Climate change and inequality in a global context. Exploring climate induced disparities and the reaction of economic systems

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ABSTRACT

This paper examines the impact of climate change on within-country inequality and assesses the role of adaptation mechanisms based on a large sample of countries. By using panel methodologies and exploiting the high-frequency of weather changes within given spatial areas, we aim at causatively identifying the effects of climatic variations on income inequality, which is per se a rather unexplored economic outcome. To this end, we introduce different measures of climate change hazard, exposure and vulnerability as important factors that may exacerbate inequality, while controlling for standard country-level characteristics which are known to affect economic inequality. In order to consider potential sources of heterogeneity in responding to climate changes, we also control for resilience conditions which may modify how countries deal with such changes. Finally, since the position that countries occupy in the international division of labor may moderate the impact on economic performance and income distribution within nations, we take into account the participation of countries in global value chains as a further conditioning factors in dealing with inequality effects of climate changes. Preliminary results suggest that changes and increasing variability in climate conditions are positively related to within-country inequality, while the diversification of inward capital investments across value chain activities, as well an upstream positioning in GVCs, play an important mitigating role by increasing the economies' adaptive capacity and resilience.

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Inequality; Climate change; FDI; Global value chains.

1. INTRODUCTION

Climate change represents a major threat to our societies. According to the IPCC report (IPCC, 2014), catastrophic consequences will be triggered inasmuch as average global temperatures will be allowed to exceed 1.5°C – or, at worst, 2°C – above pre-industrial levels (Hoegh-Guldberg et al., 2018).[1] The dramatic effects of environmental degradation have already manifested in diverse forms, such as heat extremes, heavy precipitation, droughts, rising sea levels, floods, mudslides, water scarcity and biodiversity losses, with corresponding impacts on health, livelihoods, food security, water supply, and human security (DARA, 2012; IPCC, 2014; Antimiani et al., 2017; Markandya et al., 2017). The consequences of extreme events already caused global losses for an estimated overall amount equal to $174 billion (PPP) per year from 1998 to 2017, according to the estimates provided by Eckstein et al. (2018).

Scholars have begun to investigate how climate change may exacerbate income inequality, especially in the context of emerging and least developed economies.[2] In particular, relatively extensive research has been carried out on the role played by climate change in explaining between-country inequality (Ahmed et al., 2009; Hallegatte & Rozenberg, 2017; Rao et al., 2017; King & Harrington, 2018). However, the impact of climate-related events on within-country inequality is far less investigated. Aim of this paper is to contribute to this strand of research by exploring the links between different aspects of climate change and within-country inequality. In addition, we will stress the relevance of some key structural factors conditioning the ability of countries to deal with the inequality effects of climate change.

To this end, this work provides a large-scale econometric analysis including more than 150 countries over the period 2003-2017. While accounting for the key drivers of within-country inequality detected by the literature (Piketty & Saez, 2003; Atkinson & Piketty, 2007; Atkinson et al., 2011; Alvaredo et al., 2018; Bogliacino & Maestri, 2014; Franzini & Pianta, 2016), we identify the most important channels through which climate change affects income disparities, including the share of population living in rural areas and the role of agriculture production in national income. At the same time, we use data on Foreign Direct Investments (FDIs) related to different value adding activities to provide a detailed assessment of the participation of economies in Global Value Chains (GVCs) as a key factor mediating climate change induced inequality.

Our results show that climate change, in terms of temperature increase and precipitation anomalies, represents a major driver of income inequality. We also find that temperature increases are particularly associated with inequality in the presence of high shares of population and workers in rural areas, hence confirming the importance of the agricultural

[1] Rogelj et al. (2016) stress that Intended Nationally Determined Contributions (INDCs) submitted in the context of the Paris climate agreement have to be strengthened to limit global warming to 1.5°C by 2100, as they currently still imply a median warming of 2.6–3.1°C by 2100.

[2] As we will briefly discuss below, poorest countries are the most vulnerable to the negative impacts of climate change – even though they have contributed least to the causes of climate change – mainly due to geographic characteristics and economic structure.

channel through which climate change affects income distribution. Moreover, we find that opening economies to foreign capital flows might exacerbate inequality in some circumstances, especially when the insertion of countries in GVCs as captured by inward FDIs goes hand in hand with the hyper-specialization in selected GVC functions. Conversely, the diversification across value chain activities of incoming cross-border investment flows – allowing an increasing sophistication and economic complexity of local economies' production structure – emerges as a resilience-enhancing factor which results negatively associated with within-country inequality.

The remainder of the paper is organized as follows. Section 2 reviews the literature on the linkages between climate change and income disparities in the broader context of other factors affecting inequality. Section 3 describes data and methods used for our econometric exercise. Section 4 illustrated the main results of our study and section 5 concludes.

2. LITERATURE REVIEW

In this review section we first account for the relatively scanty research on the impact of climate change on economic disparities. We then place this stream of literature in the broader context of research on other economic, technological and institutional determinants of inequality. Among the factors addressed in the latter literature, we emphasize the role of FDIs and of the degree of economic diversification across GVC activities as important mediating factors which affect countries' ability to react to climate change-induced inequality.

2.1 Climate change-inequality nexus

The Earth's warming affects societies very unequally. Besides the inter-generational inequity due to the trade-off between the costs of implementing climate policies today and the benefits that will accrue to future generations (or the costs of inaction today and the climate damages in the future), also the intra-generational inequality is nowadays widely recognized (Tol et al., 2004; Mendelsohn et al., 2006; Hallegatte et al., 2016).

Even though low-income countries have contributed very little to greenhouse gas emissions – advanced and emerging market economies have contributed the lion's share to actual and projected warming – they would bear the brunt of the adverse consequences of climate change (Moore & Diaz, 2015). The uneven distribution of climate change impacts across countries reflects the exposure of economic systems to climate-related risks and their capacity to adapt. Poorer and Least Developed Countries (LDCs) are more likely to be negatively affected by a changing climate since they are mostly located at low latitudes and hence they are among the hottest regions on the Earth, where additional climate variability would be particularly harmful (Diffenbaugh & Burke, 2019). Besides the intensity and frequency of climate extremes, the risk (and magnitude) of being adversely affected is relatively large also due to their economic structure, institutional capacity, and the lack of resources to implement adaptation measures (Otto et al., 2017). For example, Burke et al. (2015) show that in countries with a relatively hot climate, such as most low-income countries, a rise in temperature lowers per capita output in a long-lasting manner. Similarly, Dell et al. (2014) suggest that both temperature increase and lower precipitation have a clear negative effect on per capita income only in poor countries (especially in African ones).

Given that LDCs are located in the hottest parts of the globe and they are subject to rising temperature, climate variability and extreme events, they have also to pay the higher price for adaptation, recovery and redevelopment loans, while being the least equipped to deal with such changes, due to limited resources. This vicious circle, the so-called climate debt trap, tends to increase the government debt, with negative consequence on the sovereign borrowing cost of capital, especially if they are already charged with high level of public and private debt. The climate debt trap, therefore, arises for these countries from the combination of financial and climate vulnerability, producing an adverse mechanism which threatens their development prospects (Buhr et al., 2018).

The heterogeneity of climate damages also depends on the interaction of different measures of climate and weather variability (e.g., temperature, precipitation, and frequency of extreme events) and their impact on specific sectors (e.g., agriculture, industry output, labour productivity, health, energy, coastal zones). For example, higher temperatures may lower agricultural output, reduce the productivity of workers exposed to heat, slow down investments, and damage health; at the same time, by forcing the biophysical limits of ecosystems, climate change can potentially trigger more frequent natural disasters, fueling migration pressures and conflict risk (Dell et al., 2014).

Also adopting a within-country perspective, the cost of climate change unevenly affects different regions and population groups. For instance, Hsiang et al. (2017) focus on the impact of projected global temperature increase in a high-developed country as the United States. They analyse the county level effect of climate damages in market and non-market sectors (agriculture, human mortality, energy expenditure, labour, coastal damages, and crime) providing evidence of the stronger impact in poorer counties, thus reinforcing income disparities.

In addition to the heterogenous impacts of climate change across country and regions, Hallegatte & Rozenberg (2017), Rao et al. (2017), and Diffenbaugh & Burke (2019) agree that vulnerable and poor people are more deeply affected. In particular, both Hallegatte and Rozenberg (2017) and Rao et al. (2017) suggest that agriculture is among the main channels through which climate change affect poverty and economic inequality.[3] Consistently, De Laubier et al. (2019) use data on Vietnam and show that one day more per year featured by an extreme temperature strongly worsens the distribution of income among income quartiles through adverse consequences on rice cultivation, highlighting the unequal impact of climatic hazards. Asfaw et al. (2020) analyse the impacts of soil erosion on agricultural productivity in Malawi and conclude that the effects are confined to the most vulnerable households, with no effects on higher quantiles.

[3] Further mechanisms can also affect the dynamics of poverty and inequality, as for example energy, conflict and political stability, ecosystem. At the same time, the interactions across different channels could results in self-reinforcing negative effects.

Notably, the agriculture channel is particularly relevant because of its effects on both the income and consumption side. With respect to the former, and in line with existing evidence that already suggests that climate change tend to reduce agricultural yields and productivity, climate change may result in negative effects on the income of farmers, with more pronounced effects on rural income in developing countries (Dell et al., 2014). On the other hand, the agricultural channel affects households through the consumption side because of the climate change impact on food prices. The effect also depends on the share of households' income dedicated to food consumption and the reliance on international market for food and agricultural purchases (Bandara and Cai, 2014; Janssens et al, 2020).

In addition to effects on income and consumption of agricultural goods, climate change may reduce the labour productivity and lead to output losses also in other sectors, although these effects appear to be more relevant for outdoors workers as those working in the agriculture sector (Graff Zivin & Neidell, 2014; Day et al., 2019).[4] Moreover, the occurrence of natural disasters and extreme events (as flood and drought) produces asset losses of both physical and human capital (e.g. damage to agricultural grassland, children pull out of school, permanent health consequences), ultimately reducing income with long lasting effects (Carter et al., 2007; Hallegatte et al., 2017). Considering that poorer households often live in marginalized (and cheaper) areas which are also more exposed to natural hazards, this is a further channel that is likely to increase income inequality (Yamamura, 2015). As highlighted by Hallegatte and Rozenberg (2017), climate change further acts throughout channels such as health, in the form of diffusion of diseases, as child stunting, diarrhoea and malaria, and increasing mortality. This appears particularly relevant in developing countries with lower access to medical facilities. Nonetheless, adopting a within-country perspective, it has to be acknowledged that some individuals are more at risk than other for both biological reasons (e.g. elderly and infants) and socio-economic aspects (e.g. health insurance, or being able to afford medical expenses) (Deschênes & Greenstone, 2011).

Accordingly, and considering that poor people are likely to live within the margins of subsistence and often in rural areas (Castaneda et al., 2018) and less-favoured agricultural lands with poor market access (Barbier & Hochard, 2018), the interactions between the different channels may also reinforce each other in a vicious cycle. Areas featured by pollution, tree cover loss and land degradation are also marked by a higher incidence of poverty such that more disadvantages households face greater environmental risk (Narloch & Bangalore, 2018). In other terms, they live in more marginal areas with assets and occupation often more affected by environmental constraints, scarcity or volatility. It follows that, on the one hand, they are more exposed to extreme climate conditions; on the other hand, they are more vulnerable also because of their high dependence on natural resources and lower adaptive capacity (Angelsen & Dokken, 2018; Narloch & Bangalore, 2018; Wunder et al., 2018). In particular, Wunder et al. (2018) find that household living in rural areas of developing countries mostly rely on crops, forest extraction and other income sources and this kind of livelihood is greatly sensitive to climate change.

[4] Other sectors subject to labour productivity loss due to climate change are forestry, mining, construction, and utilities (see for example Hsiang, 2010).

Overall, the theoretical and empirical evidence reported by the reviewed literature shows that the impact of climate change on income disparities occurs through specific sectoral channels, highlighting the need of detailed analyses able to properly account for the mechanisms through which climate-related events can affect income distribution. We will empirically address this key point in Section 3 and 4, while in what follows we account for other major drivers of within countries inequality.

2.2 Non-climate related drivers of income inequalities

While climate change is a relatively unexplored albeit relevant driver of inequality, its impact on economic disparities needs be addressed in the context of several other determinants that have long been at center stage. These include tensions related to economic and technological development, institutional mismatching and globalisation, all of which contribute to shaping income distribution both within and across countries. Let us briefly recall these tensions, as to draw the broader context in which our analysis of the role played by climate change factors will be developed.

