that early stage of the depression, massive dislocation had occurred, with 43% of respondents having closed at least temporarily. Reasons for closure included reduced demand, financial fragility, and employee health concerns, but rarely supply chain disruptions. Using a sample of more than 2,500 US small businesses obtained from The Study of Internet Entrepreneurship, Bloom et al. (2021b) found the pandemic had a significant negative impact on sales of 29% on average through the third quarter of 2020, with large heterogeneity. Around 40% of firms reported a positive or zero impact, and almost 25% reported a decline of more than 50%, concentrated among small off-line firms and women- and black-owned businesses. Significantly, they predicted these trends would persist, based on forecasts provided by the firms.

Recent data provided by the IMF (2021), the OECD (2021c) and the WB (2021) are consistent with a V-shaped depression based on three global activity indicators, world trade volumes, global industrial production, and manufacturing new orders. These data also illustrate the divergences in the depth of the depression and the speed of recovery between advanced and emerging market economies, and within each group, depending on access to medical interventions, exposure to cross-country spillovers, and the quality of macroeconomic management. Concurrent evidence,

reported below, also suggests an inverted V-shaped increase in unemployment in the OECD and the US.

Labour Markets and Employment

Numerous studies have examined and/or predicted the impact of the pandemic on various aspects of labour markets and employment. Much of the work explores the impacts on the nature of work and socioeconomic distributional effects rather than aggregate unemployment, and the primary finding is one of heterogeneity.

Cajner et al. (2020) took stock as at late May 2020, surveying the short-term effects of the pandemic on US employment, using weekly payroll data from the largest US payroll processing company. They found an initial decline in aggregate employment of 21%, followed by a modest rebound to a decline of 15%, with wide variation across occupational and socio-economic groups. Employment declines were disproportionately concentrated among lower-wage workers, were greater for women than for men and for younger workers than others and varied widely across industries. The US Bureau of Labor Statistics periodically updates these statistics; see below. Barrero et al. (2020b) looked to the future, generating one-year ahead forecasts from a May 2020 Survey of Business Uncertainty to predict the impact on jobs of the pandemic. Their exercise predicted substantial reallocation effects across industries, with three new hires (e.g., Walmart and Amazon) for every 10 layoffs (e.g., tourism and hospitality), 32%-42% of layoffs resulting in permanent job loss, 10% of jobs shifting from the office to home, and reallocation effects among job categories. They usefully identified several constraints to adaptation in the form of currently active public policies likely to retard employment responses to the reallocation shock. These included unemployment benefits that exceed earnings for many employees, land use restrictions that inhibit the reallocation of jobs and workers, licensing restrictions that impede mobility across occupations and states, and regulations that inhibit business formation and expansion. Barrero et al. (2021c**)** updated the Survey data to the end of 2020, and argued that the reallocation will persist, for three reasons. First, rates of sales and employment reallocation have increased through 2020. Second, firm-level forecasts of future revenue growth continue recent trends, positive for some and negative for others. Third, employment reallocation has been toward industries with a high capacity for employees to work remotely, a trend covered in more detail below.

Reallocation eventually raises aggregate productivity, but it is not instantaneous, and this has contributed to widespread, and widely reported, labour shortages. Wage increases have reduced the shortages, but different rates of economic recovery among sectors and regions have combined with generous fiscal handouts and a fear of returning to work before the virus is under control to deter labour force participation and hamper reallocation.

Autor and Reynolds (2020) and Chernoff and Warman (2020) have explored the likely impacts of the pandemic on US labour markets. Autor and Reynolds predicted that the pandemic would reshape labour markets in four ways. The first they

called “telepresence”, which will replace much office time, commuting and business travel, with uncertain impacts on productivity. This in turn will have distributional consequences, reducing demand for related service occupations that make up a fourth of US jobs. The second is urban de-densification, which will have unpredictable impacts on innovation activity and productivity. The third is employment concentration in large firms, as the ranks of small firms decline, further diminishing labour’s share of aggregate income and increasing inequality. The final consequence they called “automation forcing”, the trend toward leaner staffing and the adoption of various new technologies that save labour *at the workplace* such as robotic automation, drones and the like, which are likely to enhance aggregate productivity. Chernoff and Warman wryly observed that computers and robots are unaffected by pandemics and predicted that the pandemic will lead to the introduction of labour-saving technologies that will increase productivity and wages in some occupations and lower productivity and wages in others as some workers are displaced. They also predicted demographic variations and found that the risk of both virus transmission and automation is higher for females than males in all occupational groups. Consistent with other findings that automation is most pervasive in the middle of the skill distribution featuring routine tasks, they found that the joint risk of automation and virus transmission is highest for occupations in the middle of the educational attainment distribution.

A lengthy study by McKinsey & Company (2021a) identified three features of work accelerated by the pandemic and likely to be long lasting. A continuation of hybrid remote work, particularly at higher skill levels, will affect real estate, mass transit, business travel and urban centres. A growth of e-commerce and other types of virtual transactions and the delivery economy at the expense of bricks and mortar establishments will influence the occupational and locational structure of the work force. An acceleration of the digitisation of customer and supply chain interactions and the adoption of internal automation, robotics, and artificial intelligence (AI) will alter the way businesses operate. These trends will generate changes in the mix of occupations, which will require substantial worker retraining and occupational transitions of up to 25% across countries, with the burden falling most heavily on women, young and less-educated workers, ethnic minorities, and immigrants. These trends will present a challenge to business managers, who must decide where, when and how work is performed, and policy makers, who must expand health care and digital infrastructure and support workers in transition. The *Economist* (10/04/2021) expressed optimism, asserting that the pandemic will speed up changes that were already under way and highlight areas in need of further improvement. The shift to a hybrid work model gives employees more flexibility over where and when they work and forces managers to become better communicators, both of which improve employees’ job satisfaction. These trends already are spurring changes in employment law and expanding governments’ role in combatting rising inequality.

In its Employment Outlook 2020, the OECD (2020f) documented a sharp increase in the unemployment rate from 5.3% at the end of 2019 to 11.4% in June 2020, followed by a small recovery to 9.4% at the end of 2020 and a projected 7.7%

at the end of 2021. These rates represent an increase many times greater than that experienced at the beginning of the 2008 global financial crisis, and they are magnified by a decline in hours worked per employee. The OECD also documented wide variation in unemployment growth across member countries and among employment categories. In its March 2021 survey of the employment situation, the US BLS (2021a) tracked the seasonally adjusted unemployment rate from 4.4% in March 2020 to a high of 6.7% in December 2020 and a partial recovery to 6.0% in March 2021. It also noted wide variation across race, sex, and age categories, with the pandemic exacerbating pre-existing labour market inequalities.

Productivity

The pandemic has disrupted aggregate output, employment and investment in human, physical and organisational capital, and therefore can be expected to have influenced aggregate productivity. A growing literature explores the magnitude and sources of pandemic-induced productivity changes.

Dieppe (2020), di Mauro and Syverson (2020) and Blit et al. (2020) have studied the impact of the pandemic on productivity, and the potential for near-term productivity gains. Looking backward, Dieppe examined the productivity impacts of major adverse events, including natural disasters, which include climate disasters such as cyclones and floods, biological disasters such as SARS and Ebola, and geophysical disasters such as earthquakes. He found all three to have had significant adverse cumulative impacts on productivity since 2000, with common transmission mechanisms including the disruption of value chains, the erosion of human capital, the destruction and misallocation of physical capital, a tightening of credit, and the disruption of innovation. He also found major adverse events to have reduced the rate of convergence of developing economies to the advanced economy productivity frontier. Dieppe traced these adverse impacts to uncertainty that weakened domestic and foreign direct investment, mobility restrictions that slowed the reallocation of labour toward higher productivity employment and weakened corporate and public sector balance sheets that constrained investment and exacerbated employment losses. Looking ahead, he envisioned productivity-enhancing opportunities for businesses and countries that adopt complementary policies toward the integration of new technologies that automate production, the improvement of human resource management, and the development of financial institutions. He also noted, however, that the productivity gains may be unevenly distributed. After asserting that there is no silver policy bullet, Dieppe recommended a comprehensive multi-pronged approach to improving productivity and through it economic performance, including such targeted policies as the support of health care systems, enhancing the mobility of labour and other resources toward more productive sectors, and supporting wider internet access.

di Mauro and Syverson distinguished true from measured productivity, noting that government relief programs that encourage labour hoarding will cause the latter to decline in the short run. Among the anticipated long run impacts on productivity

growth, they cited scarring from impacts on schooling and the development of human capital, disruptions to the growth of knowledge capital and other intangible inputs, the closing of national borders and the shortening of global supply chains, the growth of zombie firms, and tightening financing constraints, particularly for new and small firms. The lone bright spot was the likelihood of inter-sectoral reallocation of economic activity away from tourism toward healthcare and communications. Blit et al. examined declines in output and labour input in Canadian industries from April/August 2018 to April/August 2020. They found an "…immediate massive and unprecedented increase in measured labour productivity", defined by Statistics Canada as real GDP per labour hour and therefore consistent with the distinction raised by di Mauro and Syverson and suggestive of counter-cyclicality of labour productivity. They also found both inter-industry and within-industry composition effects, with the latter increasing inequality through a greater impact on low-wage and low-productivity jobs. They found limited evidence that inter-industry variation in labour productivity was associated with the ability to work from home, and no evidence of its association with occupational health risk.

The *Economist* (08/12/2020) has speculated that the pandemic might spawn a new era of rapid productivity growth. Their reasoning began with the recipient of the 1987 Nobel Prize in Economic Sciences Robert Solow's (1987) celebrated quip that "[y]ou can see the computer age everywhere but in the productivity statistics" and continued with David's (1990) reminder from the economic history community that it takes time for general-purpose technologies to bear fruit; Professor Solow was impatient. It almost concluded with recent work of Brynjolfsson et al. (2019, 2021) that builds on the contributions of Solow and David. These authors argued that AI is a general-purpose technology, which enabled them to exploit the literature on general-purpose technologies, including the dynamics insights of David, to address a current version of Solow's productivity paradox; see Jovanovic and Rousseau (2005) for such technologies. The adoption of general-purpose technologies such as AI requires investment in complementary intangibles such as R&D, organisational capital, and workforce training, which takes time, as the authors documented with many historical examples. In addition, the intangibles tend not to appear in company balance sheets or in national accounts, and this has important consequences for productivity measurement. The role played by intangibles generates what the authors called a *productivity J-curve*. Soon after the adoption of a general-purpose technology, true productivity growth will be underestimated because measured inputs produce unmeasured intangibles. Eventually true productivity growth will be overestimated because the unmeasured intangibles produce measurable outputs. The productivity J-curve declines and then increases, measuring the deviation between estimated and true productivity growth. The authors applied the productivity J-curve to US data for pre- and post-financial crisis years 2008-2009 and found trillions of dollars of intangible outputs were produced, but not included in national accounts, resulting in a 16% underestimate of the productivity level in 2017.

Brynjolfsson et al. developed the productivity J-curve prior to the onset of the pandemic depression. The contribution of the *Economist* was to extend the idea to the pandemic depression, arguing that the pandemic, despite its economic damage, has quickened the adoption of new technologies and made a productivity boom more likely to develop. It cited office closures that have forced firms to invest in digitisation and automation, and related adoption of AI, E-commerce, 3D/4D printing and numerous other tangibles and intangibles. If economies remain in the downward-sloping portion of the productivity J-curve, the pandemic has brought the upward-sloping portion forward.

Refocusing from national economies to businesses and their employees, Bartholomeusz (2020) predicted that the pandemic would do what the global financial crisis failed to do---purge zombie firms and their zombie jobs from the economy by reducing undiscriminating lending to firms with unsustainable business models and balance sheets, which would lead to reallocation and increased aggregate productivity. Quiggin (2020) provided a second example, finding what Bartholomeusz predicted, but for a very different reason. Quiggin observed that the pandemic has led to a sudden shift of around half the workforce to working at home, reducing unproductive commuting time by an average of one hour per day, thereby generating an impressive 6.5% increase in labour productivity. Results of a recent survey of 4,700 home workers in six countries by Slack (2020), a corporate messaging firm, as reported in The *Economist* and *Forbes*, found that flexible working eliminated the money and time cost of commuting, enhanced workers' work-life balance and increased their productivity.

