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Climate change impacts on the insurance industry

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I would like to spend a couple of words to thank my supervisor, Valerio Dotti, for the support that he has given me during my final thesis, with great insights and very well welcomed considerations about the topic of my work.

I would like to dedicate this paper to my dad, who, since 2021, is no longer here by my side and has left an unbridgeable void in my life.

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ABSTRACT

The paper aims to analyze the potential impacts of climate change on the insurance industry, both in qualitative and quantitative terms. The transition to a Net Zero Emissions scenario implies the presence of a transition risk for companies that rely on nonrenewable energy sources, as they would have to change their energy sources in a short period of time. On the other hand, the increasing number of weather phenomena entails a physical risk of destruction and disruption of economic activity, causing large losses for home and/or business owners and, from the perspective of insurance companies, more policies requiring compensation. The purpose of the analysis is to estimate the impact of the increase in average temperature on total insurance coverage purchased in different business lines in the States of the United States of America. Empirical evidence shows that as the average temperature increases, purchased insurance coverage increases in some business lines, which refer to categories of policyholders who are more exposed to climate change risk.

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Summary

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1 Introduction

Climate change is on the way of becoming one of the biggest threats to the economy and to the whole world. All of us know how extreme weather events have dramatically increased in frequency and severity over the last years, causing massive damages to people, buildings and so on. This issue has been addressed and taken into account by many governments, central banks, public authorities and investors which consider the implications of climate change when deciding their actions. There has been an increasing recognition of climate change effects on the environment and also on the financial system and, therefore, there have been many related new worldwide agreements and policies, the most important one being the Paris Agreement in 2015, signed by 196 Parties at Conference of Parties (COP) 21, which aims at reducing the greenhouse gases (GHG) emissions and keeping the increase in temperature well below 2° C, hopefully 1.5° C, compared to pre-industrial levels, trying to mitigate the effects of climate change and its related risks. In order to do that, countries will have to shift from a high carbon economy based on fossil fuels to a low carbon and more sustainable one, relying on renewable sources of energy. Greenhouse gases are a main concern in this context because the contribute to adding heat to the atmosphere and to the Earth's surface. In fact, the Sun radiation is initially reflected back by the Earth's surface; that radiation, due to the presence of a high quantity of greenhouse gases in the atmosphere, is reflected back again to the Earth's surface which is therefore being heated even more.

Climate change, as said before, is having considerable effects on decision makers, companies, and consumers. All of them can no longer take any action without considering the potential consequences on the environment and what to expect from the environment itself, thereby facing dramatic weather events (e.g., hurricanes, floods, droughts) which have the potential to cause very huge losses. The increasing frequency of occurrence of these events make us understand how important it is to take some measures to prevent these risks, i.e., to mitigate the risks from climate change. The Intergovernmental Panel on Climate Change (IPCC), however, stated that mitigation alone cannot work against the effects of climate change because climate effects are already in place and it is not something that will happen in an undefined future; in fact, it has to be accompanied by an adaptation to these consequences, i.e., "*taking action to prepare for and adjust to both the current effects of climate change and the predicted impacts in the future*"[1]. The reverse also works, because adaptation on its own is not able to cushion the consequences of climate change. If there is no mitigation, these consequences will become irreversible and too much severe that any action to adapt will simply be no effective. IPCC, in its Climate Change 2014 Synthesis Report Summary for Policymakers, states that "*Many adaptation and mitigation options can help address climate change, but no single option is sufficient by itself. Effective implementation depends on policies and cooperation at all scales and can be enhanced through integrated responses that link adaptation and mitigation with other societal objectives*". Substantial reductions in greenhouse gases emissions can reduce climate risks in the future decades and make climate mitigation less costly in the longer term. The conclusion is that without a mixture of adaptation and mitigation, in one way or another, we will not be able to manage the risks and the losses coming from climate change. No single option can be used by itself; effectively addressing climate change requires cooperation at all levels and policies that tackle the issue. One of the main industries that are involved in the context of climate change is the insurance sector, which is one of the most exposed to the risks coming from extreme weather events that can cause huge physical and financial losses.

This paper aims to analyze the possible consequences of climate change on the industry. After a quick historical overview of the changes occurred in the sector during the last four major macroeconomic crises (i.e., the financial crisis of 2007-2008, the sovereign debt crisis, the pandemic and the ongoing conflict in Eastern Europe between Russia and Ukraine and the consequent rise in inflation and interest rates), the focus shifts to a more "quantitative" analysis, by looking at some measures of risks widely used in risk evaluation. One side of the story tells that insurance companies are facing and will face remarkably high threats from situations linked to climate change; the other side tells that more risks can transform in more

[1] As defined by the European Commission

business opportunities for them. In fact, nowadays people are more inclined to buy an insurance policy to cover themselves against losses related to climatic events. This whole story can be summarized in a simple relationship of events. Increasing frequency of severe climatic events brings more risks which people want to hedge against, therefore they shift these risks to insurance companies by buying an insurance policy. Insurance companies bear the risks in exchange for an insurance premium and cover the losses of the insureds in case of a claim. In the current climatic condition and looking at the projections of frequency and severity of climatic events, insurance policies will likely increase with respect to both the number of insurance policies signed (consumers hedge more against possible losses) and to the insurance premiums asked by insurance companies, due to a greater demand and to a higher number of claims coming from losses related to climate events. In this scenario of ongoing global warming and climate changing, insurance companies may want to hedge against risks too; in that case they may take on reinsurance, which is basically transferring some risks borne from the insureds to one or more other insurance companies as we will see later in this paper.