The role of economic and technological development as determinants of inequality

Kuznets (1955) suggested that income inequality patterns are strongly related to the level of economic development. According to the so-called Kuznets curve, the process of capitalist development would firstly produce growing income inequality; afterwards, further economic development would run hand in hand with a decreasing level of the latter. Whether GDP per capita has been usually employed to capture the level of economic development, other structural factors are likely to have important consequences in terms of income distribution. For example, the industrialization of the economies and the following growing share of value added coming from the industrial sector represents a key driver of economic growth, giving access to better-paid jobs to a growing share of population previously employed in the agricultural sector. This kind of structural dynamics has often been accompanied by huge population shifts from rural to urban areas, so that the share of population living in the former is likely to represent another good predictor of the pattern of income inequality – especially in developing countries (Young, 2013). Further, the availability of basic services for rural population, such as the access to electricity constitute a further important determinant of income disparities (Castaneda et al., 2018; Wunder et al., 2018; Sarkodie & Adams, 2020).

Moreover, technological change has been detected by the literature as one of the main driver of increasing inequality, especially through its positive impact on wage income dispersion in advanced countries (Autor et al., 1999; Acemoglu, 2002, 2003; Card & Di Nardo, 2002; Van Reenen, 2011; Goos et al., 2014; Dao et al., 2017). In particular, neoclassical authors have argued that inasmuch as the introduction of information and communication technology is found to be skill-biased – i.e. substitute for lower-skilled, routine tasks, while being complement to higher-skill, non-routine functions –, it tends to relatively increase the demand for high-skilled workers while decreasing the one for the low-skilled. This would result in greater wage polarization and consequent growing inequality.

Nonetheless, technology may also result capital-biased as long as reduces the price of capital with respect to labour, inducing a substitution of labour for capital and thus a replacement of workers with machines. An increase in the capital-output ratio therefore ensues, which in turn reduces the labour share to the extent that the elasticity of substitution between capital and labour is larger than one (Bassanini & Manfredi, 2014; Karabarbounis & Neiman, 2014).[5] Finally, given that the functional income distribution represents a major driver of personal income distribution (Daudey & Garcia-Penalosa, 2007; Atkinson, 2009; Wolff, 2010; Wolff & Zacharias, 2013), also through this channel technology leads to higher inequality.[6]

The institutional drivers of inequality

Institutions shape the functioning of the markets, the political system and the overall power relations within societies. In this sense, they largely contribute to define the incentives of economic agents related to their strategic choices, e.g. the kind of investment to be undertaken, the timing and level of knowledge accumulation and the stock of human capital available. Therefore, the channels through which institutions may impact on income inequality should not disregarded.

On the one side, institutions define the "governance readiness" of the economies, shaping their capability to timely and virtuously respond to adverse phenomena, including climate-related extreme events (Sarkodie & Strezov, 2019). Indicators related to governance readiness include corruption control, government effectiveness, political stability, regulatory quality, rule of low, and voice and accountability. For example, corruption may exacerbate inequality giving preferential access to public resources to wealthy elites, lobbies and "insiders" of the political system, distorting the redistribution mechanisms (Sarkodie & Adams, 2020). More in general, social and political rights and the accountability of governments to political pressures remarkably influence the relative strength of different social groups in economic bargaining.

On the other side, and mostly relevant in our framework, institutions critically shape the "social readiness" of countries, which is related to the social safety nets made available to different population groups. Key indicators in this context are represented by the affordability of healthcare services (IMF, 2015; Berg et al., 2018) and the level of education (De Gregorio & Lee, 2002; Bergh & Fink, 2008), as they play a major role in

[5] Technology and trade globalization may also reinforce each other, inasmuch as technological change is induced by international trade. Indeed, whether firms' opportunity cost of introducing innovations decreases in response to being subject to foreign competition from labour-abundant economies (e.g. China), it follows that trade globalization may foster technological change in those industries more exposed to import competition (Bloom et al., 2013). Another potential driver of income polarization is provided by Autor et al. (2020), who show that greater market concentration has allowed "superstar firms" to increase the mark up at firm-level. In other terms, while the wage share stagnated in most other companies, the larger mark-up of superstar firms has resulted in falling labour share and growing inequality.

[6] OECD (2012) reports that the average Gini for capital income in developed economies is remarkable higher with respect to the one for wages and self-employed income and that in most OECD countries the concentration of capital income has increase more than that of labour income. Consistently, Piketty and Saez (2006) and Fräßdorf et al. (2011) find that the share of capital income is greater at the top of the distribution. Finally, Dao et al. (2017) show that lower labor shares are strongly associated with higher income inequality, both across and within countries.

defining the distribution of resources and opportunities of domestic social groups, and the welfare regime of the country. In other terms, social readiness is strictly related to the relative inclusiveness of institutions and may thus greatly affect the distributive patterns of nations and their overall development trajectory (Gupta et al., 2002; Rodrik et al., 2004; Chong & Gradstein, 2007; Levy & Temin, 2007; Acemoglu & Robinson, 2012; Perera & Lee, 2013; Batabyal & Chowdhury, 2015; Ostry et al., 2018).[7]

The impact of trade, FDIs and financial globalization

There are different channels through which globalization can impact on inequality. According to the standard trade theory, and in particular to the Stolper-Samuelson (1941) theorem, trade liberalization rises the remuneration of the relatively abundant production factor, entailing a higher remuneration of high-skilled workers in advanced economies, while the opposite occurs in emerging and least developed countries. Trade globalization should thus increase income inequality in advanced economies while reducing it in less developed countries. Further, if firms located in capital-abundant economies offshore labour-intensive tasks to labour-abundant ones, the higher capital-output ratio in the former countries reduce the wage share, provided that capital acts as a gross substitute for labour (Bassanini & Manfredi, 2014; Helpman, 2016; IMF, 2017a, 2017b).[8]

However, the possibility that trade globalization increases inequality also in developing economies cannot be excluded. As suggested by Feenstra & Hanson (1996), offshoring of relatively low-skilled, labour-intensive production tasks from advanced to emerging countries may result in growing income disparities (also) in the latter. In fact, to the extent that emerging economies are marked by a lower level of education with respect to advanced countries, offshored value chain functions which are relatively low-skilled for latter may represent relatively high-skilled tasks for the former (see also Elsby et al., 2013). It follows that trade globalization may entail an increasing demand for high-skilled labour in both advanced and less developed economies, increasing wage inequality.

This mechanism could also be at work as a result of FDI flows in relatively low-skilled functions from Multinational Corporations (MNCs) located in advanced economies increase the demand for relatively high-skilled workers of emerging economies (Feenstra and Hanson, 1997; Jaumotte et al., 2013). Sheng & Yang (2017) present a theoretical

[7] Other institutional changes, especially financial deregulation and the decline in top marginal personal income tax rates, have also been proven to contribute to higher inequality (Philippon & Reshef, 2012; Bivens & Mishel, 2013; Alvaredo et al., 2013; Piketty et al., 2014). Further, several studies have found that declining union density and the weakening of labour market institutions have also negatively affected the personal distribution of income (Dunhaupt, 2016; Piketty et al., 2014; Jaumotte and Buitron, 2015). More in general, labour market tightness – usually proxied by the unemployment rate – represents an important determinant of the relative bargaining power of labour with respect to capital and is thus likely to influence the dynamics of income distribution (Kristal, 2010; Shaikh, 2016; Stockhammer, 2017; Pariboni & Tridico, 2019). However, data on unemployment are not available for a rather large share of countries, so that the inclusion of this variable in our model would significantly reduce the size of the sample, also giving rise to the risk of selection bias. Besides, even when available, the reliability of data on unemployment rate in emerging and especially LDCs is often doubtful due to the large informal sector in these economies. Nevertheless, a control for unemployment is included in the regressions reported in Table A.2 of the Appendix as a robustness check.

[8] The functional dimension of income distribution represents a major explanatory factor of personal income distribution. Further details are provided in footnote 6.

model according to which captive offshoring through FDIs contribute to a higher extent to increase the demand for skilled labour in developing countries with respect to trade in GVCs (i.e. arm's length outsourcing), leading to greater wage inequality. Furthermore, they empirically test the model using data on China's manufacturing sector over the period 1992-2008, finding support to their theory.

Furthermore, trade and capital account openness are likely to impact on income distribution by affecting the bargaining power of labour with respect to capital (Stansbury & Summers, 2020). To the extent that globalization allows firms to move production abroad, so that offshoring of production represents a credible threat for workers, the bargaining position of the latter turns out weakened (Burke & Epstein, 2001; Choi, 2001). As suggested by Rodrik (1997), globalization would therefore favor the most mobile (rather than the most abundant) production factor, i.e. capital, reducing the wage share and increasing inequality in both advanced and less developed economies (Harrison, 2005; Jayadev, 2007; Stockhammer, 2017; Coveri & Pianta, 2019).

Overall, different research streams suggest that trade and financial globalization would tend to increase inequality, a conclusion rather supported by most of the recent empirical literature on the topic.[9]

Among the others, Wu and Hsu (2012) perform endogenous threshold and instrumental variable threshold regressions for a sample of 21 developed and 35 developing economies over the period 1980-2005 and show that share of inward FDIs over GDP leads to higher income inequality, especially in those countries with a low level of absorptive capacity (meant in terms of host country's ability to adopt new technologies coming from abroad and measured by the infrastructures local economies are equipped by).

Asteriou et al. (2014) use panel data techniques to investigate the impact of both trade and financial globalization on income inequality for the EU27 countries over the period 1995-2009. They find that trade openness tends to have a beneficial effect on inequality, while inward FDI flows result being the stronger driver of income disparities.

Jaumotte, Lall & Papageorgiou (2013) provide empirical evidence on the association between trade and financial globalization on the one hand, and the increasing pattern of income inequality registered in both advanced and emerging countries over the period 1981-2003. They find that the financial globalization, and FDIs in particular, plays a major role in explaining the increased inequality, while trade globalization seems to reduce income disparities. The result concerning the adverse impact of financial liberalization on inequality is consistent with findings of Ostry et al. (2018), who report evidence on a trade-off between growth and equity. In particular, they show that capital account liberalization tends to improve both growth and inequality.

[9] Conversely, some of the literature that has flourished before the world financial crisis has suggested that capital account liberalization fosters financial development, hence improving the access to credit market by poor people, and enabling to overcome the financial constrains which prevent them from smoothing consumption patterns and gaining access to resources to be invested in new activities (Beck et al., 2007). From this perspective, financial liberalization might decrease inequality.

Furceri and Loungani (2018) perform an empirical analysis on a panel of 149 economies over the period 1970-2010 and find that episodes of capital account liberalization increase income inequality, measured by the Gini index. They also find that adverse effect of capital liberalization on income disparities is stronger when the former is followed by a financial crisis. Finally, they highlight that the wage share falls after episodes of capital account liberalization, showing that the liberalization of capital markets increases the bargaining power of capital against labour.

Furceri and Ostry (2019) employ model-averaging techniques to identify the most important determinants of between- and within-country income inequality in advanced, emerging and low-income economies. They find that unemployment and financial globalization exert the most adverse effects on inequality, while trade globalization is associated with lower inequality. Financial deregulation and technological change emerge as important drivers of inequality, especially in advanced economies. Finally, they show that the industry share, the access to electricity and education contribute to reduce income inequality, especially in non-high income countries.

Erauskin and Turnovsky (2019) set up a general equilibrium model to show that the financial liberalization, by decreasing the costs of investing and borrowing abroad, mostly favors the wealthiest groups of population and thus increases income inequality. Moreover, they perform empirical estimates using data on 96 countries from 1970 to 2015 and conclude that the overall liberalization of capital markets occurred in the period provided an important contribution to the rise in inequality registered over that period.

2.3 The ambivalent impact of GVCs on inequality

While international investments are a major component of globalization and contribute to inequality through the channels briefly recalled above, FDIs also represent a key driver of international fragmentation of production. Their trajectories contribute to shape Global Value Chains (GVCs), their governance structure and the distribution of value added across value chains activities (Gereffi et al., 2005; Gereffi and Fernandez-Stark, 2016). In this context, it is therefore worth reviewing briefly the channels through which the modern GVC-driven internationalization of production may impact on within-country income disparities.