The savings in commuting time from working from home have been confirmed in a survey of 10,000 US workers conducted and interpreted by Barrero et al. (2020a), who reported spending just over one third of the time they saved from not commuting on work from home at their primary job. The authors drew no productivity gain conclusions from their findings. Barrero et al. (2021a) expanded the sample size and drew some additional conclusions. They argued that working from home will become permanent, with 20% of work supplied at home, for several reasons. Experience to date working from home has been better than expected, the stigma associated with working from home will decline, concerns about virus contagion risks will linger, new investments in physical and human capital will enhance work from home, and a pandemic-driven surge in innovations will support work from home. Perhaps most significantly for our purposes, they predict a 5% increase in aggregate productivity attributable to re-optimised work arrangements although significantly for our purposes, only part of this gain will show up in conventional productivity measures that do not capture the time saved from reduced commuting. Barrero et al. (2021b) followed up on their previous study, focusing exclusively on internet access. They found an improvement in internet access from its current penetration to universal would raise labour productivity by 1.1%, increase the extent of work from home by 0.7%, have no significant impact on earnings inequality, and increase subjective well-being conditional on work status. Patnaik et al. (2021) studied the performance of over 1,800

firms in Italy, the first country to implement lockdowns. They found firms with above average management practices endured slower declines in sales growth than firms with below average management practices, and the share of employees engaged in remote work to be a key driver of slower sales decline, and perhaps of superior productivity performance. Emanuel and Harrington (2021) gathered data on 3,440 hires from call centres of a Fortune 500 online retailer between 2018 and 2020. They found working remotely increased the productivity of workers who accepted opportunities to transition from office work to remote work by 7.5%, and workers who were forced to work remotely due to closure of their call centres by 7.6%, although remote work also reduced the likelihood of promotion, leading to a selection problem.

Based on a model calibrated to US data, Davis et al. (2021) postulated that the pandemic would accelerate the widespread adoption of technologies that increase the productivity of remote work relative to office work for high-skill workers, the key parameter being the elasticity of substitution between market work done remotely and market work done at the office. The main finding is that adoption of remote work technologies such as robotic process automation (RPA) increases the productivity of remote work relative to working at the office by one-third, with gains increasing as the through time as experience accumulates. The gains to the technology from remote work have secondary effects, reducing office rents in cities and raising residential rents in the outer suburbs, and increasing income inequality between high-skill and low-skill workers and shrinking the urban productivity advantage first noted long ago by Sveikauskas (1975) due to firm selection and a decrease in agglomeration economies. A July 2020 Global Survey of executives by McKinsey & Company (2020f) argued that the pandemic was a tipping point, with businesses already implementing new technologies and operating systems that enhanced the productivity of remote work, primarily among the highly educated, well-paid minority of the workforce. New technologies also increased productivity in other ways, by raising consumer demand for online purchasing, and speeding operations and decision-making. Executives expect these changes to become permanent. Bloom et al. (2021a) uncovered additional evidence in support of the Davis et al. postulate. They used US patent applications filed during 2010-2020 to find empirical evidence that the pandemic that has expanded remote work has in turn induced innovations directed toward technologies such as video conferencing, telecommuting and remote interactivity that enhance the “quality and productivity” of remote work. Both studies support the Davis et al. hypothesis that the pandemic has accelerated the adoption of new technologies that enhance the productivity of remote work, but the proclaimed productivity gains have yet to be quantified. Ramani and Bloom (2021) have used US Postal Service data to document migration out of cities to surrounding suburbs and a consequent decline in urban rental rates and increase in surrounding suburban rental rates, hollowing out patterns they call the “donut effect” of the pandemic.

Andrews et al. (2021a) have used anonymised and aggregated near-real-time microdata from Xero, a cloud accounting firm, to explore the Schumpeterian cleansing hypothesis that asserts that recessions can accelerate the productivity-enhancing

reallocation process in three OECD countries, Australia, New Zealand, and the UK. Based on nearly 150,000 observations, they found changes in firm-level employment and hours worked were significantly and positively related to productivity during the year beginning February 2020, and the introduction of a high-tech dummy enhanced the productivity impact. Thus, labour reallocation occurred from low-productivity firms to high-productivity firms, with technology adoption that enhanced firms' digital transformation and the productivity of remote work reinforcing the impact, consistent with the findings of Barrero et al. (2020b, 2021b), Davis et al. (2021) and Bloom et al. (2021a). They found this reallocation of labour despite a policy response incorporating job retention schemes that emphasised job preservation over reallocation, a phenomenon to which I return in the Public Policies section below.

Not all evidence on the impact of remote work on productivity is positive. The Association of Chartered Certified Accountants (2020) surveyed its members in March 2020 and received over 10,000 responses. Among the impacts of the pandemic on business, major supply chain disruptions were cited by nearly 25% of respondents, and related disruptions to operations and logistics networks were cited by almost 20%. By far the most frequently cited business impact was reduced employee productivity, by nearly 60% of respondents, although two thirds reported some remote work. In an undated subsequent study, the Association of Chartered Certified Accountants (nd) reported the findings of a more recent member survey. It continued to report a decline in employee productivity, even though 80% of respondents have implemented flexible work strategies, and most of them identified workplace transformation as a long-lasting pandemic impact. Neither of these surveys reported how productivity was defined and measured. In their study of the switch from office work to remote work by over 10,000 highly skilled employees in a large Asian IT company, Gibbs et al. (2021) tracked employee productivity by the ratio of an output measure provided by the company to hours worked on a relevant task. They found a significant increase in hours worked, no significant change in measured output, and a productivity decline of about 20%. They suggested that remote work hampers communication, coordination, and collaboration, important to IT professionals, and that the productivity of highly skilled professionals may differ from that of other workers due to the specialised nature of the IT job requirements.

The bulk of the remote work literature focuses on the impact of new technologies on productivity in *existing* businesses. In a complementary study, Haltiwanger (2021) has catalogued *new* business applications in the US during the pandemic. Widespread business failures, especially among small businesses, and job losses predominated through mid-2020, and he found new business applications also declined sharply during that period. However new business applications then surged through mid-2021, a significant finding given the historical positive lagged relationship between applications and new business formation, and the role new businesses play in creative destruction, reallocation, and productivity growth.

Looking to the future, McKinsey & Company (2021b) predicted productivity gains across the US and six large European economies during 2019-2024, ranging from over 2% annually in health care and construction to under 0.5% in travel and automotive. It conditioned the predicted productivity gains on the ability to sustain growth in investment and innovation, and to direct both to the right places. However, this study and other related studies expressed concern about a continuation of growing demographic inequalities amidst rising productivity and economic growth, citing minorities, women, younger workers, and workers with relatively low educational attainment. The danger, expressed by Tyson and Mischke (2021), is that efficiency-oriented productivity growth will generate cost-saving reductions in employment accompanied by accelerated automation and digitisation, impeding growth in labour income and consumption and raising inequality. The WB (2021) has expanded the purview of concern about inequality from national to global, noting that the pandemic has reversed the downward trend in global poverty for the first time in a generation. It also expressed concern for growing inequality, with a disproportionate effect of the pandemic among vulnerable groups, including migrant workers and those working in the informal economy.

Choudhury (2020) and Choudhury et al. (2021) extended the concept from work from home to work from anywhere. The distinction is important because work from home provides workers temporal flexibility, while work from anywhere offers temporal and geographic flexibility. Choudhury found evidence that employees were more satisfied and more productive working from anywhere. He also observed that working from anywhere solved employer visa problems and reduced brain drain from developing countries. A few concerns emerged, including difficulties encountered in brainstorming, knowledge sharing, mentoring, and performance evaluation. Choudhury et al. evaluated the impact of work from anywhere on the productivity of patent examiners at the US Patent and Trademark Office. They found the transition from work from home to work from anywhere negotiated between managers and the union increased examiner productivity by 4.4%. This is in addition to the productivity gains from transitioning from office work to work from home. Perhaps unsurprisingly, the concept of work from anywhere has itself been extended, to work from nowhere by Hobsbawm (2021).

There is scant evidence on actual trends in aggregate productivity since 2019. Productivity statistics for 2020 are not yet available from the OECD or the World Bank Group. However, the OECD (2021b) has predicted that labour productivity will bottom out in the second quarter of 2020 and increase almost continually thereafter through its forecast period of 2019-2022, for both the Euro area and the OECD. This predicted pattern is common to all member countries, but it disguises wide variation, from strong productivity growth in Ireland, Estonia, and Lithuania to virtually no productivity growth in Italy and Portugal and productivity decline in Luxembourg. Predicted patterns of total productivity look like spaghetti junction. The WB (2021) predicts that the pandemic will leave lasting scars on productivity, including through its impact on the accumulation of human and physical capital, and calls for decisive policy action,

discussed below. The US BLS (2021b) has reported 2020 productivity statistics. For the private nonfarm business sector, which accounts for approximately 75% of GDP, labour productivity increased 2.5%, the largest in a decade. Total productivity declined by 1.7%, the difference accounted for by an improvement in labour composition of 1%, and an increase in capital intensity of 3.3%. The two largest components of the growth in capital intensity were information processing equipment and intellectual property products, supportive of discussions above concerning the significance of business innovation and investment in new technologies.

Public Policies

Interest has naturally grown in the development of a range of public policies intended to combat the health and economic effects of the pandemic. A very large number of studies have called for increasing the capacity of the health care system, which would confer both health and economic benefits. I noted above that Dieppe has proposed a set of complementary policies likely to enhance productivity growth, and Barrero et al. (2020b) have listed four policies that hinder the creation component of adaptation to the depression.

Balmford et al. (2020) observed vastly differing reported COVID-19 cases and deaths across OECD countries through June 2020 and attempted to attribute this pattern to differences in socio-economic characteristics over which governments have no control and differences in policy interventions that are controlled by governments. They found socio-economic characteristics (age, population density, wealth, and date of first reported case) to explain little of the variation in outcomes, the majority being explained by the timing and severity of lockdown policies. Céspedes et al. (2020) have constructed a macroeconomic model of the pandemic depression, with an objective of identifying the most effective public policies to combat its effects. They found traditional expansionary fiscal policy to have no beneficial effect, while low existing real interest rates limit the ability to cut interest rates further. However, they found several unconventional policies having the potential to move an economy toward a full-employment high-productivity equilibrium, among them being wage subsidies, injections of physical and financial assets that can be used as collateral to attract loans, and loan guarantees. Ilzetzki (2020) summarised the results of a survey of experts asking what policies would have the greatest impact on mitigation of the economic effects of the pandemic depression in the UK. The preferred policies were targeted, including government credit support for businesses, government transfers to and bailouts of businesses, and improving unemployment benefits. Kotz et al. (2021) noted that the pandemic has changed our economic environment and cited two conditions for a healthy pathway for productivity and growth after the pandemic. The first is diffusion away from superstars of technological, operational, and managerial advances on the supply side. The second is robust demand conditions, which are satisfied in the short run by government interventions but uncertain in the long run, depending on strong investment in the public and private sectors. In a survey of the world economy, the *Economist* (08/10/2020) worried that governments will fail to

respond adequately to the pandemic and all its side effects, and simultaneously worried about “misguided interventionism”. It proposed a range of carefully targeted policies aimed largely at preserving competition. Targeted policies included removing regulatory obstacles to global trade in digital services, reducing strict occupational licencing, provision of grants and retraining subsidies to unemployed workers and, hardest of all, spreading the benefits of growth.

Implicit in the policy-oriented discussion above is a much-debated trade-off between the health and economic outcomes of the pandemic, and the ability of public policies to influence the trade-off. Tisdell (2020), Kaplan et al. (2020) and Acemoglu et al. (in press) have created models of the trade-off with great potential value for productivity analysis in general, and specifically for the analysis of productivity dispersion, productivity gaps, distance to the frontier, the identification of zombies, and even the measurement of holistic productivity change incorporating health outcomes. The models differ in their definitions of health and economic outcomes and in other details but have a common analytical structure. Geometrically, measure health outcomes such as number of COVID-19 cases or deaths per capita on one axis and economic outcomes such as GDP per capita on the other axis and introduce cross-sectional or panel data on the two outcomes from countries or regions within a country. The data form a pandemic possibility set consisting of all feasible combinations of the two outcomes, with the set bounded by a pandemic possibility frontier that describes the trade-offs between the two outcomes. Conventional frontier estimation techniques project each country to different points on the frontier, reflecting variation in public policies. Some countries seek to avoid adverse health outcomes by imposing social controls such as restrictive lockdowns, perhaps targeted at certain susceptible groups, and promoting vaccinations, while others seek to avoid economic damage at the cost of adverse health outcomes with generous business and employment stimulus packages. Kaplan et al. and Acemoglu et al. stressed the advantages of targeting, by occupation or age or pre-existing co-morbidities, a strategy Tisdell questioned on freedom of choice and ethical grounds, citing Adam Smith and George Orwell. Independently of social preferences, the discovery and dissemination of new medical technologies have the potential to shift the frontier in a favourable direction. A current example of new technologies that shift the frontier is the application of genetics to medicine, in particular the development of messenger ribonucleic acid (mRNA) vaccines to combat the virus. There is guarded optimism that mRNA may be useful in combatting other conditions, including HIV, rabies and even cancer. The *Economist* (27/03/2021) has surveyed the development, the current significance, and the potential of these new biomedical technologies.