To study the consequences of climate change in the insurance industry, an empirical analysis will be performed later in the paper. In particular, the analysis will focus on the implications of three factors related to climate change (i.e., the average temperature increase, a measure for the deviation from the mean of the levels of precipitations and of the Palmer Drought Severity Index[2]) in five different lines of insurance in the US insurance market. As an anticipation of the results of the analysis, the average temperature comes out to be a driver of the amount of insurance coverage purchased by US citizens only in some business lines, while in others there's no significant impact. The other two measures come out to be statistically significant in some business lines, but the value of the coefficient turns out to be negligible. The two lines that see the average temperature as a driver of the insurance purchased are the ones, among the five analyzed, that are most exposed to damages arising

[2] This index indicates the level of moisture of the soil. Negative values represent moist conditions, while negative values are symptom of dry conditions

from climatic events. Hence, there is a concrete reason for which these two are concerned by climate change while the other three do not take into account this factor.

2 Insurance and macroeconomic crises

Over the 21st century there have been some major macro-economic and financial crises that have changed the shape and the resilience of the world's economy. These crises have had an impact on the society and on the way in which companies conduct their business and develop their investment strategies deciding their asset allocation. Among the companies hit by these macro-economic crises, insurance companies are included, and reinsurance ones as well. The aim of this chapter is to provide an overview of what happened during the four major macro-economic crises (i.e., the financial crisis of 2007-2008, the sovereign debt crisis of 2011, the Covid-19 pandemic of 2020, and the conflict in Eastern Europe between Russia and Ukraine of 2022) of the current century and to give a summary of the impacts on the insurance industry (and on policyholders) and of its responses to face the consequences of those periods.

2.1 Financial crisis of 2007-2008

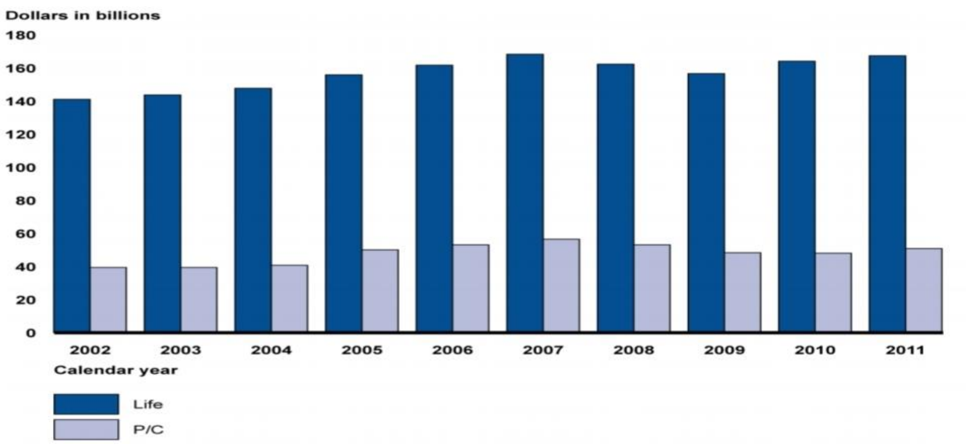
The financial crisis in the late 2000s, also called the Global Financial Crisis (GFC), was the most severe economic and financial crisis since the Great Depression of 1929. It was mainly driven by the burst of the US housing bubble, which caused a massive shock on financial institutions' balance sheets, since there was a high exposure to mortgage-backed securities. Differently from what one would expect, the 2007-2008 financial crisis has had limited consequences on the insurance industry; in fact, in the US, according to a report from the United States Government Accountability Office (GAO), only a few companies failed during the period of crisis with respect to other industries. Namely, the number of companies that fell into receivership and liquidation increased significantly from 2008 to 2009, but 2009 levels were in line with the average of the previous years, both for life insurance companies and for property and casualty insurance (i.e., it was 2008 that played as an "outliar"). Furthermore, the companies that were placed under receivership had been experiencing financial distress for several years, so the financial crisis seemed not to be directly the trigger for their status. In general, insurers faced capital and liquidity pressure during the crisis, but the number of insolvencies were limited. In particular, insurance companies felt capital decline due to a deterioration of net income and a degradation of their investment assets. They realized losses from impairments on bonds (particularly on mortgage-backed bonds) and from capital loss in the selling of equities that experienced a decline in price. Life insurers were the most impacted, since their net income dropped from $31.9 billion in 2007 to a negative income (i.e., a loss) of $52.2 billion, before bouncing back in the following years and returning to slightly lower levels than the ones experienced before the crisis. These decreases in net income were offset by high issuances of new company equity or debt, by asset transfer from holding companies or by agreements with the US Treasury. AIG, which was the most hit in the decrease in net income and realized losses accounting alone for 45% of the realized losses, had an agreement with the Treasury for the purchase of $40 billion of newly issued equity. On the other hand, also property and casualty insurance companies felt a steep decline in the level of net income, with a substantial drop from over $60 billion in 2007 to a small, but still positive, $3.7 billion. As it was for life insurance companies, also property and casualty ones issued new equity to raise new capital, thereby they were still able to pay shareholders dividends; the net income in the following years bounced back to higher levels, although to lower magnitude with respect to 2006 and 2007.