First, production in GVCs can increase inequality as is often more skill-biased and capital-intensive than traditional trade (Antràs, 2019). This is due to the higher level of capabilities required to perform value chain tasks with strong complementarities with other geographically dispersed value-adding activities (Antràs et al., 2006); and to the more skill- and capital-intensive production techniques used by firms operating in GVCs than domestic firms (Bernard et al., 2018). This has implications for both advanced countries, where highly skill-intensive headquarter services are concentrated and a lower demand for labor-intensive tasks reduces the income share of blue collars; and less developed ones, where the participation of local suppliers in GVCs is associated with greater skill requirements and higher wage disparities between workers. Overall, incoming FDIs may therefore rise the relative demand for skilled labour, leading to higher wage inequality and lower labour share, especially in developing economies (Dao et al., 2017).

Second, World Bank (2020) recently provided evidence on the association between, on the one hand, increasing GVC participation of the economies, and, on the other hand, greater mark-ups seized by MNCs located in developed economies combined with falling mark-ups of emerging countries' firms. This fact recalls the asymmetries in power relations among participants to GVCs as a crucial determinant of income distribution and suggest that production in GVCs being a likely contributor to the global decline in labour share (Antràs, 2019).

Nonetheless, the composition of incoming FDIs across value chain activities should not be disregarded, as the specialization patterns of economies in different value-adding functions may represent a major source of heterogeneity in terms of distributional outcomes. However, the evidence on this aspect of GVC participation drawn less attention in the literature, arguably also because of the lack of available data on going beyond the industry-level, i.e. at value-chain level.

For example, inward FDIs in knowledge-intensive value-adding functions of value chains as R&D and Design & Development activities might allow domestic firms to take advantage of international technological spillovers, fostering skill and organizational upgrading and dynamic returns to scale (Castellani and Zanfei, 2006; Colantone and Crinò, 2014; Pöschl et al., 2016; Morris & Staritz, 2017; Tajoli and Felice, 2018). As opposed to FDIs in manufacturing stages of productions, cross-border investment flows in the most upstream value chain functions may therefore promote structural change of receiving economies, offering batter-paid jobs in new developing sectors. On the other hand, knowledge-intensive FDIs might exacerbate the skill-biased character of production in GVCs, increasing the skill premium and rising inequality (Hale & Xu, 2016; Bogliaccini & Egan, 2017).

Moreover, the relative diversification of GVC activities performed by economies, as opposed to the functional specialization induced by the international fragmentation of production, constitutes another dimension whose distributional consequences have not been fully explored by the literature. As widely recognized, modern internationalization of production has enabled an ever finer-grained specialization, as the ICT paradigm and major reductions in communication and transportation cost has allowed firms to concentrate on specific value chain functions as opposed to final goods (Baldwin, 2016; World Bank, 2020). In this context, we suggest that this specialization pattern can unfold at the detriment of a more equal distribution of income. Conversely, we suggest that a greater GVC diversification, namely a higher dispersion of FDIs across value chain activities, may help the process of structural upgrading of receiving economies, with beneficial effects on income distribution.

In particular, we argue that the diversification of FDIs in terms of value-adding functions, by fostering the development of both backward and forward linkages, may play a crucial role in shaping the productive structure of domestic economy (Cimoli et al., 2009; Hausmann et al., 2007). In other terms, GVC diversification might induce greater knowledge spillovers than functional specialization, as the learning effects would be augmented by the strong complementarities among the activities constituting the value chain. In this regard, the combination of knowledge allowed by the accumulation of capabilities related to different value-adding functions promote the expansion of the product space. This is conducive to enlarge the opportunities for economic diversification and increased sophistication of the economy (Hartmann, 2014; Hartmann et al., 2014; Hidalgo, 2015).

There is limited empirical evidence confirming our conjecture. Javorcik et al. (2017) use data on Turkish manufacturing firms for analyzing the relationship between inward FDIs and product upgrading, the latter being measured by an index of economic complexity developed by Hidalgo & Hausmann (2009). Notably, they find that firms in industries and regions most interested by incoming FDIs tend to introduce products with a higher level of economic complexity. Lectard & Rougier (2018) perform an empirical analysis on a large panel of countries over the period 1992-2012 to assess whether defying comparative advantages by promoting export diversification and sophistication through attracting FDIs effectively allows to diversify the export basket. They find general support for the hypothesis that defying comparative advantages allows to expand the product space and to export more sophisticated manufacturing items, while slightly contrasting evidence is provided with regards to lower-income economies. Finally, Li et al. (2020) concentrate on equipment manufacturing industry of China using input-output data from 2000 to 2014 and find that participation in GVC may promote the export technical complexity of the sector. They also show that, whether both backward and forward GVC linkages foster export technical complexity, the impact of backward linkages is stronger.

Furthermore, our argument is consistent with recent studies showing that the productive structure of a country is a key driver of the economic diversification as well as of its pattern of income inequality (Hidalgo et al., 2007; Hidalgo & Hausmann, 2009; Hausmann et al., 2014; Cristelli et al., 2015; Hartmann et al., 2016; Hartmann et al., 2017; Hidalgo & Hartmann, 2017; Gala et al., 2017; Flávio et al., 2018; Pinheiro et al., 2018; Hartmann et al., 2019). As recently stressed by Hartmann et al. (2017), a diversified productive structure tends to be a necessary condition to obtain high living standards and well-paid jobs (see also Hartmann, 2014; Gala et al., 2017). In this regard, they provide empirical evidence that – after controlling for aggregate measures of income, institutions, export concentration, and human capital – the product complexity of regions is a strong predictor of their patterns of inequality and show that income dispersion is higher in countries exporting simpler products than those that produce more sophisticated ones. Finally, Hartmann et al. (2019) show that the modern structure of trade specialization involving both core and peripheral countries crucially affects not only the between-country income inequality, but also inequality within countries (see also Hausmann & Rodrik, 2003). It follows that, by increasing the product sophistication and the economic complexity, a higher GVC diversification may contribute to reduce income disparities.[10]

[10] See also Cheng et al. (2015), who show that countries with a higher economic complexity, measured by the economic complexity index developed by Hidalgo & Hausmann (2009), tend to capture a greater share of value added from GVCs.

Going one step further, we also suggest that GVC diversification may play a positive role in increasing the economic resilience of countries (Pike et al., 2010; Martin, 2012; Boschma, 2015; Martin & Sunley, 2015). More precisely, we argue that the productive diversification induced by a more even distribution of inward FDIs across value chain activities may push the economy towards a more balanced productive structure, reducing the vulnerability to adverse, unexpected phenomena. On the opposite, functional specialization increases the interdependence of countries, with the consequence of making them more vulnerable to external shocks and changing global conditions (Coveri et al., 2020).

Similarly, Conroy (1975) showed that the mix of economic activities – and the interdependencies among them – characterizing a region crucially affects its capacity to cope with adverse economic fluctuations. In particular, a diversified economic structure is usually better equipped than a more specialized country in terms of adaptation and recovery a shock (see also Dissart, 2003; Ormerod, 2008). Nonetheless, a strong specialization in selected GVC activities also risks making conversion of domestic production harder in case of artificial disasters or climate-induced extreme events.

Moreover, the diversification of GVC could be a proper strategy for escaping the so-called resource curse phenomena, that mostly affect natural-resource-dependent regions. As it allows for the development of new productions in complementary activities, GVC diversification may represent a fundamental tool for promoting economic diversification out of primary activities, which are often sensitive to climate-related events.

Building on recent evidence in this regard, we therefore guess that a more balanced participation of economies in GVCs might constitute an alleviating factor of the adverse consequences of climate change on income inequality (Seo, 2010; Roesch-McNally et al., 2018; Birthal & Hazrana, 2019; Bowles et al., 2020). Contrary to functional specialization, attracting FDIs in several value-adding activities may indeed expand the production matrix of regions, foster complementarities among different tasks and improve the capacity to economically withstand the impact of dramatic changes in economic and business conditions, including sharp climate-related events. Ultimately, GVC diversification may represent a resilience-enhancing factor which increases the responsiveness and adaptation of the productive system to both internal and external conditions, allowing to mitigate the potential negative consequences of climate change on income disparities.

In the next section we explicitly account for climate change drivers of inequality, while controlling for standard factors that have long been acknowledged in the literature, as briefly recalled above. Building on previous analyses on the channels through which extreme climate conditions are likely to mainly impact on poorer segments of population, we also provide evidence on the relevance of the production structure of the economies in mediating the effects of climate events on the distribution of income. Furthermore, we exploit value chain-based data to empirically assess the hypothesis that – contrary to the hyper-specialization induced by the international fragmentation of production – the GVC diversification of economies in terms of incoming cross-border investment flows allows to alleviate the adverse consequences of climate change on distributive patterns.

3. METHOD AND DATA

3.1 Empirical approach

Although recent literature points to the role of climate change in worsening income disparities, empirical evidence based on historical data is per se a rather unexplored economic outcome. Accordingly, we aim at empirically investigating the adverse consequences of climate change on income inequality within countries at global level. Specifically, by using panel methodologies, exploiting high-frequency weather changes within given spatial areas, we aim at identifying effects of climatic variations on income inequality looking at large sample of countries.

In doing so, we aim at: i) considering the widest possible countries' coverage (hence including the largest number of LDCs, considering the data availability constraints); ii) focusing on the agricultural channel (identified in literature as involving the most crucial mechanisms in the climate-inequality linkage).

Our identification relies on observing how income distribution is impacted by country variation in climate after controlling for standard country-level characteristics which are known to affect economic inequality. In other words, we compare how income distribution varies across time in a country when a climate variation is registered, all else being equal. To this purpose, we introduce different measures of climate variations based on temperature and precipitation variability to investigate climate change as a channel that may exacerbate inequality. In doing so, and in order to consider potential sources of heterogeneity in responding to climate changes, we explicitly consider indicators of vulnerability and resilience conditions which may modify how countries deal with such changes. By including country and time fixed effects, we further control for time-invariant characteristics of the country. Given the aim of the study, we conduct our analysis on a global unbalanced panel database, composed of 155 countries and covering the time span from 2003 to 2017. The data sources and metrics used to build both the dependent and the explanatory variables are described below, while the full list of variables included in our empirical model is reported by Table A.1 in Appendix.

3.2 Data on climate change and within-country income inequality

As for the dependent variable, the Gini index is the metric we use to assess income inequality distribution within a country. Data is pooled from the Standardized World Income Inequality Database (SWIID) that aggregates a wide array of official data sources which provide clear welfare definition and a scale of equivalence for household income. In order to allow cross-national analysis, data is harmonized using a Bayesian approach which returns comparable estimates of Gini index of inequality in equivalized (square root scale) household income. With respect to other data sources, SWIID data maintains the widest possible coverage across countries and over time, and it is well suited for broad cross-national analysis (Solt, 2009; 2019; 2020). In addition, SWIID data is considered highly reliable since it is harmonized with the Luxembourg Income Study (LIS), which is considered the most trusted database providing GINI data at the country level, but it has the disadvantage to cover less countries for a smaller number of years with respect to the SWIID data. Our primary measure of income inequality is based on the Gini index computed on the household disposable income, that is the income available to household after government taxes and transfers (*post-tax, post-transfer*), excluding indirect and value-added taxes, public services, and indirect government transfers.[11]

To have a first look at the income inequality and climate resilience at the global level, Figure 1 provides a graphical representation comparing the country-average (2003-2017) of Gini index (panel *a*) to the Notre Dame Global Adaptation Initiative (ND-GAIN) index (panel *b*). The ND-GAIN is an indicator of country level climate vulnerability constructed such that a high value indicates that a country is less vulnerable to climate change with respect to another country featuring lower values (i.e., the higher the value, the more resilient the country is). Accordingly, from comparing panel *a* and panel *b* in Figure 1 (and as summarized in panel *c*) we observe that countries with higher value of ND-GAIN index (i.e., less vulnerable, or more resilient to climate change), are mostly characterized by lower value of the Gini index (e.g., lower level of income inequality).

More in details, the ND-GAIN index results from the aggregation of two dimensions: vulnerability and readiness. The variables belonging to the measure of vulnerability are broadly defined as measures of "*a country's exposure, sensitivity and capacity to adapt to the negative effects of climate change or the propensity of human societies to be negatively impacted by climate hazards*". While the variables belonging to the measure of readiness are instead those that measure "*a country's ability to leverage investments and convert them to adaptation actions thanks to a safe and efficient business environment*". While for the vulnerability dimension lower values indicates countries more resilient to climate change, for the readiness dimension the opposite direction holds (higher is better).