These and other policies that governments and businesses have taken or might take that help or hinder mitigation of or adaptation to or the economic impacts of the pandemic depression have a downside noted above by Bartholomeusz. An important consideration with all such policies is their potential to interfere with the process of creative destruction, with overly generous business and employment support schemes capable of creating zombie firms and/or zombie jobs. In one of many articles devoted to zombification, the *Economist* (26/09/2020) has expressed these concerns colourfully, warning that the corporate landscape has changed from one populated by

"…red-blooded creatures of creative destruction…" to a grey zone of "…the living dead, incapable of innovation or dynamism." The danger is that as economies emerge from the pandemic, firms that should be allowed to fail will remain on life support, which in turn will reduce productivity through credit and employment misallocation. This concern has been widespread ever since Japan's lost decade of the 1990s. Multinational financial services company Allianz SE (2020) has quantified these concerns, predicting that pre-crisis activity levels will not return until late 2021, and that in the interim support schemes will continue in changing form. On this basis, they estimated that in the five largest European countries nine million workers are likely to become unemployed in 2021 because of the delayed recovery and a policy cliff effect. They call these jobs zombie jobs, accounting for 6% of total employment. They also foresee an unwillingness of zombie workers to move from protected sectors to more productive unprotected sectors, highlighting the need for targeted labour market policies.

Calvino et al. (2020) have chronicled a declining business dynamism since the turn of the century, its heterogeneity across countries and sectors, and its implications for aggregate economic and social outcomes, using firm-level data from 22 industries in 18 countries. They attributed the decline in entry, exit and job reallocation rates to structural characteristics, including globalisation, regulatory burdens and red tape, restricted access to finance, and limited digital intensity, innovation, and skills, and proposed a set of policy reforms to enhance dynamism, foremost of which was enhancing entrepreneurship, innovation potential and skills. The OECD (2021e) has picked up soon after Calvino et al. left off, exploring business dynamism during the pandemic. They tracked business registrations and bankruptcies and found, consistent with Calvino et al. (2020), large cross-country and inter-sectoral heterogeneity in the process of creative destruction. Entry into ICT-intensive sectors and those that can accommodate remote work declined marginally and recovered quickly, while net entry into sectors relying more heavily on face-to-face contact with customers declined more severely and recovered more slowly. They proposed a series of policy interventions to foster business dynamism, including timing the phasing out of emergency support to minimise the two zombie problems, supporting the adoption of productivity-enhancing digital technologies and their diffusion, and minimising transitory firing and re-hiring costs and the loss of potential output by supporting the transition to new jobs, especially for more disadvantaged groups of workers.

Laeven et al. (2020) adopted a somewhat contrary position, suggesting that this time is different, for three reasons. First, the pandemic depression has hit firms throughout the economy, some of which are only temporarily distressed, and will recover and are undeserving of zombie status. Second, banks have entered the pandemic depression with relatively high capital ratios and have little incentive to misallocate credit. Third, the large-scale government support that threatens zombification also has mitigated the liquidity squeeze and the risk that illiquidity turns into insolvency. The threat to productivity is thus overblown, although the authors suggest some useful policies. Fine-tuning credit toward viable firms with liquidity problems should minimise the misidentification problem and its zombification risk. Ensuring that banks maintain sound capital positions should minimise zombie lending.

It is essential to improve the efficiency of insolvency frameworks and bankruptcy laws. Cros et al. (2021) also suggested that this time is different, at least in France. They noted that governments face two challenges, the standard zombie problem of failure to allow unproductive firms to exit, and its opposite, allowing productive firms to exit. They found firms filing for bankruptcy in 2020 were indebted and less productive, and relatively productive firms did not file for bankruptcy. They concluded that the normal selection process was not distorted, and Schumpeter did not catch COVID-19.

Andrews et al. (2021b) have provided evidence that this time is different in Australia. They used high frequency Australian Tax Office data on employment and firm-level measures of labour productivity, financial constraints, and relevant controls to generate a sample of over 400,000 observations on cumulative employment change from March 2020 to November 2020. They found employment change to be significantly and positively related to firm labour productivity, and the probability of firm exit to be significantly and negatively to firm labour productivity. Reallocation and exit enhanced productivity. When they added a policy variable that emphasised job preservation over reallocation ("JobKeeper"), they found this variable reinforced the reallocation impact; reallocation was stronger in local labour markets that had a higher proportion of workers on JobKeeper. More productive firms, especially financially constrained firms, were more likely to take up the subsidy, thus preventing scarring effects. However, they argued that the policy became more distortive over time, and if it had not been phased out the productivity-enhancing reallocation may not have occurred.

Revoltella (2020) summarised the findings of a 2020 European Investment Bank survey of EU businesses. Short-term uncertainty concerning the timing of vaccine development and deployment, the depressed state of consumer demand and the parlous state of business finances has caused businesses to reduce or delay investment projects. Long-term plans include adjustments to global value chains, updated product and service mixes, increased digitisation of operations, and reductions in employment. Based on these findings, Revoltella predicted simultaneous job destruction and creation, across occupations and regions, creating a need for policies that would enhance mobility, education, and retraining. These policies would support resilience during the "twin transition" to a new normal green recovery. Across the channel in an edited volume, McCann and Vorley (2021) have surveyed the social, regional, economic, labour market and productivity impacts of the pandemic in the UK, at national and business levels, and considered the policy options available, as of mid-2020.

The academic literature has evinced an almost instant recognition of the economic and public health significance of the 2020 pandemic depression. In addition to a flood of working papers, we also have two new peer-reviewed academic journals devoted to vetted real-time economic analysis of the pandemic, *Covid Economics,* from the Centre for Economic Policy Research, and *The Economics of the Coronavirus Crisis,* from *Intereconomics / Review of European Economic Policy*.

4. Climate Change and Productivity

A pandemic is (arguably) an exogenous shock to an economy, while climate change is (again, arguably) endogenous to some agents and exogenous to others. A pandemic also is relatively short-lived, while climate change is a continuing event. In contrast to the pandemic depression, climate change has attracted a multitude of studies directed toward its impact on productivity. This may be because it has been occurring for centuries and is approaching a tipping point, whereas the pandemic depression began in 2020.

Estimating the economic damages from climate change, and the economic cost of limiting the damages, is extremely difficult, as Auffhammer (2018) explains. This has not deterred forecasters, however, with predicted costs of abating global warming very large and predicted costs of failure to abate larger still. To provide an idea of the magnitude of the likely cost of limiting global warming to the 2015 Paris Agreement 1.5°C aspirational level by the IPCC date range of 2030-2052, van Vuuren et al. (2020) have constructed a meta-model from climate and integrated assessment models to generate an estimate of the cumulative abatement cost of meeting the target. Using a 5% discount rate, their median estimate of the cost is 30 trillion USD, with a 90% confidence interval of 10-100 trillion USD. To put this estimate in perspective, the 2020 EU GDP was approximately 15 trillion USD. Sanderson and O'Neill (2020) have estimated the cost of achieving a 2°C (1.5°C) target at 17% (35%) of global GDP by 2035 if mitigation efforts begin in 2020, with an incremental cost of delaying mitigation efforts of 5 trillion USD annually. Swiss Re Institute (2021) has predicted a 14% contraction in world GDP relative to a no global warming scenario under the most likely outcome of a 2.6°C increase by mid-century. This predicted contraction declines to 11% if a 2°C target is met and declines further to a 4.2% contraction if the Paris Agreement target of "well below 2°C" is met. Thus, the cost of failing to meet the Paris Agreement target, but meeting the most likely target, is nearly 10% of world GDP. These predicted costs have large standard errors attached, and are unevenly distributed, with the Middle East, Africa and Asia experiencing relatively large economic declines.

A prominent source of global warming is greenhouse gases. They are external effects consisting of carbon dioxide (CO_2) emissions from fossil fuel combustion for electricity generation, transport and cement production, methane (CH_4) emissions, far more potent over a twenty-year period than CO_2, from agricultural livestock and the extraction, liquification and transport of natural gas, and a few other gases, some more powerful, others longer lasting. At this point, a warning is appropriate. It is not always clear whether reported greenhouse gas emissions refer to CO_2 emissions exclusively, or to CO_2-equivalent emissions, which include the weighted contributions of CH_4 and other greenhouse gases. This lack of clarity is significant because CH_4 emissions account for 80% of agricultural emissions and 16% of total emissions.

In the latest in a series of documents chronicling the emissions gap, loosely defined as the difference between current global emissions trends and those required to meet climate mitigation pledges under the Paris Agreement, The United Nations Environment Programme (UNEP) (2020) reported a large and growing gap, despite a

temporary reduction in emissions during the pandemic depression. It devoted a chapter to the potential of the ongoing pandemic fiscal rescue and recovery measures to close the emissions gap and concluded that generous spending has so far supported the global status quo of carbon-intensive production. It proposed several actions required to reach net zero emissions by 2030, including improved agricultural management and decarbonisation of the energy, transport and building sectors. I return to public policies designed to stimulate these and other actions below.

Since these effects are externalities emanating primarily from production activities (some consumption activities create environmental externalities as well; see Zhou (2018) for a conceptual model and an empirical application to the environmental performance of consumer durables such as passenger cars that create air pollution as a by-product of their provision of consumer transportation services), two issues naturally arise.

One is the impact on the productivity of the externality source of a regulated reduction in emissions, an important policy application of the Porter (1991) hypothesis. Porter claimed that "[t]he conflict between environmental protection and economic competitiveness is a false dichotomy". This claim has generated a plethora of empirical studies testing the hypothesis, varying in their definitions of environmental protection and economic competitiveness, and differing in their findings. A "weak" version of the hypothesis, which asserts that properly designed environmental regulation spurs innovation, has found extensive support. However, a "strong" version, which asserts that regulation spurs innovation that enhances firm performance, as measured variously by competitiveness, productivity, or financial performance, has not found much support. What support that does exist explores the missing link between the weak and strong versions, the impact of innovation-induced environmental performance on economic and financial performance. Ambec et al. (2013) and Dechezleprêtre and Kruse (2018) have provided broad surveys of the empirical literature examining the impact of environmental regulation on the environmental and financial performance of business. They found that environmental regulation tends to improve business environmental performance without weakening financial performance.

Albrizio, Kozluk and Zipperer (2017) have examined the impact of environmental regulation on productivity at industry and firm levels in the OECD during 1990-2009, using the OECD's Environmental Policy Stringency (EPS) indicator, which includes market-based instruments such as taxes and trading schemes, and non-market instruments such as standards and limits. They found a tightening of the EPS indicator had a positive short-term effect on industry productivity growth for the most productive industries in the most technologically advanced countries. At the firm level, only the most productive firms reaped productivity gains following a tightening of EPS, a difference the authors attributed to entry and exit dynamics, with the exit of the least productive firms raising industry productivity. High productivity firms benefit, while low productivity firms suffer. Dechezleprêtre, Nachtigall and Stadler (2020**)** have estimated the effect of environmental policy stringency on manufacturing employment and

broadened the scope of environmental regulation to include energy prices, an important concern for policy makers and a consequence of carbon taxes and cap-and-trade mechanisms, together with the OECD's EPS indicator. Their study covered the OECD during 2000-2014, at sectoral and firm levels. At the sectoral level, increases in energy prices and EPS have a small statistically significant negative on employment, with elasticities on the order of -0.07 and -0.06 respectively. At the firm level, higher energy prices have a small statistically significant *positive* impact on employment in surviving firms, with elasticity 0.07, whose expanded output and employment is a consequence of firm exit from the sector. Increases in EPS do not affect entry and exit, and so reduce employment in surviving firms, with statistically significant elasticity -0.04. The authors emphasise two facets of their empirical analysis, a wide variation in impacts across sectors, and transition costs of enacting stricter environmental policies, particularly those leading to higher energy prices, as some workers are forced to exit sectors and regions.

Dechezleprêtre and Sato (2017) have extended the analysis of the impact of environmental regulation on business competitiveness to include the pollution haven hypothesis, which asserts that stringent regulation drives polluting firms and employment toward pollution havens, countries or regions with relatively lax environmental policies. Their review of the recent empirical literature found weak evidence for the hypothesis, although the magnitudes of these effects are small, compared with those of other determinants of trade and investment location, and support tends to be concentrated in energy-intensive sectors in which environmental regulatory costs are significant and cannot be shifted easily to consumers.

The OECD (2021d) has summarised evidence from a decade of OECD research into the impacts of environmental policies on business performance, employment, the Porter hypothesis, and the pollution haven hypothesis. It found environmental policies to have been effective at reducing emissions from industry, while having had relatively small impacts on economic outcomes such as employment, investment, trade and productivity. It also found that environmental policies generated winners and losers, with more productive firms from low-polluting sectors and regions benefitting at the expense of less productive firms from high-polluting sectors and regions.

The second issue, which has attracted far more attention, concerns the impact on the productivity of the rest of an economy, or the rest of the world, of a change, historically an increase, in emissions from the externality source. This issue is of growing concern in part because the source of emissions is predominantly high-income countries, while the negative effects disproportionately affect low-income countries. Tol (2018) updated his previous review of the economic impacts of climate change, surveying the literature on the total economic impacts and their distribution around the world. He summarised the aggregate impact somewhat controversially as "…no worse than losing a decade of economic growth", and its geographic variation by noting that poorer countries are more vulnerable to climate change than richer ones, because of their reliance on weather-dependent agriculture, their location in

malaria-prone hot places, and their limited adaptive capacity. He also cited empirical evidence showing that climate change has an impact on economic growth, and perhaps on its productivity growth driver, although its impact on productivity growth has received insufficient attention in the literature.

In this Section, I touch on five topics related to climate change of relevance to productivity analysis. The first is adaptation, the first line of defence. The second concerns its impacts on agriculture, which are particularly severe and inequitably distributed. The third concerns its impact on business, whose managements must adjust their business models to adapt. The fourth is its impact on productivity, the ultimate concern here. The fifth is the pursuit of public policies, including promoting investment in adaptation opportunities, designed to reduce its impacts. These topics are inter-related, so the allocation is somewhat arbitrary.

The topics omit an increasingly significant form of environmental damage, the depletion and degradation of natural capital surveyed by Costanza and Daly (1992) and Guerry et al. (2015). A related omission concerns the development of a suitable accounting framework for valuing natural capital and its ecosystem services. Important contributions have been made by Costanza et al. (1997) who valued global ecosystem services at 16-54 trillion USD a quarter century ago, Agarwala et al. (2014), and Brandon et al. (2021) at the aggregate level, and by Barker (2019) and Freiberg et al. (2020) at the business level. An accounting framework can enhance efforts to incorporate natural capital in the estimation of an augmented model of productivity change and levels initiated by Brandt et al. (2017), Cárdenas Rodríguez et al. (2018) and Freeman et al. (2021) discussed below.

For an insider's view of the difficulties encountered in attempting to implement a policy agenda for dealing with climate change I recommend Garnaut (2019), who has provided an accessible survey of the economic and political issues involved, with a global perspective against an Australian backdrop.

Adaptation and Vulnerability

Climate change is multidimensional, including global warming, melting glaciers and rising sea levels, and climate-related extremes such as heat waves, droughts, floods, cyclones and wildfires. The year 2021 has witnessed all of the above, from drought in southern Africa to heat extremes and wildfires in western North America and southern Europe to floods in Germany, Belgium and China and typhoons in the western Pacific. The World Meteorological Organization has assessed that the world was already 1.2°C above pre-industrial levels in 2020. Evidence to date suggests that we are likely to surpass the 2015 Paris Agreement aspirational goal of 1.5°C above pre-industrial levels, and by no means guaranteed to achieve its 2°C target. This makes investment in adaptation to a warming climate, both public and private, critically important. Whether adaptation activities take on a green hue or enhance productivity depends on business practices and government policies.

The IPCC (2014) noted that societies have been adapting to climate change throughout history, with varying degrees of success. It defined adaptation as the

process of adjustment to actual or expected climate change that seeks to avoid or moderate harm or exploit beneficial opportunities. It also recognised multiple constraints to adaptation, including knowledge, awareness and technology constraints, physical and biological constraints, economic and financial constraints, human resource constraints, social and cultural constraints, governance and institutional constraints, and competing values among participants. The significance the IPCC attaches to adaptation is demonstrated by its allocation of four chapters, nearly 150 pages, to addressing adaptation needs and options, planning and implementation, constraints and limits, and economic aspects.

Mendelsohn (2000) viewed adaptation, both ex ante and ex post, as an important moderating link between environmental change and the final consequences to society, and enumerated adaptation strategies across market sectors. He stressed the significance of efficient adaptation from a cost-benefit perspective and was sceptical that adaptation would be efficient. Although self-interest motivates most agents to engage in efficient *private* adaptation, it may not motivate them to support an efficient level of *social* adaptation, which generally requires government action, although political forces are likely to lead governments to engage in inefficient adaptation. Anderson et al. (2019) stressed the critical role played by markets, especially urban, coastal, and agricultural land markets, in efficient climate change adaptation by means of price signals. They acknowledged that markets might not contain a sufficient number of traders or allow flexible prices, and when these conditions are not satisfied market-driven adaptation declines, creating a role for government, although achieving an efficient outcome is likely to be politically difficult. History has demonstrated that the concerns expressed by Mendelsohn and Anderson et al. were well founded.

In the fourth of a series of adaptation gap reports, the United Nations Environment Programme (UNEP) (2018) has defined an adaptation gap as the difference between that required to achieve a societal goal and that actually achieved, and has encouraged target-setting and data generation, with an ultimate objective of measuring these gaps across nations and through time. To date it has emphasized adaptation in financing and health. It concludes that the gap between higher-income and lower-income countries has narrowed over the last two decades. The adaptation health gap is “significant”, and the finance gap remains “considerable” and likely to increase significantly in the future. The emphasis on gaps brings to mind something similar to Kaplan’s pandemic possibility frontier, with climate change substituted for pandemic and inspiration drawn from the literature on productivity dispersion and distance to frontier.

The OECD views adaptation as indispensable to saving lives and livelihoods, to addressing inequalities exacerbated by climate change, and to safeguarding natural capital. Among the adaptation measures the OECD cites are adapting to sea level rise, maintaining infrastructure resilience to global warming and a range of extreme events, securing natural capital, and boosting disaster risk reduction. The OECD

stresses the importance of safeguarding natural capital and emphasised the role played by nature-based solutions, concentrated in forestry, agriculture and land management, coastal ecosystem protection, freshwater management and urban planning. It also acknowledged challenges to implementation of nature-based solutions, including organisational co-ordination, methodological and valuation, regulatory, and financial. Additional information is available on the OECD website (https://www.oecd.org/env/cc/climate-adaptation/).

The EU adaptation strategy has four components. Improving knowledge about adaptation, including more and better climate-related risk and loss data, and improving adaptation planning, including fostering local, individual and just (a popular word in the climate change literature) resilience, are foremost. Including climate resilience in national fiscal frameworks, and promoting nature-based adaptation, accelerating adaptation action, including by closing the climate protection gap and ensuring freshwater availability and helping to strengthen adaptation globally, follow. Information on adaptation is available on the EU Climate-ADAPT website (https://climate-adapt.eea.europa.eu/), a partnership of the European Commission and the European Environment Agency.

Societies may adapt to climate change and variation, and what remains after adaptation is vulnerability.

The IPCC (2014) defined vulnerability as the extent to which climate change may adversely affect a system, depending on a system's exposure and sensitivity to harm, and its ability to adapt to new climatic conditions. It also noted the inequity of vulnerability, asserting that people who are socially, economically, culturally, politically, institutionally, or otherwise marginalised are especially vulnerable, to which it added those subject to large-scale violent conflict that harms assets that facilitate adaptation, including infrastructure, natural resources, social capital, and livelihood opportunities. Kelly and Adger (2000) viewed vulnerability as the endpoint of a sequence of events beginning with climate change or variability and continuing with adaptation, leaving vulnerability as determined by the adverse consequences that remain after the process of adaptation has taken place. There remains the challenge of constructing a set of reliable vulnerability indicators that can inform public policy. Eriksen and Kelly (2007) have critically surveyed five national-level studies and noted the lack of agreement on a credible set of indicators, concluding that existing indicator sets display a number of weaknesses that limit their usefulness in developing adaptation policy. Subsequently the Notre Dame Global Adaptation Initiative (https://gain.nd.edu/) has developed a set of vulnerability indicators for six sectors (food, water, health, ecosystem services, human habitat, and infrastructure) in 181 countries through time. Within each sector vulnerability is a function of two exposure indicators, two sensitivity indicators, and two adaptive capacity indicators. The Initiative thus enables the use of standard index number procedures to construct adaptive capacity and vulnerability indices across countries and through time.

Edmonds et al. (2020) have used these data to construct a new endogenously weighted composite index of climate change vulnerability for each country, the structure of which was very different from the fixed weight structure of most composite

environmental indices such as the popular Yale Environmental Performance Index of Wendling et al. (2020). The new index has three virtues. It is possible to interpret the endogenous weights as shadow values of each component, which in principle can provide guidance for adaptation policies. The shadow values support a test of the hypothesis that one or more components is superfluous to the evaluation of vulnerability and can be deleted from the index. The composite index forms the basis of a climate change vulnerability frontier, relative to which dispersion and gaps can be calculated, both across countries and through time. Like the pandemic possibility frontier of Tisdell (2020), Kaplan (2020), and Acemoglu et al. (in press) the climate change vulnerability frontier has great potential to inform resource allocation, both across countries and across components within countries.

Countless studies of adaptation and vulnerability exist.

Behrer and Park (2017) have studied a panel of weather, payroll, and air conditioning data across US counties during 1986-2011 to assess the impact of hot weather on labour, and the regional variation in adaptation in non-agricultural sectors. They found payrolls declining with increasing heat, with an elasticity of -0.22%, the marginal impacts much higher in highly exposed sectors such as construction, and much lower in very hot regions that adapt with air conditioning and other measures than in relatively cool regions that adapt less extensively due to the lower frequency of hot days. Finally, they estimated future lost payrolls under a no-adaptation scenario to exceed by half future lost payrolls under a mean observed adaptation scenario. Deryugina and Hsiang (2017) have conducted a similar study of the effect of heat on production in a panel of US counties during 1969-2011. They found a strong and stable relationship across time, space, and seasons, with hotter climates having lower average production or revenue per capita, with differences ranging up to 2,000 USD annually. These findings were qualitatively similar for non-agricultural and agricultural sectors. They also estimated the value of projected changes in US production due to 21st century warming at -6.7 trillion constant USD, net of all currently available adaptation technologies. Gourio and Fries (2020) have modified an analytical model of the sensitivity of income to temperature with an element of heterogeneity, augmented this model with a model of adaptation, and used it to estimate the sensitivity of income to temperature variation across US counties. They find that adaptation to rising temperatures reduces both the median and the dispersion of income losses, with magnitudes depending on the flexibility of adaptation activities. In all three studies the monetary benefits of adaptation, or the monetary costs of failure to adapt, are apparent, but as Behrer and Park note, adaptation may come at substantial costs, and these studies did not incorporate adaptation costs. Nath (2020) did, at least implicitly. He studied the impact of temperature on sectoral reallocation around the world and found that extreme heat reduced non-agricultural output per worker, but by less than in agriculture. This implied that hot countries could adapt by reallocating resources from agriculture to manufacturing. This did not happen, since subsistence food requirements dominated comparative advantage, with a perverse reallocation effect that exerted downward pressure on global GDP.

McLeman and Smit (2006) have surveyed human migration patterns through history and interpreted migration as an adaptation strategy for climate change and variation, with an empirical example of 1930s migration from drought-stricken Oklahoma in the US. Oliveira and Pereda (2020), Branco and Féres (2021) and Mullins and Bharadwaj (2021) have incorporated adaptation costs into their study of labour migration. Oliveira and Pereda used a spatial equilibrium model in their study of internal migration in Brazil, which has large regional climate variation. Among their findings were increased migration rates under an assumed future hotter scenario, a decline in agricultural employment and productivity, a deepening of existing regional inequalities in population and income, with initial losses mitigated by housing price declines in the negatively affected regions. However, when migration costs are incorporated, including rising housing prices in destination regions, migration is reduced. Their major conclusion was that the least developed northeast region will lose population and be worse off, while the most developed southeast region will gain population and be better off, with losses and gains varying with migration costs. Branco and Féres studied agricultural labour migration in northeast Brazil, which is increasingly susceptible to drought. In their analysis, adaptation through migration is not geographic, but occupational. They found increased drought conditions caused family members to reduce their agricultural labour supply and hold a secondary non-agricultural job. Mullins and Bharadwaj studied migration decisions in the US as adaptive responses to temperature changes. They found that migration responded to expectations regarding local implications of climate change, but not to temporary temperature variation. They did not consider the sensitivity of the migration-temperature relationship to variation in migration costs. Both studies analysed internal rather than international migration, which faces additional barriers. Both studies found adaptation in the form of internal migration leading to resource reallocation likely to raise aggregate productivity. While these studies focused on climate-driven labour migration in Brazil, Albert et al. (2021) examined the impacts of drought on the migration (which they usefully call reallocation) of capital as well as labour in Brazil. They found affected regions experienced capital outflows as investment opportunities declined, as well as population and employment outflows, concentrated in agriculture and related services.

While on the subject of Brazil, it seems appropriate to mention Amazonia, home of the world's largest tropical forest and heretofore an important carbon sink. However, in a recent study in *Nature,* Gatti et al. (2021) have found that western Amazonia remains a weak carbon sink, but deforestation, drought and fire in eastern Amazonia have reversed the role of this region from carbon sink to carbon source.

Somanathan et al. (2021) have studied the impact of temperature on worker performance in plants and firms across industries in India. They find that an increase in temperature of 1°C reduces the productivity of those at work by 2.1% and increases absenteeism, which reduces aggregate productivity. Using a panel of 438 districts over 21 years they estimate the impact of a 1°C increase in temperature on district output of about 3%. They speculate that value added per worker in some sectors may be too low to justify adaptation through costly investment in climate control.