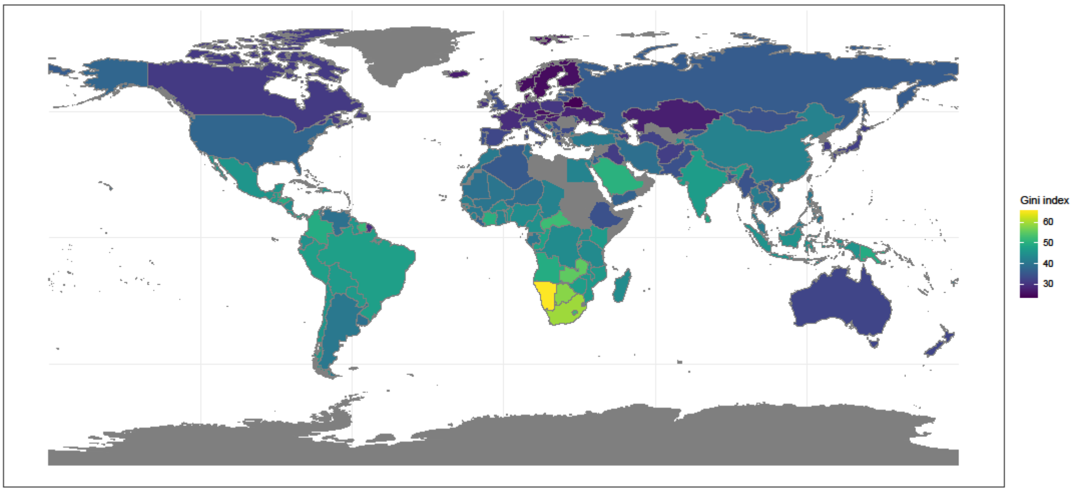
Coherently with this classification and recalling that countries are differently affected by climate damages due to heterogeneity in exposure to warming and extreme events, vulnerability and adaptive capacity, we build our database in line with this multidimensional framework.

First, being the climate indicators our main variables of interest, we follow Baarsch et al. (2020) and consider both temperature and precipitation in the analysis. The metrics used have been elaborated aggregating the national-level data recorded for each month in a given year provided by the Climatic Research Unit (CRU) at the University of East Anglia, thus resulting in the yearly averages for each country.[12]

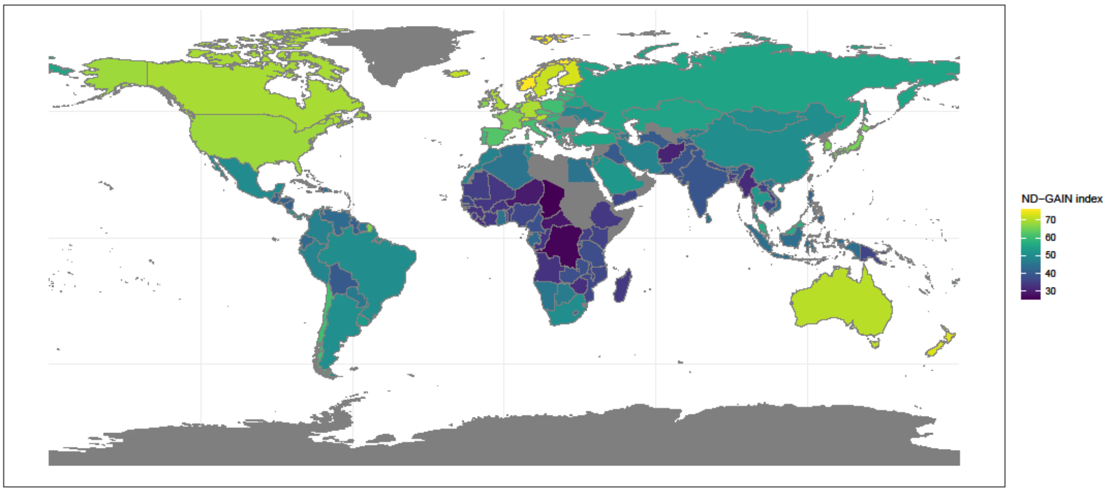
[11] Robustness check will also consider the Gini index computed on the household market income, that is the income available to household prior to any of government taxes and transfers (*pre-tax, pre-transfer*).
[12] Observe that CRU provides country level data in terms of area-weighted means from gridded (0.5x0.5 degree) time-series dataset (Harris et al., 2014, 2020).

Figure 1. Gini index and ND-GAIN index

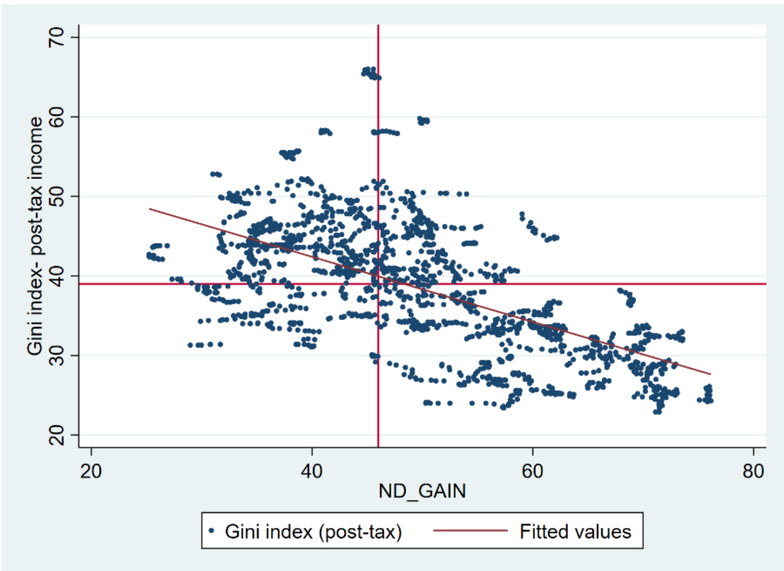
(a)



(b)



(c)



Source: authors' elaboration on SWIID and ND-GAIN data.

For each considered year and country included in the dataset, temperature indicators are obtained from CRU recording the following information: *temperature*, *temperature increase* and *extreme temperature*. *Temperature* data is calculated as the average monthly temperature recorded in a given year. *Temperature increase* is equal to the ratio between the variable *temperature* associated to country *i* in year *y*, and the same variable recorded at time *y-1* and can be considered as a proxy of the existence of a warming trend. *Extreme temperature* is a dummy variable taking the value of one if a heat wave is registered in country *i* in year *y*, and zero otherwise. A heat wave is roughly defined as an average increase of the temperature recorded in a country at time *t*, with respect to the average temperature recorded in that country between 1900 and 1950. Put in formula, a heat wave is equal to $tmv_{i,y} = \frac{1}{12} \cdot \sum_{m=1}^{12} temperature_{i,y,m} - base\_temperature_{i,m}$, where $temperature_{i,y,m}$ is the temperature recorded in country *i*, year *y* and month *m*, and $Base\_temperature_{i,m} = \frac{1}{50} \cdot \sum_{y=1901}^{1950} temperature_{i,y,m}$ (i.e., the average monthly temperature in the base period). Consistently, the variable extreme temperature is formalized as:

$$\mathbb{I}_{(x=tmv_{i,y})} \begin{cases} 1;\ x > 1.5 \\ 0,x\ \leq 1.5 \end{cases}$$

Where $\mathbb{I}$ is an indicator function.

This strategy allows to mutually account for the existence of a warming trend as well as cases in which a country has been hit by extreme events.

As for our second main variable, we use CRU precipitation data to construct indicators for extreme precipitation and the existence of drying/flooding trend. More specifically, precipitation data can be used to provide information about: i) meteorological droughts, ii) agricultural droughts, and iii) hydrogeological droughts (WMO, 2012). This data can be obtained by using different aggregations of the Standardized Precipitation Index (SPI), which is an index that registers drought (or flood) on different timescales. The SPI index can be interpreted as the number of standard deviations by which an observed precipitation anomaly recorded in a specific time period deviates from the long-term mean. As reported in Table 1, when taking positive values, SPI signals the presence of wet conditions. On the contrary, when taking negative values, SPI indicates the presence of dry conditions (McKee et al, 1993). In both cases, larger absolute values signal the presence of extreme drying or flooding conditions.

Table 1. SPI index

SPI values	***Drought and flood condition***
2.0+	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2.0 and less	Extremely dry

Source: WMO (2012).

Within the long-term scale, SPI approximates the groundwater and reservoir storage. On a short-term scale instead, it is closely related to the value of soil moisture. Accordingly, the value of the SPI index can be interpreted as follows: 1- or 2-month SPI to record meteorological droughts; from 1- to 6-month SPI for agricultural droughts; from 6- to 24-month SPI to register the presence of hydrogeological droughts (WMO, 2012).

To construct our indicators, we have used the monthly precipitation data from the CRU dataset to calculate the SPI index by using the R package SPEI by Beguería and Vicente-Serrano.[13] Given our focus on the agricultural channel, we primarily rely on the SPI-3 indicator and create two additional variables from this metric. Specifically, referring to country *i* in year *y* we compute:

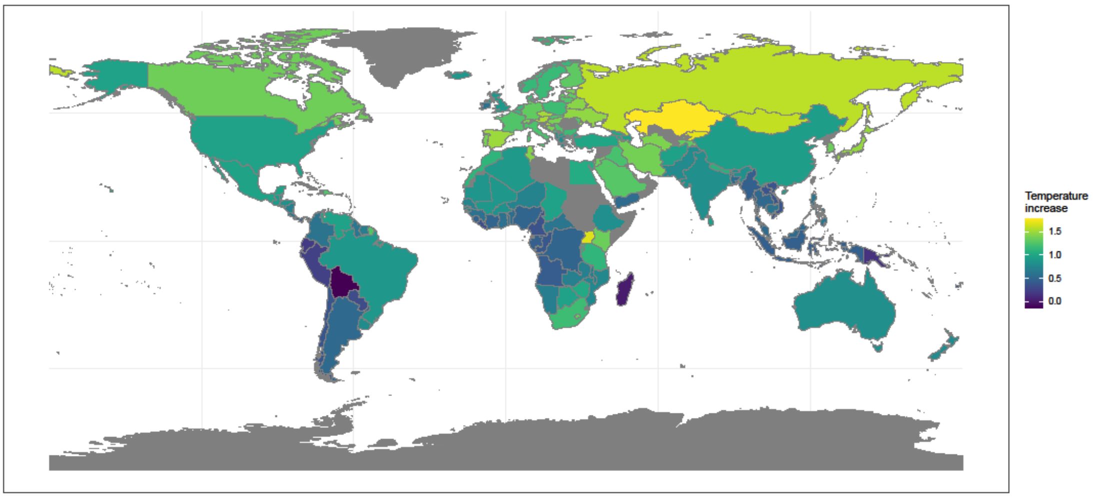
1. the average absolute value of the metric from time *t* to time *t-5*. For this variable, referred as to *absolute value of SPI-3 index 5-years average*, larger values represent more severe drying/flooding conditions;
2. a dummy variable taking the value of one if the ratio of the SPI index registered at time t and the average in the 10 previous years is higher than one, and zero otherwise. This variable, referred as to *increasingly extreme SPI-3 index (10-years average)*, indicates if the country *i* has experienced an extremization trend of either drying or flooding.

Figure 2 provides a graphical representation comparing the country-average (2003-2017) of the temperature increase with respect to 1900-1950 (panel a) and the SPI-3 index (panel b). The figure reveals an increase of heat and precipitation anomalies across all over the world, with substantial variation from country to country.

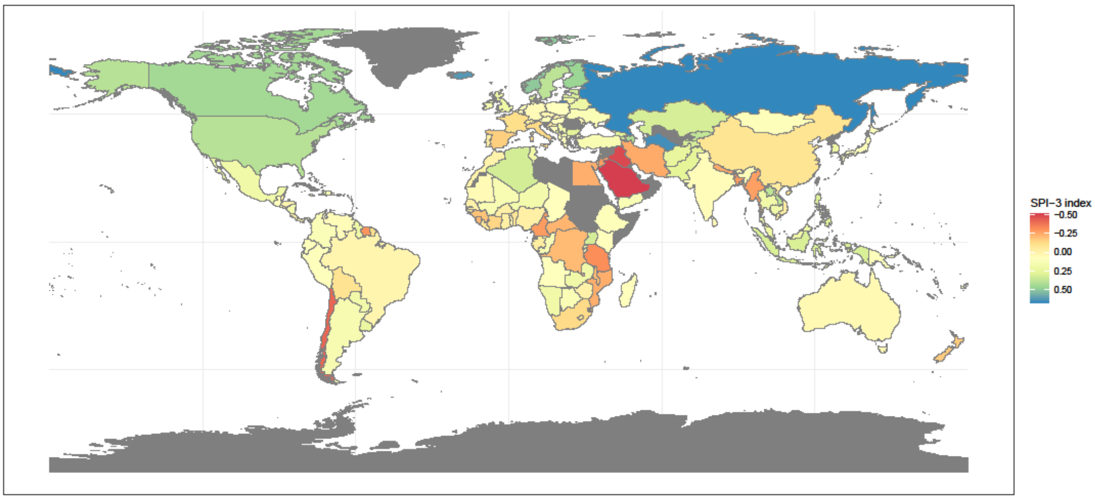
[13] https://cran.r-project.org/web/packages/SPEI/SPEI.pdf

Figure 2. Temperature increase and SPI-3

(a)



(b)



Source: authors' elaboration on CRU data.