International trade is another important adaptation mechanism, enabling the exploitation of regional differences in climate change impacts, and a particularly significant adaptation mechanism in agriculture. Costinot et al. (2016) and Janssens et al. (2020) have studied a critically important adaptation role of international trade, its potential to reduce hunger, and thereby to increase productivity, by exploiting specialisation and comparative advantages. Costinot et al. noted that climate change affects agricultural production differently for different crops and in different regions, creating the potential for trade to reallocate production and dampen the aggregate impacts of climate change. They used the Food and Agriculture Organisation's Global Agro-Ecological Zones data containing geographic and climate information and predicted crop yields for 1.7 million grid cells around the world to predict the aggregate impact of various IPCC climate change scenarios on the productivity of ten crops. They found climate change would reduce global GDP by a modest 0.34% under existing cropping patterns and international trade arrangements, but if both adjusted optimally, the reduction would decline to 0.26%. Janssens et al. studied the consumption, as well as the production, of food under alternative climate change scenarios, and found the impacts to be far from modest. They analysed 60 integrated scenarios that capture variability in trade barriers, which are particularly high for food products, and alternative climate projections, and have calculated that, under current levels of trade integration, climate change would make 55 million people undernourished by 2050. Without adaptation through trade, the number would increase by a third, and with reductions in tariffs and other institutional and infrastructural barriers, the number would decline by two thirds. The gains from reducing trade barriers accrue largely to import dependent regions and regions that increase agricultural exports. For a qualification directly related to trade in food products, see Nath above.

If international trade is a significant adaptation mechanism, it follows that domestic trade can have a similar impact. Dall'Erba et al. (in press) have studied interstate trade in agricultural crops in the US, where over 90% of production is consumed domestically and trade barriers are absent, as an adaptation strategy to climate change, in particular drought. Their initial finding was that a crop grower's production and profit are hampered by local drought and enhanced by drought in destination locations. They predicted domestic trade to convert a drought-induced loss absent trade into a profit, a domestic finding analogous to the international finding of Costinot et al.

Agriculture

Because agriculture is particularly sensitive to the vagaries of the weather, with climate change expected to reduce agricultural productivity by as much as 15% by 2050, and since crop productivity is commonly measured by easily observable yield, crop output per area, it has attracted a large volume of research into the impacts of climate change. The following studies illustrate the diversity of issues involved and the importance of developing flexible models of the relationship.

Gornall et al. (2010) surveyed the literature as at 2010 on the expected impacts of climate change on global agricultural productivity as measured by crop yields through 2050. They considered a variety of indicators of climate change, including

mean climate, climate variability and extreme weather events of temperature and rainfall, pests and diseases, and mean sea-level rise. They found some impacts, such as those of extreme temperatures and draught, and extreme rainfall and flooding, easy to predict, at least qualitatively, and other impacts, such as sea-level rise, to be context-dependent, varying on the timing and location of the event. To these impacts, we can add labour migration out of agriculture, which has its own consequences.

Some studies have used US county-level data to study adaptation to climate change in agriculture. Burke and Emerick (2016) invoked the Le Chatelier principle to explore the implications of short- and long-run adaptation to climate change in US agriculture, with counties the unit of observation, climate change measured by temperature and precipitation, and the two dominant crops of maize and soy as outputs. They found crop productivity to be more sensitive to temperature than precipitation and, consistent with the Le Chatelier principle, long run adaptation reduces yield losses by at most 25% more for maize and 32% more for soy than short-run adaptation. However, these estimates come with large standard errors attached, and it was not possible to reject the hypothesis that long run adaptation is no more effective than short run adaptation. They considered various explanations for their findings, including policy disincentives to adapt, primarily crop insurance programs that insure farmers against climate-related losses. Once again, the design of public policy is an important determinant of productivity. Malikov et al. (2020) focused on more than the mean of the distribution of climate impacts on US agriculture, reasoning that commonly used reliance on means conceals valuable information contained in the rest of the distribution. They employed a quantile regression model that allowed for distributional heterogeneity and temporal variation in the dependence of maize yields on climate changes, using data from US counties during 1948-2010. They found considerable distributional heterogeneity across yield quantiles, with marginal climate effects smaller in absolute value for higher yield quantiles. They also found a declining temporal responsiveness of yields to weather variables, particularly at high-yield quantiles, suggesting that technological and managerial advances have reduced sensitivity of yields to climate effects. Projecting their findings into the future, they found conventional time-invariant models to over-estimate adverse climate impacts on yields relative to a time-varying specification, with some time-invariant yield reduction projections being more than twice as large as their time-varying counterparts, particularly at low-yield quantiles.

Other studies have used US state-level data to study adaptation to climate change in agriculture. Wang et al. (2019), Chambers and Pieralli (2020), and O'Donnell (2021) have used US state-level data to study the impact of weather and climate change on agricultural productivity. These studies used the same economic data, a state-by-year panel of three outputs and four inputs covering 1960-2004 available at https://www.ers.usda.gov/data-products/agricultural-productivity-in-the-us/, although they used these data to measure productivity very differently. Wang et al. added two climate variables, a temperature-humidity index that measures the effects of extreme heat and humidity on livestock production, and an aridity index that measures the effects of rain deficit on crop production. They found productivity to have been mildly sensitive to *long term trends* and interstate variation in both climate variables, but that both impacts have diminished through time as states have adapted

to changing climate conditions. However, *unexpected shocks* of both types have had substantial productivity impacts. Chambers and Pieralli added two different climate variables, matched data on growing degree-days and moisture. They used these data to construct an agricultural production frontier incorporating observed weather variables to estimate agricultural productivity change using nonparametric techniques, which they decomposed into four components: technological change, weather-related shifts in the frontier, aggregate input growth, and efficiency change, which the authors call adaptation to the frontier. They found productivity growth dominated by technological progress, with the two climate variables contributing a small negative impact that varied substantially across Climate Hub Regions. O'Donnell added three different weather variables, a pair of heat indicators and a precipitation indicator. He found the main drivers of productivity change through time to be technical change and change in scale and product mix efficiency, and the main drivers of productivity variation across states to be variation in time-invariant production environments (e,g,, soil type and terrain) and variation in scale and product mix efficiency. Consistent with the findings of Chambers and Pieralli, O'Donnell found intertemporal change and interstate variation in weather variables to have exerted a relatively small impact on US agricultural productivity.

Reidsma et al. (2010) studied adaptation to spatial and temporal climate variability in European agriculture, using data from the Farm Accountancy Data Network during 1990 – 2003. The authors noted that climate variability affects farm productivity and farm financial outcomes, and stress that adaptation, defined as the difference between potential impacts as simulated by crop models and actual impacts based on observed data, is best analysed at the farm level. They found the impacts of climate variability differed through time and regionally, and adaptation to impacts depended on farm characteristics such as farm type and location, intensity, and size, and on the quality of management practices, including production practices, financial management and technology adoption. Management matters in agriculture.

More recently, the European Environment Agency (2019) has explored the interactions between climate change and European agricultural productivity. Crop and livestock production generate greenhouse gases, particularly CH_4, and are influenced by temperature and precipitation patterns. These influences can be positive or negative, depending on several factors including topography, location (the Mediterranean basin is at high risk), and adaptation strategies. The EEA assessed the risk for agriculture of a 1.5°C global warming above pre-industrial levels as medium to high, and the change in risk of moving from a 1.5°C increase to a 2°C increase as large, with a medium to high degree of confidence. The EEA proposed numerous adaptation strategies at farm level, generally by improving farm management practices including crop diversification and rotation, improvement of irrigation efficiency and adoption of precision and organic farming. It also proposed expanding the adaptation component of the EU Common Agricultural Policy.

Australian agriculture is particularly sensitive to climate change and variability, and the impacts have been studied extensively. Hughes et al. (2019) and Hughes and Gooday (2021) have estimated the impacts of climate change on the profitability of cropping and livestock sectors since 2000. Controlling for non-climatic factors, the

authors estimated that climate changes have reduced average farm profit by 22% - 23%, with wide variation across regions and between cropping and livestock. They also found that productivity gains have helped offset adverse climate financial effects, and they found management practice changes and technology gains as additional adaptation strategies.

Business

The impacts of climate change on business are significant because government policies influence these impacts, and because business impacts aggregate to macro impacts. As a seemingly ancient introduction, McKinsey & Company (2015) identified six risks climate change imposes on business, including three value chain risks and three external stakeholder risks, and proposed adaptation strategies to deal with each that would minimise impacts on business performance. More recently, the *Economist* (17/09/2020) called the impact "the great disrupter" and identified channels through which climate change has influenced business behaviour, and how government policies have influenced the relationship. These channels include the disruption of global supply chains, the increasingly intense regulation of emissions, (the paucity of) carbon pricing, a growing risk of climate litigation, a growing incentive to orient process and product innovation away from fossil fuels toward the use of renewable resources such as the sun and wind, and the development of requisite improvements in energy storage capacity. Adaptation strategies to deal with these disruptions include geographical variation and decarbonisation of supply chains, selling dirty assets and buying clean assets, finding cleaner energy sources, and investing in new low-carbon products and services. Some strategies are more costly than others and have larger productivity impacts.

Many of these issues, and more, have been raised in the business press. In one of many studies of the impacts of climate change on business, McKinsey & Company (2020c) emphasised the growing risks to business performance posed by climate change, especially its impacts on global supply chains, which are "optimized for efficiency, not resilience". They suggested (costly) business strategies for adaptation, including the maintenance of buffer inventories and sourcing from different suppliers across multiple regions. McKinsey & Company (2020g) stressed the economic and employment opportunities associated with an investment in climate-resilient infrastructure and the transition to a lower carbon future. Their pathway to a 1.5°C future involves reforming agriculture, a major source of methane gas, and forestry, an important and shrinking carbon sink, electrifying transport, buildings and industrial operations, decarbonising power, and fuel, and increasing carbon capture and sequestration. Deloitte (2020) conducted a survey of over 1,000 European CFOs, who revealed growing pressure to act from a broad range of stakeholders. Despite the growing pressure, few companies have analysed risks or have governance structures in place and have reacted largely by pursuing short-term cost-saving strategies and setting emissions reduction targets not aligned with the 2015 Paris Agreement. Deloitte does however point to potential business opportunities such as improving energy efficiency, creating new products or services that are less energy-intensive,

and enhancing the resilience of their supply chains. Each of these strategies has the potential to improve business productivity, holistically if not conventionally defined.

Adhvaryu et al. (2020) have provided an example of the impact of the adoption of energy-saving technology on business productivity, based on daily production patterns in a sample of 26 garment factories over three years in India. They first demonstrated nonlinear negative relationships between an index of temperature and humidity and both factory productivity (defined as the ratio of actual to target output), and worker attendance. They then demonstrated that the introduction of LED lighting raised productivity, although not attendance, on hot days, yielding both a savings in power consumption cost and a pure productivity bonus, shortening the break-even period for the investment by 80%.

A growing literature, beginning with Bloom and Van Reenen (2007), has emerged demonstrating a positive relationship between the quality of management practices and various measures of business performance, including productivity. Recognising that increased productivity might come at the expense of the environment, Bloom et al. (2010) extended this literature to include greenhouse gas emissions as an indicator of business performance. They combined production data from the UK Office of National Statistics with management data from a survey conducted at the London School of Economics to relate the three variables. They found a strong positive correlation between the quality of management practices and business labour and total productivity, with an improvement in the quality of management practices from the 25th to the 75th percentile increasing total productivity by 3.7%. They also found a strong negative correlation between the quality of management practices and business energy intensity, an important source of greenhouse gas emissions, with an improvement in the quality of management practices from the 25th to the 75th percentile reducing energy intensity by 17.4%. Management matters for the environment. While Bloom et al. studied the impact of business production on the environment, Adhvaryu et al. (in press) reversed the role of the environment in their study of the Indian garment sector, by exploring the adverse impact of exogenous air pollution on worker productivity, and the role of good management practices in mitigating this impact. They found a one standard deviation increase in air pollution decreases worker productivity by about one percent of mean productivity, but by more for some workers and tasks than for others. They also found, using a management survey similar to that of Bloom et al., that high-quality managers who monitor workers more intensely and notice productivity declines are more likely to reassign the most affected workers to less exposed tasks, thereby reducing the adverse productivity impact. These two studies are contextual, but they provide strong evidence that management is central to the relationship between business and the environment, influencing both the impact of business on the environment and the impact of the environment on business.

Adaptation opportunities can be constrained. De Haas et al. (2021**)** have studied the impacts of two constraints on the ability to invest in new green technologies to reduce the carbon footprint of more than 11,000 firms in 22 European emerging markets. They found credit constraints, especially following the financial crisis, to have varied across banks and therefore across localities, and to have inhibited the ability of

firms, particularly small firms, to access external funding for investment in new green technologies. They also found green management practices, represented by prior experience with extreme weather events, to have enhanced investment in new green technologies. Based on these findings, they recommended policies that ease access to bank credit for green investments, and policies that strengthen business environmental reporting requirements.