3.3. Data on economic, technological and institutional drivers of inequality

In addition to our focal explanatory variables related to climate change, we include a set of control variables – selected on the basis of the economic literature discussed in Section 2.2 – with the aim of accounting for other major drivers of income inequality.

With regards to the economic indicators, we introduce the following three control variables. First, the GDP per capita (at PPP in constant 2011 international dollar) from the World Development Indicators (WDI) database of the World Bank. Following the debate previously highlighted, we include both the linear and squared terms. Second, the share of industry value added (including construction) as percentage of GDP (from WDI). Finally, given that the structural dynamics related to urbanization processes and the relative relevance of the primary sector is crucial to understand the link between climate and inequality, we include the rural population as percentage of total population (from WDI).

Moreover, we account for the role of technological change in shaping income distribution by including the following three indicators. First, the number of mobile-cellular subscriptions per 100 inhabitants, which is an ICT indicator available for a wide range of countries at global level (data are drawn from the World Bank – International Telecommunication Union, World Telecommunication/ICT Development Report and database). Second, the percentage of rural population with access to electricity, which also acts as a proxy on the access to basic services for people living outside urban areas). Lastly, the percentage share of the Gross Fixed Capital Formation (GFCF) over GDP (from World Bank), as an additional, albeit rough, proxy of technology.

As regards the institutional drivers of inequality, we classify our control variables following the criteria adopted in defining the different components of the readiness dimension of ND-GAIN index. The first one is the "social readiness", which is defined as the "social conditions that help society to make efficient and equitable use of investment and yield more benefit from the investment" and combines education, ICT, and innovation indicators. Accordingly, from WDI we drawn data on the years of schooling (as in Hartman et al., 2017), and the domestic general government health expenditure (% of GDP). The second institutional dimension is the "governance readiness", which is defined as "the stability of the society and institutional arrangements that contribute to the investment risks". Therefore, we include a set of variables capturing the quality of institutions and the functioning of the political system. In particular, we use data provided by the World Bank's Worldwide Governance Indicators and select the same indicators used in the ND-GAIN index, which are: Corruption control; Government Effectiveness; Political Stability; Regulatory Quality; Rule of Law; Voice and Accountability.

3.4 Data on financial globalization, FDIs and the Value Chain dimension

Following the discussion reported in Section 2.2, we regard the financial globalization as a phenomenon which has likely impacted on the distributional dynamics of the economies in the last decades. With the aim of accounting for this factor, we firstly include in our model the *de facto* Financial Globalization Index provided by the KOF Swiss Economic Institute database of ETH Zurich.[14]

Most importantly, our dataset includes variables proxying the countries' production structure and participation in GVCs as captured by the composition of FDIs. To this aim,

[14] The *de facto* measure of financial globalization is computed as the weighted average of the following components: (a) sum of stocks of assets and liabilities of FDI (% of GDP); (b) sum of stocks of assets and liabilities of international equity portfolio investments (% of GDP); (c) sum of inward and outward stocks of international portfolio debt securities and international bank loans and deposits (% of GDP); (d) international reserves, including foreign exchange (excluding gold), SDR holdings and reserve position in the IMF (% of GDP); (e) sum of capital and labour income to foreign nationals and from abroad (% of GDP). Data are drawn from the KOF Swiss Economic Institute (ETH Zurich) database (Dreher, 2006; Gigly et al., 2019). See https://kof.ethz.ch/en/forecasts-and-indicators/indicators/kof-globalisation-index.html

we classify inward FDIs according to several selected dimensions, which regard both industries drawing the FDIs and value chain activities the FDIs are related to, with the aim of obtaining proper indicators on the level of insertion of economies in GVCs and their capability to attract FDIs in different value chain functions.

In particular, we distinguish the incoming FDIs according to the development level of the country of origin: advanced countries (i.e., North America, EU27, UK, Norway, Switzerland, Australia, New Zealand, Japan and the Four Asian Tigers) or emerging countries (i.e. those countries not categorized as advanced countries).

Since the position that countries occupy in the international division of labor may also moderate the impact on economic performance and income distribution within nations, we take into account the participation of countries in GVCs as a further conditioning factor in dealing with inequality effects of climate changes. In doing so, we distinguish between the FDIs received in each GVC stages (i.e., upstream; production; downstream) and consider the share of each category over the total number of inward FDIs received.[15]

Finally, we also calculate an FDI based GVC diversification index based on the Herfindahl–Hirschman index (HHI) that, for each country *i* and year *y*, is calculated as follows: $FDI\ GVC\ diversification_{i,y} = 1 - HHI_{i,y} = 1 - \sum_{k=1}^{3}\left(\frac{FDI_{i,y}^{k}}{FDI_{i,y}}\right)^2$, where the ratio in parenthesis represents the share of FDIs over the total inward FDIs for each *k-th* of the three GVC stages in country *i* and year *y*.

Data on FDIs are drawn from the fDi Markets database. fDi Markets is an online database provided by fDi Intelligence – a specialist division of Financial Times Ltd – which collects detailed information on announced cross-border greenfield investments (i.e. new wholly-owned subsidiaries, including joint ventures whether they lead to a new physical operation) from several publicly available information sources, covering all sectors and countries worldwide from 2003 onwards. The database represents one of the main data source in UNCTAD’s World Investment Report (notably, fDi Markets is the only source on greenfield FDIs used by UNCTAD) and has been exploited in publications by the Economist Intelligence Unit. Notably, since fDi Markets includes planned future investment projects, some of the latter might not be carried out or may be realized in a form which differs from the one reported by the database. Although the database is daily updated, this data-collection method may cast some doubts on the reliability of information on the most recent FDIs. We thus chose not to consider the FDI projects recorded during the last available year, namely 2018, limiting our analysis to the time span 2003-2017. Over this period, fDi Markets includes almost 190,000 investment projects worldwide (on the reliability of the distribution of the number of investment projects included in fDi Markets see Castellani & Pieri (2013, 2015), Crescenzi et al. (2014) and Ascani et al. (2016)). Finally, it is worth emphasizing that the classification

[15] Following Stöllinger (2019), the activities classified as Upstream are: R&D; Design; Development & Testing; Education & Training; Headquarters; ICT & Internet Infrastructure. The activities classified in the Production stage are: Manufacturing; Recycling; Extraction. The activities classified as Downstream are: Business Services; Logistics, Distribution & Transportation; Sales, Marketing & Support, Maintenance & Servicing, Customer Contact Centre; Shared Services Centre; Technical Support Centre.

of value chain activities associated to FDIs is a key characteristic of the dataset and represents a fundamental piece of knowledge for whom, as who are writing, is committed to investigate the FDIs' patterns adopting a GVC perspective (Castellani, Jimenez & Zanfei, 2013; Zanfei et al., 2019).

4. RESULTS

Complementing with extant research, we begin our investigation by looking at potential drivers of between-country inequality. This is done using pooled OLS estimations (we control for time fixed effects but do not include country fixed effects), where the Gini index is regressed against indicators of climate variability, while controlling for GDP per capita in linear and squared terms, and the additional vulnerability and adaptation controls previously described. The results of this analysis are presented in Table 2.

Target variables of interest in our specification model are temperature (here expressed in terms of the natural logarithm)[16], and the average absolute value of the SPI-3 from time *t* to time *t-5* (to account for the magnitude of the drying/flooding anomalies). Both indicators have a statistically significant and positive effect, meaning that they contribute to increase between-country income inequality. Results remain qualitatively unchanged also when controlling for factors associated to economic and technological development (linear and squared GDP per capita, industry share of value added, ICT as proxied by the relative number of mobile subscriptions, GFCF over GDP, rural electricity access and rural population share); governance and especially social readiness of the economies (the latter being proxied by education and the percentage share of government health expenditure over GDP); and for factors related to the overall incoming FDIs and financial globalization. After introducing all of these (standard) controls factors possibly affecting inequality, the sign and the statistical significance of our variables of interests remain unchanged: both key measures of climate change retain their positive and significant impact on income disparities within countries. It is worth stressing that the signs of the linear and squared GDP per capita suggest an inverted-U shaped relationship (Kuznets curve). The coefficients of technology indicators (rural electricity access and GFCF), and health expenditure are negative and significant, while the industry share and the total number of incoming FDI are statistically significant and positively correlated with the Gini index.[17] Results about the two measures of climate change are also robust to the inclusion of the unemployment rate. However, given the lower data availability in the rest of the analysis we do not include it among our set of controls (see footnote 7 for a discussion, and Table A.2 in Appendix).

Next, we move to deepen the analysis of the causal links and moderating factors in the relation between climate variations and within-country inequality. Hence, all models in Tables 3, 4 and 6 include time and country fixed effects.

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[16] This implies that estimated coefficients are to be interpreted as follows: e.g. a 1% increase of temperature increases the Gini index by x (where x is the estimated coefficient).

[17] We interpret this result coherently with the GDP coefficient and the heterogeneity resulting from the large number of countries in the sample (see also the discussion provided below about the rural and urban different level of inequality).

In Table 3, we start with a simple model where we control only for the linear and squared GDP per capita, and include one by one each of the climate indicators described in the previous section: temperature (computed in log terms), temperature increase, extreme temperature, the magnitude of the drying/flooding conditions (*absolute value of SPI-3 index 5-years average*), and the dummy registering if a (medium-long term) process of drying or flooding is in place (*increasingly extreme SPI-3 index 10-years average*).

Table 2 – Pooled OLS

	(1)	(2)	(3)	(5)	(6)	(7)
ln(temperature)	7.396***	4.837***	3.709***	3.955***	3.850***	4.083***
	(1.047)	(0.847)	(0.872)	(0.961)	(0.973)	(0.976)
abs_SPI 3 (av. 5)	4.456**	4.470**	4.045**	3.942**	4.154**	4.250**
	(1.774)	(1.800)	(1.807)	(1.813)	(1.801)	(1.701)
ln(GDP pc)		23.601***	37.926***	45.666***	46.933***	19.388
		(5.904)	(10.434)	(11.049)	(11.193)	(24.840)
ln(GDP pc)^2		-1.467***	-2.150***	-2.666***	-2.732***	-1.257
		(0.334)	(0.532)	(0.597)	(0.603)	(1.294)
Country FE	No	No	No	No	No	No
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Additional controls	No	No	Eco-tech.	Eco-tech., institutional	Eco-tech., institutional, financial globalization, FDI	Eco-tech., institutional, financial globalization, FDI, unemployment
Observations	1918	1884	1715	1688	1688	1121
r2	0.325	0.459	0.524	0.569	0.581	0.621
r2_a	0.320	0.454	0.517	0.561	0.573	0.609

Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Controls classified as economic and technological are: Industry share (%); Mobile subscription; GFCF over GDP (%); Rural electricity access; Rural pop (%). Controls classified as institutional are: Corruption control; Government Effectiveness; Political Stability; Regulatory Quality; Rule of Law; Voice and Accountability; Schooling; Gov health expenditure (%). Financial globalization is measured by the *de facto* measure of financial globalization provided by KOF-ETH; FDI is measured in terms of the number of Incoming FDIs. See Table A.2 in Appendix.

First, we note that all model specifications confirm our previous finding that inequality is linked to income through a relationship à la Kuznets, as captured by the linear and squared GDP per capita. The first term is positive and the second is negative, and both are statistically significant, meaning that increasing economic development, the (within-country) income inequality first rises and then decreases.