Beltramello et al. (2013) have stressed the important role of radical and systemic eco-innovation in business green growth. The adoption of novel innovations boosts business productivity, energy efficiency, and cost competitiveness, and enhances business value creation. However, adoption depends crucially on the quality of corporate governance and the supportive nature of policy initiatives at national and local levels. It also encounters barriers, both internal and external. Internal barriers include a lack of knowledge of sustainability matters, risk aversion, a paucity of reference cases, or role models, and rising development and adoption costs. The lack of adequate size is a frequently mentioned barrier to adoption. External barriers include lack of government support, regulatory barriers and subsidies, finance and administrative constraints, and a lack of knowledge among stakeholders of the economic benefits of green growth. Based on 55 case studies from 14 OECD countries, they demonstrate a growing recognition by business managements, stakeholders, and policy makers that green business models offer a new avenue for value creation. A complementary literature demonstrates that innovation of all colours can be productivity enhancing. Nadeem et al. (in press) have explored the impact of a business' organisational capital, consisting of business practices, systems, and culture, on its propensity to invest in eco-innovation, using data on US businesses during 2002-2018. They found significant positive relationships between organisational capital and both environmental process innovation (e,g,, reductions in emissions, natural resource usage, and waste) and environmental product innovation (e.g., product environmentally responsible use, sustainable building products). These findings survived the splitting of the sample into high- and low-profitability subsamples and high- and low-environmentally sensitive industry subsamples.

"If you can't measure it, you can't manage it" is a maxim often, and incorrectly, attributed to Peter Drucker. Regardless of its source, it is particularly appropriate to the role of management in dealing with climate change. A growing number of studies, within and beyond academe, have recommended the incorporation of environmental accounts in conventional corporate reports. Kareiva et al. (2015) focused on multinational corporations for their size and reach and noted that the integration of environmental costs and benefits into corporate accounts, and therefore corporate decision-making, has great potential to promote sustainable development. It would also aid in the development and implementation of a holistic measure of productivity change.

Productivity

I now turn to the impacts of climate change, most frequently in the form of temperature and precipitation, on productivity, variously defined but rarely as total productivity.

Heal and Park (2013) used country-level panel data on temperature and income to derive temperature-driven productivity impacts, and they found significant temperature sensitivity of per capita income that varies with a country's position relative to the temperate zone. In hot zones, the impact of an increase in temperature is large and negative, while in cold zones the opposite happens, both with approximately 3% - 4% productivity change per degree C. Heal and Park (2016) surveyed an "emerging" literature examining the impact of a quantifiable dimension of climate change, increased temperature stress, on labour supply and labour productivity. They cited numerous panel data studies across sectors and at plant, regional and national levels, many of which found labour supply and labour productivity responses to increased temperatures to be elastic. They did not explore the reallocation possibilities created by these opposing effects.

Gosling et al. (2018) estimated the effects of anticipated climate change on temperatures, and the impact of temperature increases on labour productivity, in several southern European countries, which the EEA noted were particularly susceptible to the adverse impacts of climate change. Without adaptation, the predicted daily average outdoor labour productivity decline would be 10% - 15% by the end of the century, smaller with adaptation, and smaller for indoor labour productivity. Cruz Alvarez and Rossi-Hansberg (2021) have documented the wide geographic variation in the impacts of global warming and have predicted large productivity and welfare losses in parts of Africa, India and Latin America, and gains in Siberia, Alaska, and northern Canada. They used a computable general equilibrium model to generate these impacts and emphasised that their magnitudes depend crucially on economic adaptation mechanisms, the extent of migration and interregional trade, and endogenous local innovation. Kalkuhl and Wenz (2020) used a novel data set of gross regional product for over 1,500 regions in 77 countries to estimate the effects of warming temperatures on productivity levels and growth rates. They found no evidence of temperature rise affecting productivity growth rates, but they found a large impact on productivity levels. They estimated that an increase in mean surface temperatures of 3.5°C through the end of the century would reduce global output, and hence output per capita, by 7% - 14% in 2100, with even larger impacts in tropical and poor regions. Each of these studies points to the importance of the design of policies to enhance adaptation.

To document the very real possibility that climate change can increase productivity, Campana et al. (2020) have used a large-scale geospatial analysis of the population dynamics of Arctic Canadian freshwater fish to predict an increase in yield per recruit, a standard measure of fishing productivity, by 20% by 2050 under current IPCC climate warming projections of 2.8°C. Moore et al. (2021) have studied the geographic migration of marine species in response to warming ocean temperatures

and have projected trends in commercial landings for 16 US fisheries during 2021-2100, under two climate change scenarios. Projections suggested increased landings for some fisheries and decreased landings for others, largely independent of climate change scenario.

Climate change involves more than temperature and precipitation. Dieppe (2020; Chapter 3) has calculated that the world has experienced 3,897 extreme climate events such as cyclones, floods and droughts during 1960-2018, most of them in emerging market and developing economies. He found these events reduced labour and total productivity by about 0.5% in the short run and had additional long run scarring effects. Sheng and Xu (2019) have explored the impact of an extreme weather event, Australia's millennium drought of 2002-2010 arising from El Niño, on productivity in Australia. Using a synthetic control method, the authors calculated that the drought reduced Australia's total productivity growth rate from its long-term trend of over 2% per annum to 0.53% per annum and reduced its total productivity level at the end of the drought by 18%. The two primary transmission channels were a decline in output per unit of input, and a reduction in profits that impeded investment in new productivity-enhancing technologies. The record heat levels and wildfires that ravaged the west coast of North America in 2021 caused large loss of life and extensive economic and environmental damage, and can be expected to have similarly dire consequences for productivity in the region.

It is possible to incorporate environmental impacts into a holistic analytical model of productivity growth. The OECD (2018) has used the conventional growth accounting methodology of Jorgenson and Griliches (1967), as augmented to account for the depletion of natural capital by Brandt et al. (2017) and augmented again by Cárdenas Rodríguez et al. (2018) to account for greenhouse gas emissions, to estimate environmentally adjusted (for greenhouse gas emissions) productivity *growth* in China. In this framework, environmentally adjusted output growth is output growth less emissions growth, and environmentally adjusted productivity growth is a residual, environmentally adjusted output growth less growth in conventional inputs less growth in natural capital. They estimated China's growth during 2000-2013 at approximately 2.5% pa, substantially lower than its unadjusted rate of growth, with a strongly declining trend. Additional estimates confirmed China's reliance on natural resources and ecosystem services at the time to fuel economic growth. Freeman et al. (2021) followed Brandt et al. (2017) in an international comparison of productivity *levels* when natural resource inputs are included, or excluded, as they are in the Penn World Tables and elsewhere. They found substantial differences in productivity levels, particularly for countries where natural resource rents account for a sizeable share of GDP. Traditional productivity levels in resource-rich countries were biased upwards relative to a US benchmark; Saudi Arabia, for example, had estimated relative productivity levels of 1.80 excluding natural resource use and 1.15 including natural resource use. To no surprise, incorporating previously missing inputs leads to significant adjustment to international productivity comparisons.

Li and Ouyang (2020) have used an alternative two-stage methodology to estimate green productivity growth in Chinese cities during 2004-2105. Although their study and that of the OECD predate the recovery from the pandemic depression, both include natural capital and the environment, and their methodologies and findings are widely applicable. Li and Ouyang started from the premise developed by Acemoglu et al. (2012) that technical progress may be directed to green or brown technologies, and although it enhances conventional productivity growth, it does not necessarily enhance green productivity growth. They incorporated three components of technical change: indigenous technical change embedded in the existing stock of knowledge in patents, technology transfers from foreign direct investment, and absorptive capacity, the ability to assimilate and apply new technologies to commercial ends and estimated the direction of technical change toward one or more of these components. They specified three inputs, labour, capital, and electricity consumption, and two outputs, GDP and sulfur dioxide emissions. They found green productivity to have trended downward during this phase of the Chinese extensive development model, which promoted rapid energy- and resource-intensive growth that made China the world's largest contributor to global greenhouse gas emissions. They also found indigenous technical change to have had an adverse impact on green productivity growth, since patents tended to protect existing brown technologies, and they found the impact of technology transfers to have been contextual, depending on a city's per capita income among other determinants. Only absorptive capacity had a positive, albeit small, impact on green productivity. They also found that environmental regulation enhanced green productivity growth in an expanded model of technical change, which provided support for the Porter Hypothesis. A new Chinese economic growth model was enshrined toward the end of the study period, emphasizing slower green growth with an energy- and resource-saving orientation augmented with restrictive environmental protection policies. Growth has indeed slowed, and the energy- and resource-intensity of GDP has declined. The direction of technical change has assumed increased significance in the debate about the structure of post-pandemic support programs and investment spending.

Chancellor et al. (2021) have developed a third approach to the estimation of total productivity controlling for the effects of climate in Australian agriculture. They used a machine learning driven micro-simulation model to predict farm level output under a variety of climate scenarios. The model predicts output production and variable input usage, conditional on commodity prices, farm fixed inputs and climatic conditions. They used Fisher output and input quantity indices based on predicted and observed variables to estimate adjusted and unadjusted productivity change during 1989-2018. The authors found long-term changes in temperature and rainfall depressed Australian farm productivity, particularly during the millennium drought at the beginning of the 21st century.

Purists prefer total productivity, but the data constraint often dictate the use of labour productivity. Aiginger (2020) has advocated the use of resource productivity, defined as output per unit of resources and energy. He noted that the European

Commission has historically used labour productivity, which an increase in fossil fuels and other natural capital per worker increases, which in turn raises greenhouse gas emissions and accelerate climate change. He argued that the use of resource productivity, which is enhanced by increases in employment and green technology, and would encourage improved environmental policies and effectively decouple economic growth from greenhouse gas emissions. The European Environment Agency also favours resource efficiency; see https://www.eea.europa.eu/themes/waste/resource-efficiency/resource-efficiency

Public Policies

Policies are, or should be, designed to promote mitigation and adaptation to climate change, with one eye looking back at the 2015 Paris Agreement and the other eye looking forward to COP 26 in Glasgow in November 2021. However, the urgency of mitigation and adaptation varies with vulnerability.

In December 2019, European Commission President Ursula von der Leyen (https://ec.europa.eu/commission/commissioners/2019-2024/president_en) stated that the newly introduced European Green Deal is "our new growth strategy", and is about reconciling our economy with our planet. An important part of the European Green Deal is a European Climate Law to set clear rules that will give investors the confidence to make long-term decisions. Later, in March 2021, she announced the support of the European Investment Bank to provide financing for the concrete policy changes adopted by the European Commission. She also acknowledged that since the EU accounts for less than 10% of global greenhouse gas emissions, there is a need for a Global Green Deal. The EU Parliament and the EU Council set into legislation the European Climate Law in June 2021. Among other things, the Law requires member states to enhance their adaptive capacity.

Documentation surrounding the European Green Deal is voluminous and growing rapidly, but it remains opaque on the "clear rules" and "concrete policy changes" for implementing the new growth strategy. Objectives abound, including improving air, water, and soil quality, protecting biodiversity, reducing waste generation, reducing health inequalities, engaging stakeholders, and making the transition "just and inclusive for all". Among the more explicit objectives are the development of a scorecard of EU regions' green performance (however measured), reducing the EU's external pollution footprint by restricting the export of products and wastes to developing countries, and consolidating the EU's knowledge centres for zero pollution. A final objective is stronger enforcement of zero pollution and other environmental authorities, a laudable goal to which I return below. Updated information is available at https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.

Wolf et al. (2021) have suggested subsidiary requirements for the European Green Deal to succeed. Net zero 2050 can only be successful if it shifts the economy to a new development path that generates broad social and political support. This

requires complementing emissions reductions with a combination of carbon taxes and direct regulation with green public investment that reduces unemployment and inflation rates, while strengthening regional and social convergence and cohesion.

The World Economic Forum Alliance of CEO Climate Leaders (https://www.weforum.org/projects/alliance-of-ceo-climate-leaders) have announced the adoption of a range of business strategies, including emissions disclosure, setting aggressive emissions reduction targets, and taking explicit actions designed to pursue these targets. They have urged world leaders to adopt policies that will decarbonise at the speed and scale required to achieve net zero by 2050, including carbon pricing, disclosing emissions, and setting credible emissions reduction targets, eliminating fossil fuel subsidies, boosting green R&D funding, investing in adaptation, and implementing a suite of sector-specific actions. Asset management firms continue to call for government action, particularly for the establishment of credible road maps to climate neutrality by 2050, to create the necessary confidence for investors to properly allocate trillions of dollars of investment funds. They also call for mandatory consistent and comparable corporate climate disclosures.

The *Economist* (12/06/2021) has stressed the existence of constraints to investment at sufficient scale to meet the 2015 Paris Agreement target ("green bottlenecks"). It mentioned copper, lithium, nickel, and rare earth minerals, supplies of which are economically and geographically concentrated, limited supplies of land for wind & solar farms, lengthy time requirements for regulatory approvals, the continuing existence of fossil fuel subsidies, limited green financing, etc.). Scarcity of these resources constrains the total productivity of the resources at hand and delays pursuit of green growth, net zero and the Paris Agreement target.