We now turn to the analysis of climate indicators. When entered individually in the model specification (columns 1 to 5), we observe that the estimated coefficient of each variable bears positive sign. This implies that all our variables, capturing different nuances of climate change, consistently show a positive relation with economic inequality. Among these variables, two of them register generic changes in climate variability, i.e. temperature increase and the magnitude of drying/flooding anomalies. Instead, the remaining variables proxy extreme climate variability. We test the separate effect of these two groups of variables respectively in column 6 (changes in climate conditions) and 7 (extreme changes in climate conditions). The estimates obtained show that our results are left qualitatively unchanged when using more refined model specification, where different dynamics of climate change are accounted for, i.e. generic vs extreme variability. All our results are robust to the inclusion of control variables proxying for economic and technological factors, social readiness, incoming FDIs and financial globalization (see Table A.3 in Appendix). In this respect, it is also worth noting that, as expected, an increase in the indicators of technological change and social readiness in the country (i.e. schooling, government health expenditure, relative number of mobile subscriptions, and rural electricity access) have a negative and statistically significant effect on inequality.

Among the climate indicators, all variables but one have a statistically significant impact on inequality in all model specification. Specifically, the temperature and the two indicators recording, respectively, the extent of the temperature change (with respect to the previous year) and an extreme temperature increase have positive and statistically significant coefficient. As for precipitation, the variable recording the magnitude of the precipitation anomalies in the country in the previous 5 years (*abs_SPI 3 av. 5*) does not seems to have a statistically significant effect. At the same time, the other precipitation index (*Increasingly extreme SPI 3 av. 10*), which records whether there was an increase in precipitation anomalies in the country at time t compared to the previous 10 years, increases inequality significantly and its effect is homogeneous across countries.

Table 3 – Climate indicators

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ln(GDP pc)	7.102**	6.917*	7.677**	7.057**	6.882*	7.246**	7.644**
	(3.530)	(3.526)	(3.535)	(3.496)	(3.488)	(3.502)	(3.497)
ln(GDP pc)^2	-0.489**	-0.479**	-0.519**	-0.488**	-0.474**	-0.499**	-0.517**
	(0.209)	(0.208)	(0.209)	(0.206)	(0.206)	(0.206)	(0.206)
ln(temperature)	0.519**					0.501**	
	(0.238)					(0.249)	
Temperature increase		0.070***					0.063*
		(0.023)					(0.032)
Temp extreme (increase >1.5C°)			0.243***				0.236***
			(0.088)				(0.087)
abs_SPI 3 (av. 5)				0.512		0.507	
				(0.310)		(0.309)	
Increasingly extreme SPI 3 (av. 10)					0.123**		0.123**
					(0.050)		(0.050)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1918	1918	1918	1918	1918	1918	1918
r2	0.136	0.135	0.140	0.140	0.138	0.142	0.145
r2_a	0.129	0.127	0.132	0.132	0.131	0.134	0.136
F	2.200	2.446	2.630	2.519	2.195	2.258	2.251

Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Results are robust when also controlling for: Industry share (%); Mobile subscription; GFCF over GDP (%); Rural electricity access; Rural pop (%); Schooling; Gov health expenditure (%); Financial globalization; Incoming FDIs (see Table A.3 in Appendix).

We now focus on our model specification accounting simultaneously for different measures of climate variability (column 6 of Table 3). Our model specification suggests that the variable accounting for the absolute magnitude of the drying/flooding anomalies (*abs_SPI 3 av. 5)* does not have a statistically significant effect on income. However, it might be the case that this model specification does not properly account for the effect of *abs_SPI 3 av. 5*. We address this question by testing whether *abs_SPI 3 av. 5* has some sort of heterogenous effect hindering the correct identification of this variable. Of course, a number of different sources of heterogeneity can be at play in this context. Following a consolidated strand of literature, we therefore test whether different effects are explained by different economic structures. This is consistent with the hypothesis formulated by Kuznets on the relationship between economic development and urbanization, and further expanded by Rauch (1991), according to whom "*when all inequality is between sector it tends to be maximized when the two sectors are of equal size*" (Rauch, 1991, pag. 20). If this hypothesis is correct, and the impact of *abs_SPI 3 av. 5* has an effect with similar magnitude but opposite sign for groups with different economic structures, this could explain why the *abs_SPI 3 av. 5* has an estimated effect close to zero in our first model specification.

In other terms, our findings in Table 3, column 6, suggest that we should investigate how precipitation anomalies affect inequality in countries with different structural characteristics and with different shares of population between rural and urban areas. Consequently, the role played by the agricultural channel in mediating the effect of climate change on inequality is addressed specifically in Table 4. As illustrated in columns 4 through 7, we find that temperature increases are particularly associated with inequality in the presence of high shares of population in rural areas and of high shares of agricultural workers. This is broadly consistent with the idea that the agricultural sector is a key channel through which climate change can exacerbate inequality.

However, to a closer look at Table 4, several important nuances emerge in this general picture. In the first three columns of Table 4, we investigate the presence of potential heterogenous effects of temperature, i.e. *ln(t),* and *abs_SPI 3 av. 5* by interacting these regressors with a dummy variable distinguishing between cases in which: i) more than 2/3 of the population is either rural or urban (in which case the dummy assumes value 0); ii) a more balanced distribution between rural or urban population exists (in which case the dummy *Mid pop_rur* assumes value 1). Some suggestive evidence is found when taking this approach. First, while temperature is not statistically significant, the magnitude of the SPI 3 index (*abs_SPI 3 av. 5*) is positive and statistically significant – i.e. when the population is either largely rural or urban, larger precipitation anomalies have a significant impact in worsening income inequality (columns 2-3). Moreover, consistent with our expectations, we find that the interaction term between *abs_SPI 3 av. 5* and the dummy representing the rural/urban distribution is negative and statistically significant: i.e. *abs_SPI 3 av. 5* does have heterogenous effect depending on the economic structure considered. Finally, we observe that the dummy representing the rural/urban distribution is positive and statistically significant: the lower the difference between the shares of population living in rural and urban areas, the higher the level of economic inequality. This is not surprising and consistent with a large literature indicating that in the initial development phase, when the level of urbanization is low (and the low-inequality rural sector is relatively large), inequality raises as the low rural income constitutes an incentive for workers to move to the ‘informal’ urban sector, even at the risk of being underemployed (Rauch, 1993). At later stages, inequality decreases as within-urban inequality decreases and rural income grows (Kuznets, 1955).

All in all, these results confirm the heterogeneous effect of precipitation variability depending on the balanced/unbalanced distribution between rural and urban population. At the same time, the impact of a 1% temperature increase seems to be homogeneous across countries. To further investigate the source of heterogeneous effects, we introduce an additional distinction between highly rural and highly urban population (columns 4 to 6 in Table 4), and discriminate the effect of temperature and *abs_SPI 3 av. 5* on this basis.

Before turning to the discussion of these model estimates, we thus briefly present the main socio-economic and geographic characteristics of each groups associated to a given population structure. This will be useful to better understand the mechanism driving the source of heterogeneity featured by the effect of *abs_SPI 3 av. 5*.

The characteristics of each group are presented in Table 5. Lower share of rural population is associated to countries more distant from the equator (considering the absolute value of the latitude of the capital), characterized by lower mean temperature and precipitation level. At the same time, they feature a magnitude of drying/flooding anomalies in absolute terms (*abs_SPI 3 av. 5*) that is the largest among the three group, and they are associated to the largest value of *SPI 3 (av. 5)* (thus pointing to the fact that these countries are more affected by flooding anomalies rather than by drying anomalies). Lower share of rural population is also associated to more advanced countries, with larger GDP per capita, lower Gini index and an employment in agriculture (% of total employment) largely lower than the other two groups and the overall average. On the other hand, higher share of rural population is associated to countries close to the equator (e.g., within the tropical belt), characterized by larger mean temperature and precipitation level, the lowest GDP per capita and highly reliant on the agricultural sector (with an employment in agriculture being almost 60% of total employment). Since the magnitude of the *SPI 3 (av. 5)* assumes a lowest value, it suggests that these countries are more at risk of drying anomalies.

Table 4 – Agricultural channel

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ln(GDP pc)	8.122**	8.361**	8.247**	8.520**	8.563**	8.773**	9.496**
	(3.643)	(3.681)	(3.656)	(3.689)	(3.676)	(3.693)	(3.653)
ln(GDP pc)^2	-0.515**	-0.523**	-0.520**	-0.543**	-0.533**	-0.555**	-0.593***
	(0.213)	(0.214)	(0.213)	(0.214)	(0.214)	(0.213)	(0.212)
Rural electricity access	-0.045***	-0.047***	-0.045***	-0.047***	-0.046***	-0.047***	-0.046***
	(0.016)	(0.016)	(0.016)	(0.016)	(0.015)	(0.015)	(0.017)
ln(temperature)	0.285	0.341	0.312	0.654**	0.337	0.674**	0.360*
	(0.248)	(0.251)	(0.246)	(0.311)	(0.260)	(0.319)	(0.206)
abs_SPI 3 (av. 5)	0.453*	0.846**	0.841**	0.492*	-0.163	-0.089	0.419
	(0.271)	(0.384)	(0.384)	(0.272)	(0.327)	(0.322)	(0.272)
Mid pop_rur	-0.027	0.943**	0.187				
	(0.480)	(0.420)	(0.480)				
Mid pop_rur*ln(t)	0.280		0.272				
	(0.173)		(0.167)				
Mid pop_rur*abs_SPI3		-1.021**	-1.009**				
		(0.509)	(0.505)				
Low pop_rur				0.408	-1.093*	0.125	
				(0.348)	(0.592)	(0.381)	
Low pop_rur*ln(t)				-0.471**		-0.456**	
				(0.205)		(0.199)	
High pop_rur				-5.000***	-0.618*	-4.685***	
				(1.755)	(0.370)	(1.672)	
High pop_rur*ln(t)				1.443**		1.342**	
				(0.560)		(0.536)	
Low pop_rur*abs_SPI3					1.330**	1.248**	
					(0.579)	(0.564)	
High pop_rur*abs_SPI3					-0.018	-0.044	
					(0.502)	(0.499)	
Agr. Empl							-0.003
							(0.022)
Agr. Empl*ln(t)							0.001***
							(0.000)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1888	1888	1888	1888	1888	1888	1866
r2	0.218	0.221	0.224	0.228	0.226	0.237	0.200
r2_a	0.209	0.213	0.214	0.218	0.217	0.226	0.191
F	1.911	1.907	1.900	1.961	1.753	1.950	2.053

Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Results are robust when also controlling for: Industry share (%); Mobile subscription; GFCF over GDP (%); Schooling; Gov health expenditure (%); Financial globalization; Incoming FDIs (see Table A.4 in Appendix).

Table 5 – Descriptive statistics by rural population groups

Rural population share	Latitude	Temp.	Precip.	abs_SPI 3 (av. 5)	SPI 3 (av. 5)	Gini	GDP pc (log)	Agr. empl.
Low	41.600	13.828	2.668	0.264	0.117	34.531	10.081	8.763
Mid	24.882	19.443	3.427	0.193	0.045	41.054	8.813	32.778
High	15.272	23.164	3.713	0.194	0.025	42.334	7.819	57.348
Total	27.661	17.973	3.186	0.221	0.069	38.754	9.115	28.190

Source: authors' elaboration.

Bearing these descriptive considerations in mind, the results we have anticipated above can now be better appreciated. From column 4 in Table 4, we observe that the impact of 1% temperature increase is associated to an increase in inequality, and that this effect is larger in highly rural countries (*High pop_rur*ln(t)*) and lower in more urbanized ones (*Low pop_rur*ln(t)*). Hence, the effect of temperature in exacerbating inequality is stronger in warmer and less developed countries more reliant on agricultural sector. This is also confirmed by results in column 7, where we introduce the employment in agriculture as percentage of total employment and its interaction with temperature, which results positive and statistically significant. On the other hand (column 5), the impact of an increase in magnitude of the precipitation anomalies (*abs_SPI 3 av. 5*) is positive and statistically significant in the low-rural population group (*Low pop_rur*abs_SPI3*), where the anomalies are of larger magnitude and flooding-related (rather than drying). Results from columns 4 and 5 are also confirmed if both climate-related interactions are simultaneously included (column 6). Moreover, results remain qualitatively unchanged when controlling for: Industry share (%); Mobile subscription; GFCF over GDP (%); Schooling; Gov health expenditure (%); Financial globalization; Incoming FDIs (see Table A.4 in Appendix). The results of this investigation therefore show that (as modelled by our specification) countries with an economic structure featuring the lowest share of rural population are those most affected by changes in the magnitude of precipitation anomalies, while those countries largely rural suffer the most from temperature increase.