The previous literature considers the impacts of environmental regulation on economic activity. One potential impact of these regulations is to spur the development and implementation of green technologies, which in turn may reduce greenhouse gas emissions. Empirical evidence has been mixed, although two recent studies of Du et al. (2019) and Mongo et al. (2021) have uncovered different conditions under which environmental innovations have led to a reduction in CO_2 emissions. Du et al. studied 71 economies during 1996-2012, using patent counts in environment-related technologies as an indicator of green technology innovations. They found green technology innovation to have reduced CO_2 emissions for economies having income levels sufficiently high to invest in green technologies. Mongo et al. studied 15 EU economies during 1991-2014, also using green patent counts and CO_2 emissions. All their economies are in the Du et al. high-income group, but the relationship is not entirely negative. The short run impact of green technology innovation on CO_2 emission is positive and significant, while the long run impact is negative and significant. The parallels between these two studies of the impacts of new green technologies to combat climate change and those of Davis et al. (2021) and Bloom et al. (2021) on the impacts of new technologies to combat the pandemic by enhancing

the productivity of remote work should be noted; directed technologies work, conditionally.

Several peer-reviewed academic journals specialize in either climate change or environmental economics, and both publish studies exploring economic aspects of climate change. In addition to a large and growing number of working papers, one journal is devoted exclusively to the economics of climate change, *Climate Change Economics*, which recently devoted a special issue honouring Nordhaus on his Nobel Prize. Another journal devoted to all aspects of climate change, *Oxford Open Climate Change*, launched in late 2020, and *Economic Policy* has devoted a special issue to the economics of climate change.

5. Linkages between the Two Challenges

Politicians, oceanographers, and health professionals have linked the two challenges. In his address to the 2020 meeting of the Halifax Security Forum, Canadian Prime Minister Justin Trudeau argued that the world is in crisis, citing challenges posed by the current pandemic, climate change and rising inequality. Oceanographer Fabien Cousteau (2020), grandson of Jacques-Yves Cousteau, linked environmental degradation with the pandemic from an oceanic perspective, noting that their underlying processes remain largely invisible. *The Lancet* (2020a) published an editorial about the two "converging" crises of climate change and the pandemic, noting their common causes of human activity and their common consequences for human health, and emphasizing the fact that the poorest and most marginalised people are the most vulnerable. An accompanying report in *The Lancet* (2020b) provided detailed documentation of their global common causes and consequences. A related report from *The Medical Journal of Australia* (2020) documented the common causes and consequences in Australia in 2020, where temperature extremes and bushfires magnified the health effects of the pandemic. Commonality notwithstanding, in his address to the Euroelectric Power Summit 2021, Frans Timmermans (2021), Executive Vice-President of the European Commission for the European Green deal, stated that "[t]here is no vaccine for the climate or biodiversity crisis".

Simultaneous occurrence does not imply causality, but the pandemic depression has slowed greenhouse gas emissions, at least temporarily. However, like all previous depressions, the pandemic depression will end, which has motivated a search for other ways to slow or reverse the growth of greenhouse gas emissions in an environment of economic growth. Several approaches have been proposed under the heading of inclusive green growth. Here I discuss a rapidly growing body of research devoted explicitly to interactions between the pandemic depression and climate change. As a general policy-oriented observation, there has developed a widespread agreement among scholars, if not among politicians, that synergies are there waiting to be exploited. More specifically, programs to boost economies out of the pandemic depression can promote green growth, for example by switching from

fossil fuels to climate-friendly energy sources and technologies, and by investing in expanding and greening of public transport.

Le Quéré et al. (2020) have chronicled the reduction in global daily CO_2 emissions during the pandemic depression. In their analysis, which covered 85% of the world population and 97% of global CO_2 emissions, they calculated a daily global emissions decrease of 17% through April 2020 relative to mean 2019 emissions, and they predicted emissions reductions ranging from 4% to 7% for all of 2020, with large variances depending on government actions and economic incentives. They concluded with a warning that the 2020 emissions reductions are likely to be temporary because they do not reflect structural changes in the transport and energy sectors of economies, which account for approximately two-thirds of total emissions. Lee (2021) has expanded on the study of Le Quéré et al. by constructing and testing a model in which CO_2 reduction is a function of a measure of the stringency of pandemic control policies based on business, restaurant and school closures, a measure of the size of the contact-intensive sector including leisure and hospitality, and several control variables. Using US state data during early 2020, he found states with more stringent pandemic control policies and larger contact-intensive sectors had statistically significant larger CO_2 reduction. In this manner states revealed different preferences for the trade-off between output and jobs versus public health and the environment.

The International Energy Agency (IEA) (2020**)** projected a 6% decline in energy demand with a compositional substitution away from carbon-intensive coal and oil that would yield a somewhat larger 8% decline in global CO_2 emissions in 2020. A year later, the IEA (2021a) converted these projections to actual declines of 4% and 6% respectively. It also predicted global energy demand to rebound to a 4.6% growth in 2021, with CO_2 emissions growing by 4.8%. On a positive note, it called renewables “the success story of the Covid-19 era”, noting that renewable energy use grew by 3% in 2020, and predicting an even faster 8% growth in renewable electricity generation in 2021. Recall, however, previously mentioned constraints to solar and wind growth. Although Gettins (2020) acknowledged that the pandemic depression temporarily reduced greenhouse gas emissions, she asserted that overall, it was bad for climate change, in part because it pushed “the greatest existential threat of our time” to secondary policy concern. Hurried stimulus packages channelled more money into fossil fuels than into renewable energies, financially constrained businesses delayed green investment projects, and distracted governments failed to impose carbon pricing and reform of agriculture and transport.

Liu et al. (2020) and Friedlingstein et al. (2020) predicted that global CO_2 emissions would decline by 8.8% and 7% respectively throughout 2020, the largest relative decline since WWII. Forster et al. (2020) have taken a longer-term perspective, predicting a negligible impact of the pandemic depression on global greenhouse emissions by 2030, depending on the extent to which the recovery tilts toward green stimulus and reduced fossil fuel investments. They developed three potential emissions pathways post-2030, based on a fossil-fuelled recovery, a moderate green

stimulus, and a strong green stimulus. Only the latter has a better than even chance of limiting the 2050 temperature rise to the 1.5°C target. Thus, the pandemic depression and climate change have been closely related through late 2020, are expected to be modestly correlated in the short term, and conditionally correlated in the long term. However, as the *Economist* (21/05/2020) has noted, although renewables have had a pretty good pandemic, the ability of the pandemic to flatten the climate curve is highly uncertain and will depend on the expansion of urgently needed but politically unpopular carbon pricing schemes, on government policies toward the renewable energy sector, on international policy coordination, and on China.

The pandemic has been a catalyst for action to combat climate change, but its actual impact through late 2020 has been small and temporary. The future impact on net job creation of developing a resource efficient economy is predicted to be small as well, according to the empirical findings of Chateau and Mavroedi (2020) based on a computable general equilibrium model of OECD countries. Reallocation effects are expected to be much larger, with net job creation predicted to vary extensively across sectors. Helm (2020) has summarized the short-term environmental impacts of the pandemic depression and has offered a somewhat nuanced look ahead to some possible long-term consequences. He considered two impacts in detail, the possible re-orientation of public fiscal and pricing policies in a green direction, particularly in energy and transport, and the potential for continued de-globalisation and shortening of supply chains initiated by the pandemic. Concerning the first impact, he expressed a preference for pricing environmental impacts over fiscal stimulus programs but lamented that pricing of environmental impacts was more popular with economists than with legislators, and he disputed claims of superior economic returns to green investments compared with alternative investments. Regarding the second impact, he noted that the relative decline of domestic production of five widely traded carbon-intensive goods in the EU and US since China's accession to the WTO was largely replaced by coal exports to China. This practice also exported carbon emissions from the EU and US to China, thereby increasing emissions through two channels, from shipping and aviation and from relocating production of carbon-intensive goods away from countries with relatively high environmental standards. From the recent reshoring experience during the pandemic, Helm found grounds for optimism, inferring that de-globalisation may reduce total greenhouse emissions. Barbier (2020) has proposed a range of public policies that if well designed and coordinated could accelerate the economic recovery from the depression and generate a decrease in greenhouse gas emissions. He noted that a short-term focus on public health and output and jobs largely relegated climate concerns to the background and weakened existing environmental regulations and their enforcement in some countries. He proposed a suite of pricing reforms, including the ending of the widespread under-pricing of fossil fuels and continuing the subsidization of renewable energy, and the targeting of investments toward green research, technologies and transmission infrastructure that generate spill-overs. At the same time, he noted the paucity of evidence that these policies would generate aggregate employment gains without adverse impacts on the

distribution of income and wealth. Elliot et al. (2020) also noted the negative as well as positive environmental effects of a pandemic-inspired trend toward de-globalisation and lamented the lack of evidence on the environmental and economic effects of de-globalisation on developing countries. They also questioned whether recovery stimulus plans would lead to reductions in the rate of growth of greenhouse gas emissions, and whether a Green New Deal stimulus package such as that proposed by the EU would create the same economic and environmental benefits as a colour-blind package. From a political perspective, they questioned whether the benefits would occur more slowly than those of a colour-blind stimulus package.

The *Economist* (01/05/2021) has chronicled the employment- and productivity-enhancing impacts of public investment in infrastructure, a literature that goes back nearly a century, and has considered the likely impacts of climate-friendly infrastructure investment in renewables, electric vehicle charging stations, and retrofitting inefficient buildings. McKinsey & Company (2121c) has viewed these green investments as a critical component of a post-pandemic economic recovery. At the same time, it warns that businesses must decide when to move on from stranded assets such as fossil-fuel power generation that are nearing the end of their economic lives as a result of environmental regulations and/or new green investments. Goldman Sachs (2020) has expressed a complementary vision for stranded assets, noting that in recent years investors have pushed business managements toward incorporating climate change into their business plans and strategies. This has shifted capital allocation away from fossil fuel investments, leading to a divergence in the cost of capital between fossil fuel investments and renewable energy investments. Goldman Sachs interprets this divergence as shifting the stranded asset debate from a demand problem to a cost of capital problem. Overall, Goldman Sachs predicts the cost of capital advantage will spur investment in renewable energy that is likely to foster the creation of new jobs, as many as 15-20 million within the next decade.

These studies have chronicled the short-term environmental effects of the pandemic depression and estimated the long-term effects. However, the long-term effects depend in large part on the public policies enacted in the interim. Hepburn et al. (2020), Engström et al. (2020), and Agrawala (2020) have considered a range of policies and have evaluated the relative merits of green and brown approaches. Hepburn et al. surveyed several central bank and finance ministry officials and other economic experts from G20 countries on the relative merits of 25 recovery policies, using four criteria: speed of implementation, economic multiplier, climate impact potential, and overall desirability. From their responses, the authors identified five policies having high potential on both economic multiplier and climate impact criteria: clean physical infrastructure investment, building efficiency retrofits, investment in education and training to address both immediate unemployment from the pandemic and structural unemployment from de-carbonisation, natural capital investment for ecosystem resilience and regeneration, and clean R&D investment. They declined to rank these five policies, since each can decouple economic growth from greenhouse gas emissions and reduce existing welfare inequalities that otherwise would be

exacerbated by the pandemic depression in the short term and by climate change in the long term. However, it is worth noting that a large literature preceding the two challenges indicates that the first policy, clean physical infrastructure investment, has the potential to boost private sector productivity. The EU's Recovery Plan for Europe proposes a 30% green component to its long-term budget, portending a boost to EU green growth and a potential improvement in EU green productivity. Engstrom et al. introduced another consideration, inherited from a driver of the pandemic depression, an economy's public health objectives. They proposed a set of three policy groups: environmentally friendly pandemic depression recovery policies, climate change abatement policies that have economic and health benefits, and crosscutting policies. Among the first group are policies that assist the healthcare, education, and technology sectors, among the second group are the development of labour-intensive green infrastructure projects and revenue-neutral carbon pricing coupled with reduced employment taxation, and among the third are the promotion of active modes of transportation such as walking and bicycling, and cessation of unconditional bailouts of airlines. Consistent with concerns expressed through several IPCC Assessment Reports, Agrawala et al. added to public health yet another consideration, an economy's social and distributional objectives. This led them to propose a vague "just transition", reminiscent of Clark's (1940) call for a "just" distribution of the fruits of productivity growth and defined by the International Labour Organization (ILO) (2015) as a shift to an environmentally sustainable economy which contributes to the goals of decent work for all, social inclusion, and the eradication of poverty. Pollin (2020) envisioned a just transition as an essential element of efforts to reach the Paris Agreement aspirational goal of 1.5℃ global warming. The just transition also reflects the OECD's (2016, 2017, nd) conception of inclusive growth as growth with benefits distributed fairly across society and that creates opportunities for all.

The OECD has been a prominent and persistent proponent of an inclusive green recovery from the pandemic, arguing that although overcoming the health and economic effects of the pandemic is a priority for governments, climate action must be an integral component of countries' economic recovery plans. This inclusive interpretation aligns with the OECD's *Focus on Green Recovery* website (https://www.oecd.org/coronavirus/en/themes/green-recovery), which contains numerous current policy papers, policy responses and blogs, all directed toward the importance of developing public policies that would exploit the synergies, by pursuing green growth, which the OECD defines as "fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies.