We now turn the discussion to our second model specification, controlling for extreme changes in climate conditions (column 7 of Table 3), and we test whether there are other economic mechanisms able to mitigate or exacerbate their impact on economic inequality. Accordingly, we investigate the role of international investments as an additional component that may contribute to inequality. So far, our results show that incoming cross-border investments induce a more unequal distribution of income, worsening inequality.

Therefore, in Table 6 we focus on the GVC dimension of FDIs, assessing the role played by their composition in terms of value-adding activities in shaping distributional dynamics of receiving countries. Hence, we unpack inward FDIs according to the stage of GVCs they are related to with the aim of investigating their potential heterogeneous impact on income distribution. In particular, in column 1 we include the share of FDIs in upstream activities of GVCs, while in column 2 and column 3 we account for the share of FDIs in production and downstream activities, respectively.

First of all, it is worth emphasizing that estimates reported by all columns show that our previous findings related to the impact of climate change on inequality are largely confirmed. The climate-related indicators signaling the presence of extreme variability continue to show their relevance in adversely (and uniformly) shaping income distribution. Similarly, all other relevant control variables maintain the sign and significance emerged in early estimations.

Most notably, while the coefficient of total incoming FDIs remains always significantly positive, column 1 shows that the share of FDIs in most upstream stages of GVCs shows a significantly negative coefficient, i.e. tends to reduce income inequality. Since upstream activities are mainly related to R&D and ICT-related functions, this finding is consistent with previous evidence suggesting that knowledge-intensive FDI flows entail technological spillovers which promote the structural upgrading of destination regions, creating new, better-paid jobs in receiving economies (Pöschl et al., 2016; Morris & Staritz, 2017).

Table 6 – GVC mitigating factors

	(1)	(2)	(3)	(4)	(5)
ln(GDP pc)	9.720**	9.657**	9.510**	9.525**	9.557**
	(4.111)	(4.137)	(4.138)	(4.122)	(4.120)
ln(GDP pc)^2	-0.565**	-0.559**	-0.552**	-0.550**	-0.551**
	(0.233)	(0.234)	(0.234)	(0.233)	(0.233)
Temperature increase	0.065*	0.065*	0.062	0.060	0.063*
	(0.039)	(0.038)	(0.039)	(0.038)	(0.037)
Temp extreme (increase >1.5C°)	0.145*	0.148*	0.150*	0.142*	0.140*
	(0.081)	(0.080)	(0.080)	(0.080)	(0.080)
Increasingly extreme SPI 3 (av. 10)	0.099**	0.104**	0.103**	0.111**	0.325**
	(0.049)	(0.050)	(0.050)	(0.051)	(0.131)
Incoming FDIs	0.002***	0.002***	0.002***	0.002***	0.002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
FDI sh. in Upstream activities	-0.647**				
	(0.314)				
FDI sh. in Production activities		0.290**			
		(0.136)			
FDI sh. in Downstream activities			0.071		
			(0.118)		
GVC diversification				-0.004***	-0.002*
				(0.001)	(0.001)
GVC diversification * increasingly extreme SPI 3					-0.004**
					(0.002)
Country FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Additional controls: Industry share (%); Mobile subscription; GFCF over GDP (%); Rural electricity access; Rural pop (%); Schooling; Gov health expenditure (%); Financial globalization.					
Observations	1721	1721	1721	1721	1721
r2	0.300	0.299	0.296	0.302	0.304
r2_a	0.288	0.287	0.284	0.290	0.292
F	2.396	2.286	2.405	2.455	2.418

Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. See Table A.5 in Appendix for the full set of controls.

Conversely, column 2 shows that a greater attraction of manufacturing FDIs turns out exerting a significantly positive impact on inequality, worsening the distribution of income. An explanation might be offered by the skill-biased character of captive offshoring, especially in developing economies. However, this argument would have arguably asked for an even more positive and significant coefficient of the share of FDIs in upstream functions. Given that this is not the case, we suggest that the adverse distributional impact of production offshoring on receiving economies can be traced back to the negative consequences on workers' bargaining position vis-à-vis firms (Stockhammer, 2017; Coveri & Pianta, 2019; Stansbury & Summers, 2020). Finally, as shown by column 3, we do not find any significant association between the share of FDIs in downstream GVC activities and income inequality, as the former reports a positive but not significant coefficient.

Furthermore, column 4 and column 5 allow to empirically verify our hypotheses on the relationship between GVC diversification and income inequality. Interestingly, estimation results reported by column 4 confirm that a greater GVC diversification – namely a higher dispersion of FDIs across value chain activities – is significantly associated with a lower within-country inequality. This finding seems to support our argument according to which the diversification across value-adding functions of inward cross-border investments allow to increase the economic sophistication of the production structures of destination regions, which in turn promote a more inclusive development.

Moreover, our hypothesis on the resilience-enhancing role of GVC diversification appears to be supported by results reported by column 5. In particular, we interact the climate-related indicator which resulted the most significant in previous columns, namely increasingly extreme SPI-3 index (10-years avg.), with the variable capturing the level of GVC diversification to assess whether the latter is able to alleviate the impact of climate change on income inequality. The negative and statistically significant coefficient of the interaction term shows that whereby an increase in precipitation anomalies with respect to the previous 10 years occurs, a higher GVC diversification alleviates the adverse consequences on income distribution. As we argued, this might be due to the greater productive diversification induced by a more even distribution of FDIs across value chain functions, which might allow to improve the capabilities of adaptation and reduce the vulnerability to both internal and external conditions, including climate-induced phenomena (Coveri et al., 2020).

5. CONCLUSIONS

Existing evidence already suggests that the impact of climate change is heterogeneous between-countries, with LDCs and poor regions suffering the highest costs. However, also from a within country perspective, local regions, sectors and individuals are expected to be unevenly affected. Indeed, climate change impacts economic growth but also entails a heterogenous distribution of the damages with exposure, vulnerability and adaptive capacity being the drivers of such differentiated effects.

Most literature has focused on the role exerted by climate change in increasing poverty and between-country inequality. However, few studies have explicitly addressed the impact of climate-related events on within-country inequality. This is a major drawback of extant research given that between-country inequality has declined over the last decades – almost exclusively due to the rapid economic growth experienced by China and India –, while it is inequality within countries that has risen and hence needs to be explained(Milanovic, 2005, 2016).[18] This work contributes to fill this gap by empirically

[18] In this regard, UNDP (2013) reports that income inequality increased on average by 11 percent in developing countries between 1990 and 2010; moreover, the report documents that more than 75 percent of the population living in developing economies are living today in societies where income is more unequally distributed than it was in the 1990s.

investigating the adverse consequences of climate change on income inequality within more than 150 countries.

Controlling for a large number of determinants of inequality detected by the extant literature, we find that climate change has worsened the distribution of income, playing a relevant role in increasing within-country income disparities.[19] Accounting for different climate indicators, we also show that the impacts are heterogeneous depending on the diversification of the economic structure.

Agriculture is likely to be among the most affected sectors by shifts in temperature and precipitation because of their effect on soil quality and ecosystem services. Consistent with expectations, we find that countries more exposed to the economic consequences of sudden changes in the agricultural sector, are also more exposed by climate risk. However, the multiple mechanisms through which this channel acts, make it difficult to have a straightforward understanding of the impact of climate changes and how to counteract their effects. Take for instance the case of smallholder farmers. They rely on rainfed agriculture and increasingly degraded land. In such context, they might mitigate the negative effects of climate change by accessing to adaptive technologies, e.g., water harvesting and irrigation system, land-use policies and resilient crops. This would not only decrease the negative impact on income for vulnerable people dependent on agriculture (which largely includes the poorest), but also contributes to increase socio-economic resilience through food security.

We also find that while inward FDIs *per se* induce a more unequal distribution of income, their composition in terms of value generating activities does matter. In this regard, we find that FDIs in most upstream functions of the value chain tend to reduce income inequality, while FDIs in production activities result exacerbating it. Since upstream functions are related to the most knowledge-intensive segment of GVCs – involving R&D, Design & Development, Education & Training, Headquarters and ICT-related value adding activities –,our findings might be interpreted as evidence of a potential re-distributive effect of technological change. A greater involvement in knowledge-intensive GVC functions might thus foster the creation of better-paid jobs, with the consequence of reducing income inequality. In addition, inasmuch as these findings downgrade the skill-biased technological change as driver of increasing inequality, we conjecture that the adverse effect that we observe in the case of inward FDIs in general might instead reflect the negative impact of cross-border production and fabrication activities and of captive offshoring on the bargaining power of workers with respect to firms.

Finally, we put forward the hypothesis that the modalities through which economies are involved in GVCs are likely to affect their distributional dynamics. In particular, we

[19] Among the determinants emphasized in the literature, we control for both economic, technological and welfare-related drivers of inequality. In line with previous results, we find a negative impact of social readiness indicators, i.e. education and government expenditure in healthcare services, on income distribution, while we provide empirical support to the inequality-worsening effects of financial globalization. Our proxy of ICT adoption – i.e. the amount of mobile-subscriptions per 100 inhabitants – shows a significantly negative coefficient, hence providing no evidence of skill-biased technological change.

advanced the argument that a higher GVC diversification, defined as the capability of countries to attract FDIs related to different value chain activities, increases the economic sophistication of the economies with beneficial effect on income distribution. In addition, we argued that GVC diversification – as opposed to functional hyper-specialization – may represent a resilience-enhancing factor able to mitigate the adverse impact of climate change on inequality.

The evidence provided supports our hypotheses, showing that a more even distribution of FDIs across value-adding activities contribute to reduce inequality and alleviate the worsening impact that climate change exerts on income distribution. We suggested that the rationale underpinning this evidence might be found in the inclusive structural change that a more even and comprehensive development of complementary value chain activities may trigger, increasing the economic resilience of countries to external shocks, including environmental-related extreme events. The process of economic development is fundamentally linked with economic diversification, i.e., from agriculture towards more industrialized productive structures, and in general from a single income source toward a larger range of earnings deriving from multiple sectors and activities. In a global context of increasingly disperse production activity, an upstream positioning in GVCs and diversification may constitute a further pillar of adaptation strategies.

Given the adverse impact that climate change consequences have on individual income distribution, it is important to stress that the burden of climate mitigation should not fall disproportionally on the poorest segments of population. In other words climate mitigation policies should be designed in a way that does not determine additional income disparities on top of the dismal effects of climate change.

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APPENDIX

Table A.1 – Description of variables

Variable name	*Description*	*Original source*
Gini index	Gini index, post-tax, post-transfer (computed on the income available to household after government taxes and transfers)	SWIID
ln(temperature)	Average temperature (log)	CRU
Temperature increase	Ratio between $temperature_{i,t}$ and $temperature_{i,t-1}$	CRU
Temp extreme (increase >1.5C°)	Heat wave (dummy=1 if difference of the average temperature w.r.t. historical mean 1900-1950 is larger than 1.5°)	CRU
abs_SPI 3 (av. 5)	3-month Standardized Precipitation Index (SPI-3) (absolute value, 5-years average from t to t-4)	CRU
Increasingly extreme SPI 3 (av. 10)	Extremization of drying/flooding anomalies (dummy=1 if the ratio between $SPI\text{-}3_t$ and the average SPI-3 in the 10 previous years >1)	CRU
ND-GAIN index	Notre Dame-Global Adaptation Index (ND-GAIN) Country Index (higher values, less climate vulnerability)	University of Notre Dame
ln(GDP pc)	GDP per capita at PPP, constant 2011 international dollar (log)	WDI
ln(GDP pc)^2	GDP per capita at PPP, constant 2011 international dollar (log) squared	WDI
Industry share (%)	Share of industry value added including construction (% of GDP)	WDI
Rural pop (%)	Rural population as percentage of total population	WDI
Low pop_rur	Highly urban population (dummy=1 if rural pop. share < 1/3)	WDI
Mid pop_rur	Balanced rural/urban population (dummy=1 if 1/3<rural pop. share<2/3)	WDI
High pop_rur	Highly rural population (dummy=1 if rural pop. share > 2/3)	WDI
Mobile subscription	Mobile-cellular subscriptions per 100 inhabitants	WDI
GFCF over GDP (%)	Gross Fixed Capital Formation (% of GDP)	WDI
Rural electricity access	Percentage of rural population with access to electricity	WDI
Agr. Empl	Employment in agriculture as % of total employment (ILO estimate)	WDI
Unemployment rate (%)	Unemployment (total) as % of total labor force (ILO estimate)	WDI
Worldwide Governance Indicators	Corruption control; Government Effectiveness; Political Stability; Regulatory Quality; Rule of Law; Voice and Accountability;	WGI
Schooling	Years of schooling	WDI
Gov health expenditure (%)	Domestic general government health expenditure (% of GDP)	WDI
Financial globalization index	Financial Globalization Index, de facto	KOF-ETH
Incoming FDIs	Number of incoming FDIs	fDi Markets
FDI sh. in Upstream activities	Share of incoming FDIs in Upstream activities	fDi Markets
FDI sh. in Production activities	Share of incoming FDIs in Production activities	fDi Markets
FDI sh. in Downstream activities	Share of incoming FDIs in Downstream activities	fDi Markets
GVC diversification	FDI diversification based on GVC activities	fDi Markets

Source: authors' elaboration.

Table A.2 – Pooled OLS

	(1)	(2)	(3)	(5)	(6)	(7)
ln(temperature)	7.396***	4.837***	3.709***	3.955***	3.850***	4.083***
	(1.047)	(0.847)	(0.872)	(0.961)	(0.973)	(0.976)
abs_SPI 3 (av. 5)	4.456**	4.470**	4.045**	3.942**	4.154**	4.250**
	(1.774)	(1.800)	(1.807)	(1.813)	(1.801)	(1.701)
ln(GDP pc)		23.601***	37.926***	45.666***	46.933***	19.388
		(5.904)	(10.434)	(11.049)	(11.193)	(24.840)
ln(GDP pc)^2		-1.467***	-2.150***	-2.666***	-2.732***	-1.257
		(0.334)	(0.532)	(0.597)	(0.603)	(1.294)
Industry share (%)			0.052	0.130**	0.117**	0.146
			(0.058)	(0.058)	(0.057)	(0.105)
Mobile subscription			-0.319	-0.308	-0.005	0.401
			(0.859)	(0.729)	(0.692)	(0.894)
GFCF over GDP (%)			-0.091	-0.102*	-0.114*	0.027
			(0.061)	(0.061)	(0.061)	(0.079)
Rural electricity access			-0.090**	-0.068**	-0.072**	-0.088
			(0.038)	(0.034)	(0.034)	(0.055)
Rural pop (%)			0.002	0.022	0.019	-0.016
			(0.040)	(0.037)	(0.037)	(0.040)
Corruption control				4.270***	4.471***	2.904*
				(1.363)	(1.339)	(1.497)
Government Effectiveness				-1.496	-1.972	-1.753
				(1.939)	(1.872)	(2.171)
Political Stability				0.142	0.445	-0.508
				(0.786)	(0.786)	(1.012)
Regulatory Quality				1.879	2.124*	2.236
				(1.235)	(1.268)	(1.548)
Rule of Law				-2.147	-2.472	-1.295
				(1.704)	(1.620)	(2.049)
Voice and Accountability				0.710	0.843	1.191
				(1.161)	(1.147)	(1.494)
Schooling				-0.628	-0.563	-0.654
				(0.513)	(0.494)	(0.564)
Gov health expenditure (%)				-0.058*	-0.054*	-0.079**
				(0.032)	(0.030)	(0.033)
Financial globalization index					-0.032	-0.072
					(0.031)	(0.045)
Incoming FDIs					0.005***	0.004***
					(0.002)	(0.001)
Unemployment rate (%)						0.185
						(0.118)
Country FE	No	No	No	No	No	No
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1904	1884	1715	1688	1688	1121
r2	0.325	0.459	0.524	0.569	0.581	0.621
r2_a	0.320	0.454	0.517	0.561	0.573	0.609
F	7.587	12.724	12.798	9.856	11.954	11.235

Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.3 – Climate indicators

	(1)	(2)	(3)	(4)	(5)	(6)	(8)
ln(GDP pc)	9.312**	9.180**	9.660**	9.235**	9.171**	9.354**	9.618**
	(4.122)	(4.109)	(4.120)	(4.117)	(4.096)	(4.131)	(4.110)
ln(GDP pc)^2	-0.542**	-0.535**	-0.561**	-0.538**	-0.532**	-0.546**	-0.558**
	(0.234)	(0.233)	(0.234)	(0.233)	(0.232)	(0.234)	(0.233)
Industry share (%)	-0.007	-0.007	-0.007	-0.008	-0.008	-0.008	-0.007
	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)
Mobile subscription	-0.346**	-0.349**	-0.347**	-0.345**	-0.348**	-0.342**	-0.344**
	(0.151)	(0.150)	(0.150)	(0.150)	(0.150)	(0.150)	(0.149)
GFCF over GDP (%)	-0.005	-0.005	-0.005	-0.005	-0.005	-0.005	-0.005
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Rural electricity access	-0.048***	-0.048***	-0.047**	-0.047***	-0.048***	-0.047***	-0.047**
	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)
Rural pop (%)	-0.053	-0.052	-0.054	-0.052	-0.052	-0.053	-0.052
	(0.054)	(0.054)	(0.055)	(0.054)	(0.054)	(0.054)	(0.055)
Schooling	-0.454***	-0.458***	-0.453***	-0.447***	-0.450***	-0.449***	-0.456***
	(0.162)	(0.163)	(0.161)	(0.162)	(0.162)	(0.162)	(0.163)
Gov health expenditure (%)	-0.020*	-0.020*	-0.020*	-0.020*	-0.020*	-0.020*	-0.020*
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Financial globalization	0.379*	0.374*	0.376*	0.377*	0.378*	0.376*	0.369*
	(0.199)	(0.200)	(0.197)	(0.197)	(0.199)	(0.197)	(0.198)
Incoming FDIs	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ln(temperature)	0.367**					0.358*	
	(0.184)					(0.190)	
Temperature increase		0.065**					0.062
		(0.032)					(0.039)
Temp extreme (increase >1.5C°)			0.156*				0.151*
			(0.080)				(0.081)
abs_SPI 3 (av. 5)				0.269		0.264	
				(0.238)		(0.238)	
Increasingly extreme SPI 3 (av. 10)					0.101**		0.103**
					(0.050)		(0.050)
Observations	1721	1721	1721	1721	1721	1721	1721
r2	0.292	0.291	0.293	0.292	0.293	0.293	0.296
r2_a	0.281	0.281	0.282	0.282	0.283	0.282	0.285
F	2.372	2.201	2.475	2.239	2.292	2.336	2.383

Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.4 – Agricultural channel

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ln(GDP pc)	8.590*	8.921**	8.631*	9.425**	9.281**	9.722**	10.612**
	(4.362)	(4.304)	(4.369)	(4.375)	(4.290)	(4.349)	(4.277)
ln(GDP pc)^2	-0.505**	-0.518**	-0.506**	-0.557**	-0.539**	-0.572**	-0.612**
	(0.247)	(0.245)	(0.247)	(0.247)	(0.243)	(0.245)	(0.241)
Industry share (%)	-0.008	-0.011	-0.011	-0.009	-0.010	-0.009	-0.009
	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)
Mobile subscription	-0.292**	-0.287*	-0.291*	-0.272*	-0.281*	-0.266*	-0.309**
	(0.147)	(0.149)	(0.149)	(0.148)	(0.149)	(0.150)	(0.149)
GFCF over GDP (%)	-0.005	-0.006	-0.006	-0.005	-0.005	-0.004	-0.005
	(0.010)	(0.010)	(0.010)	(0.011)	(0.011)	(0.011)	(0.011)
Rural electricity access	-0.045**	-0.046***	-0.044**	-0.048***	-0.046***	-0.048***	-0.045**
	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.018)
Schooling	-0.422***	-0.406***	-0.413***	-0.413***	-0.409***	-0.409***	-0.449***
	(0.150)	(0.149)	(0.150)	(0.148)	(0.146)	(0.144)	(0.164)
Gov health expenditure (%)	-0.016	-0.017	-0.016	-0.016	-0.017	-0.016	-0.018
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Financial globalization	0.370*	0.385*	0.358*	0.347*	0.388**	0.339*	0.372*
	(0.206)	(0.197)	(0.201)	(0.208)	(0.195)	(0.200)	(0.197)
Incoming FDIs	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)
ln(temperature)	0.263	0.306	0.284	0.547**	0.310	0.566**	0.340*
	(0.220)	(0.216)	(0.219)	(0.273)	(0.220)	(0.275)	(0.176)
abs_SPI 3 (av. 5)	0.301	0.599*	0.598*	0.336	-0.195	-0.111	0.265
	(0.248)	(0.335)	(0.337)	(0.249)	(0.346)	(0.346)	(0.248)
Mid pop_rur	0.118	0.852**	0.281				
	(0.495)	(0.396)	(0.520)				
Mid pop_rur*ln(t)	0.212		0.211				
	(0.193)		(0.188)				
Mid pop_rur*abs_SPI3		-0.813*	-0.811*				
		(0.480)	(0.481)				
Low pop_rur				0.237	-0.925*	0.030	
				(0.369)	(0.506)	(0.419)	
Low pop_rur*ln(t)				-0.372*		-0.361*	
				(0.200)		(0.197)	
High pop_rur				-5.153***	-0.579	-4.873***	
				(1.918)	(0.526)	(1.845)	
High pop_rur*ln(t)				1.523**		1.446**	
				(0.632)		(0.613)	
Low pop_rur*abs_SPI3					1.040**	0.951*	
					(0.522)	(0.514)	
High pop_rur*abs_SPI3					-0.149	-0.205	
					(0.629)	(0.629)	
Agr. Empl							0.005
							(0.029)
Agr. Empl*ln(t)							0.002***
							(0.001)
Observations	1721	1721	1721	1721	1721	1721	1714
r2	0.303	0.305	0.306	0.311	0.308	0.317	0.290
r2_a	0.291	0.293	0.294	0.299	0.296	0.304	0.279
F	2.350	2.233	2.304	2.446	2.147	2.427	2.454

Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.5 – GVC mitigating factors

	(1)	(2)	(3)	(4)	(5)
ln(GDP pc)	9.720**	9.657**	9.510**	9.525**	9.557**
	(4.111)	(4.137)	(4.138)	(4.122)	(4.120)
ln(GDP pc)^2	-0.565**	-0.559**	-0.552**	-0.550**	-0.551**
	(0.233)	(0.234)	(0.234)	(0.233)	(0.233)
Industry share (%)	-0.008	-0.007	-0.008	-0.007	-0.007
	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)
Mobile subscription	-0.344**	-0.349**	-0.344**	-0.342**	-0.343**
	(0.149)	(0.148)	(0.149)	(0.148)	(0.148)
GFCF over GDP (%)	-0.005	-0.005	-0.005	-0.006	-0.006
	(0.010)	(0.011)	(0.010)	(0.010)	(0.010)
Rural electricity access	-0.047***	-0.046**	-0.047**	-0.046**	-0.047***
	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)
Rural pop (%)	-0.052	-0.055	-0.052	-0.057	-0.055
	(0.054)	(0.055)	(0.055)	(0.055)	(0.055)
Schooling	-0.454***	-0.457***	-0.456***	-0.458***	-0.460***
	(0.162)	(0.162)	(0.162)	(0.161)	(0.162)
Gov health expenditure (%)	-0.020*	-0.019*	-0.020*	-0.020*	-0.020*
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Financial globalization	0.356*	0.361*	0.371*	0.368*	0.371*
	(0.198)	(0.199)	(0.198)	(0.195)	(0.195)
Incoming FDIs	0.002***	0.002***	0.002***	0.002***	0.002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Temperature increase	0.065*	0.065*	0.062	0.060	0.063*
	(0.039)	(0.038)	(0.039)	(0.038)	(0.037)
Temp extreme (increase >1.5CÂ°)	0.145*	0.148*	0.150*	0.142*	0.140*
	(0.081)	(0.080)	(0.080)	(0.080)	(0.080)
Increasingly extreme SPI 3 (av. 10)	0.099**	0.104**	0.103**	0.111**	0.325**
	(0.049)	(0.050)	(0.050)	(0.051)	(0.131)
FDI sh. in Upstream activities	-0.647**				
	(0.314)				
FDI sh. in Production activities		0.290**			
		(0.136)			
FDI sh. in Downstream activities			0.071		
			(0.118)		
GVC diversification				-0.004***	-0.002*
				(0.001)	(0.001)
GVC diversification * extreme SPI 3					-0.004**
					(0.002)
Observations	1721	1721	1721	1721	1721
r2	0.300	0.299	0.296	0.302	0.304
r2_a	0.288	0.287	0.284	0.290	0.292
F	2.396	2.286	2.405	2.455	2.418

Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$