I cite some particularly relevant policy-oriented documents. The OECD (2020a) has proposed "building back better" from the two challenges. In this document policies directed at improving well-being and inclusiveness occupy the central position among a circle of economic and environmental policies. The explanation for centrality of well-being and inclusiveness is persuasive: centrality is crucial to gaining social and political acceptance of economic and environmental policies. Whereas the OECD

(2020a) emphasised the importance of the *inclusiveness* of the recovery, the OECD (2020b) emphasised the *greenery* of the recovery, with an assertion that environmental health is a critical complement to public health. It proposed six outcome indicators, with particular significance attached to the share of renewable energy in the energy mix, carbon intensity of GDP, water stress, and material productivity, defined as the ratio of real GDP to the consumption of domestic raw materials from natural resources. Recall Aiginger's (2020) criticism of the European Commission for using labour productivity instead of resource productivity. It proposed seven policy indicators intended to enhance a green recovery, including the shop-worn tax, subsidy, and carbon pricing schemes, but also an expansion of environmental R&D expenditures. It reported recent performance on both outcome indicators and policy indicators has varied enormously across OECD countries. The OECD (2020c) Ministerial Council Statement summarising the October 2020 Council meeting stressed both inclusive and green approaches. The pandemic recovery plan developed at the meeting prioritised job support, clean technology development, sustainable infrastructure, increasing opportunities for those most adversely affected by the pandemic, and strong international cooperation.

The OECD (2020d) detailed three alternative pandemic recovery pathways that differ in the extent to which they encompass greenhouse gas emissions reduction and wider well-being outcomes. The "rebound" pathway returns to the old economy through productivity-driven growth in GDP, the "decoupling" pathway creates a new productivity-driven green economy featuring the greening of jobs, sectors, and industries, and the preferred "wider well-being" pathway creates a new productivity-driven decoupled green economy that exploits synergies across social objectives. The OECD (2020e) explored the possibilities of a low-carbon recovery in some detail and proposed a stimulus package designed to deal with the health crisis first and then achieve a green recovery. Parts of the package exploit lessons learned from previous green recovery packages adopted following the global financial crisis; see Agrawala et al. (2020) above. Indeed Phillips et al. (2020) have argued that global underinvestment in health care has raised the human and monetary costs of both scourges and have proposed a pandemic preparedness strategy for climate adaptation, the core of which is the provision of affordable universal health care, which has the potential to address both the pandemic and climate change. In addition to policies already cited, the OECD warned against locking in emissions-intensive technologies and weakening environmental policies to reduce uncertainty for business. It supported making direct support for business contingent on environmental considerations, providing government support for radical innovations most often provided by young and small firms most susceptible to the pandemic recession, and careful consideration of the distributional impacts of green stimulus policies "to ensure political acceptability". Paunov and Planes-Satorra (2021) proposed strengthening support to universities, public research institutions, and small innovative firms, at a time when science and innovation are most needed to deal with the climate emergency and to speed the transition to a "sustainable, equitable and resilient" future. An

objective summary of the OECD's pandemic recovery vision would be that productivity growth has a significant role, provided it is green and inclusive.

A large and growing share of global GDP has been allocated to stimulating a recovery from the pandemic recession, and interest has attached to the extent to which this expenditure has been directed to environmentally intensive sectors that affect climate change and biodiversity. Not surprisingly, several scorecards have appeared. Vivideconomics (2021) has addressed these issues with its "Greenness of Stimulus Index" to assess the effectiveness of countries' stimulus efforts toward a pandemic recovery that also pursues climate and biodiversity objectives. Their assessment as at July 2021 was that governments have largely failed in their pursuit of a green recovery, and largely ignored nature and biodiversity. It deemed less than a third of stimulus spending across five sectors (agriculture, industry, waste, energy, and transport) environmentally relevant. The Index, which has been updated periodically as announced stimulus spending grows, assigns relatively high scores to Denmark and a handful of other EU countries, and relatively low scores to Russia and 18 other countries, including the three most populous countries of China, India, and the US. The OECD (2021c) Green Recovery Database tracks numerous pandemic recovery measures with likely environmental implications across 43 countries, most recently as at March 2021. Their findings are equally discouraging. Announced funding likely to have a negative or mixed environmental impact matches announced funding likely to have a positive environmental impact, and the environmentally friendly spending amounts to 17% of total pandemic recovery spending. The OECD does not reveal allocations by country, and it does refer to four other similar scorecards, including that of Vivideconomics (2021).

In a series of posts, Dr. Fatih Birol (https://www.iea.org/authors/dr-fatih-birol), Executive Director of the International Energy Agency, has argued that the policies governments enact to help the recovery from the pandemic should be designed with the climate in mind, to achieve net zero by 2050. Such policies include expanding investment in clean energy and providing clean energy jobs, ensuring that critical minerals are an enabler of and not a bottleneck to a clean energy transition, creating reliable electricity supply networks, promoting new energy technologies such as batteries, hydrogen and carbon capture, and teaming with the private sector. These and other policies were enshrined in the IEA (2021b) Net Zero 2050 Roadmap (https://www.iea.org/events/net-zero-by-2050-a-roadmap-for-the-global-energy-system) in May 2021. The roadmap identifies several key pillars of decarbonisation, including improving energy efficiency, encouraging behavioural change, increasing investment in hydrogen and hydrogen-based fuels, and increasing carbon capture (but recall the findings of Gatti et al. above). The IEA acknowledged, however, that investment in clean energy is not on track to reach net zero by 2050.

Pollin (2020) argued that net zero 2050 has three requirements: i) improving energy efficiency standards in buildings, automobiles, public transport, and industrial production processes; ii) expansion of the supply of clean renewable energy sources,

primarily solar and wind, which would lead to net job creation on the order of 2%; and iii) cessation of deforestation and support for afforestation. McKinsey & Company (2020b) proposed a dozen government stimulus measures, overlapping with the lists above, with strong socio-economic and decarbonisation benefits that can guide business investment decisions. Among the business-oriented stimulus measures not mentioned above are scaling up electric vehicle manufacturing, expanding the electric vehicle charging network, accelerating the rollout of LED street lighting, accelerating investment in wind and solar power, and expanding energy storage capacity.

The previously cited literature is largely macroeconomic in nature, and businesses respond to macroeconomic policies with management decisions. That makes it desirable to explore the business literature linking the two challenges. Although a large business literature addresses the pandemic depression challenge, and a comparably large business literature addresses the climate change challenge, a relatively small literature links the two. McKinsey & Company (2020a, 2020d, 2020e) have been at the forefront, claiming that business simply cannot afford to ignore the dual challenge, and has set three priorities. The first is to decarbonise, primarily through early retirement of economically marginal carbon-intensive assets and increased use of videoconferencing in place of business travel. The second involves making operations more resilient and more sustainable, by investing in energy-efficient manufacturing, and increasing digitisation of operations, sales, and marketing. The third involves shortening, greening, and diversifying value chains. Recent examples of value chains disrupted by climate chains include the 2011 tsunami in Japan that shut down factories that produced electronic components for automobiles, followed by flooding that swamped factories in Thailand that produced nearly a quarter of the world's hard drives. Addressing these priorities requires investment, and McKinsey notes that, with near-zero interest rates for the near future, there is no better time than the present for such investments, a sentiment shared in much of the business literature. Green supply chains may confer an auxiliary benefit, by alleviating the adverse effects of COVID-19. Fasan et al. (2021) have examined a sample of 3,377 publicly listed US firms, one fifth of which practice green supply chain management (GSCM). They decisively rejected the hypothesis that GSCM practices have no impact on firms' abnormal stock returns during the COVID-19 outbreak through March 2020. The superior abnormal stock returns may lead to greater subsequent green investment on the part of GSCM firms. In a related study, Mukanjari and Sterner (2020) examined abnormal stock returns for 600 firms in the STOXX Europe 600 index. For firms with relatively high carbon footprints, particularly those in crude petroleum extraction and air transport, they found large and significant decreases. However, they also found that firms having an official ESG climate change policy experienced no significant change.

The academic literature has shown a growing recognition of the significance of the joint adverse impacts of, and the complementary solutions to, the pandemic depression and climate change. In addition to a small but rapidly growing number of working papers, at least two peer-reviewed journals have devoted special issues to

the joint challenge, *Environmental and Resource Economics* 76:4 (August 2020) and *Oxford Review of Economic Policy* 36, Supplement 1 (2020).

6. A Stocktake

Beginning in 2020 the world has encountered a pair of multifaceted challenges, one new and the other old. The pandemic has brought on the deepest economic depression in a century, disrupted global value chains and domestic production and employment, caused immense human suffering and innumerable deaths, and exacerbated a range of inequalities around the world. Climate change has been warming the world for millennia, and it continues to threaten the global economy, devastate human health, exacerbate inequalities, and deplete and degrade the natural environment. The two challenges have interacted in numerous ways, most prominently with economic growth contributing to global warming and damaging the natural environment, but also offering the promise of a recovery from the depression having a green hue.

The economic depression has been deep, but V-shaped, as measured by world trade volumes, global industrial production, manufacturing new orders, and output trends in major economies, albeit with considerable variation across countries. A cautious optimism prevailed at mid-2021. However, climate change continues, and at an accelerated pace, exacerbating global warming and extreme weather events. The extent of its impact on the global economy varies geographically, and depends in part on the ability to adapt, which also varies geographically and with levels of development. A wary pessimism prevailed at mid-2021.

The contrasting moods can be attributed to multiple issues, some concerning the pandemic depression, others concerning the climate, and still others cross-cutting. It is difficult, and no doubt foolhardy, to draw conclusions from a linked pair of challenges that have not concluded, but it is possible, and possibly enlightening, to engage in a stocktake.

A primary concern has involved the availability and distribution of vaccines to combat the virus in its different variants. This concern has proved justified, with adverse public health and economic implications. According to the University of Oxford (https://ourworldindata.org/covid-vaccinations), at mid-2021 just under 15% of the world's population had been fully vaccinated. The EU and the US were at 50%, with Australia and New Zealand lagging at 16%, Asia 11%, Africa 2%, and no figures were available for China.

A group of concerns involves the magnitude and structure of public policies enacted to speed economic recovery from the pandemic depression, especially in large advanced economies.

A concern emanating from the depression that has attracted intense academic interest relates to its impact on remote work, and the impact of remote work on

business technology adoption, productivity, and financial performance. The evidence to date suggests that remote work will remain and be productive and lucrative for businesses that adopt the supporting technology and workers in occupations able to work remotely. To the extent that remote work endures, it will have wide-ranging consequences.

A related concern is that ill-designed or overly generous stimulus policies would interfere with Schumpeterian creative destruction, retard productivity-enhancing reallocation, and sustain zombie firms and zombie jobs. Evidence suggests that this concern has not materialised. A variant of this concern is that ill-designed or inadequate stimulus policies would prolong unemployment. Evidence suggests that this worry was somewhat misplaced, with limited reallocation and sticky wages leading to simultaneous unemployment in some sectors and labour shortages in others.

Another related concern was that excessive stimulus would lead to runaway inflation. This concern persists, particularly for economies that received generous stimulus packages.

A second group of concerns involves the nature of public policies toward global warming and the environment.

An old concern that has gained traction as global warming intensifies involves the consequences of alternative forms of environmental regulation. One strand concerns the potentially adverse impacts of regulation on business competitiveness and the potential for business to seek safe havens. A related strand concerns the potentially adverse impact of business compliance with environmental constraints on financial performance. This second strand has extended to compliance with ESG and CSR targets. Another related strand is the looming question of whether regulation is sufficiently stringent, well enforced, and respectful of market forces. Evidence to date is mixed for the first two strands, and in the face of political opposition largely negative for the third.

A cross-cutting concern involving both challenges is whether government stimulus programs would be insufficiently green, providing adequate funding and incentive for investment in renewable energy and environmentally friendly new technologies and employment, while removing or limiting favourable treatment of fossil fuel supplied energy. This worry has been realised, with most implemented and proposed stimulus packages having a net negative environmental impact.

I conclude with some lessons learned, or lessons to be learned, from studying these two current events. One is that there is much to be gained from broadening the scope of economic research beyond the increasingly narrow confines of the market economy. Only outside these confines can one study the trade-offs among public health, economic activity, and the environment. Another is that management matters, at business, national and global levels, a lesson that has become increasingly apparent as managers at all three levels grapple with widely varying success with the two challenges. A third is that institutions matter, and their ability to address the two challenges varies widely across countries. A fourth is that current events are best studied with current information, which business, finance and other periodicals are well equipped to provide, and peer-reviewed academic journals are ill-suited to provide. A

final lesson is that, when studying broad challenges with economic and extra-economic content such as public health and climate, consulting a wide range of inter-disciplinary sources far beyond economics is fruitful. All four lessons are reflected in the reference list that follows.

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