Moreover, the income coming from investments of insurers was not particularly hit; in fact, the net income from investments of both life and property and casualty insurance companies decreased slightly in 2008 and 2009, before returning to pre-crisis levels by 2011, as represented in the figure below by the United States Government Accountability Office[3]. That small drop was due to declines in the income on US government bonds, certain type of common stock and other invested assets. The asset allocation and the percentage of income deriving from different types of assets changed too during the 2008

[3] Amounts in nominal values.

crisis. In particular, bonds represented a vast majority of the investment income even before 2008; this trend increased during the crisis, since both life and property and casualty insurance companies saw an increase of 8-10% of gross investment income during the crisis, while the other asset classes, such as equities, real estate and derivatives, changed slightly in those terms.

Figure 7: Life and Property/Casualty Insurers' Net Investment Income, 2002-2011

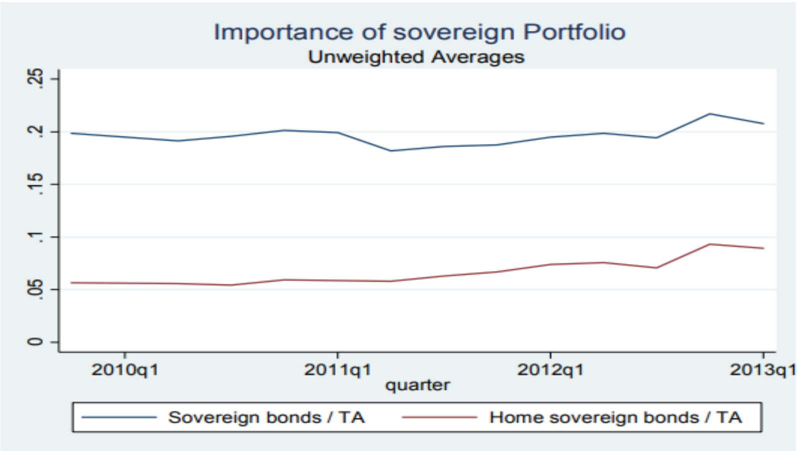


In line with the view of the report of GAO, OECD published a study that analyses the effects of the crisis in the insurance industry. Not surprisingly, mortgage insurers in the US have been hardly hit by the financial crisis, since they were insuring the asset class that was the trigger of the crisis itself, by guaranteeing that either individual or portfolio of mortgages will maintain their value. As a consequence of the turbulence in the mortgage market during those years, mortgage insurers experienced substantial losses and a deterioration of capital. Consequently, share prices of these companies dropped significantly, both independent mortgage insurers and holdings of mortgage insurance subsidiaries, while the spread of the credit default swap for these companies increased significantly, starting from September 2007 and peaking in May 2009. Along with mortgage insurance companies, life and property and casualty ones felt market valuation pressures, due to their investments in stock and bond markets. Particularly life insurance companies were under pressure since life annuities constitute a relevant cash outflow for the company and, in combination with a deterioration of capital market valuation and low interest rates on government bonds, could have significantly harmed the financial stability of these companies. The cost of hedging strategies to offset the risk on variable annuities spiked in 2008, thereby reducing insurance companies' profit margins.

Furthermore, the financial crisis has highlighted the importance of liquidity risk management in insurance companies as one of the main tasks to address by the management of the company. Even though insurance companies have typically a relatively stable cash inflows deriving from premiums collected and consequent little need for short-term funding, eventual rating downgrades could trigger collateral calls and have an impact on the availability of liquidity. Liquidity support in this industry has not been granted with the same ratio as it has been for banks, so the previously mentioned support provided by the US Treasury to AIG has been unusual. To some observers, including rating agencies, there is a perception that such financial support is provided to such entities that are considered too big and too interconnected to fail or to have financial distress.

2.2 Sovereign debt crisis

The European sovereign debt crisis in 2010s has put the world's attention on the resilience of the banking and insurance industry. In that period many Eurozone member states were no more able to repay or refinance their government debt and therefore the cost of debt skyrocketed to a level that was no more manageable and affordable for countries that were already navigating in deep waters. The intervention of the ECB was fundamental: leaded by Mario Draghi, it began to purchase government debt securities through open market operations, reaching a total volume of purchasing of $219.5 billion in February 2012; at the same time, it withdrew the same amount of liquidity from the market in order to prevent an inflation rise that would have offset the objective of the operation. Insurers in 2011 were holding a significant part of global financial assets and were highly exposed in sovereign bonds, since they held a larger share of their assets in sovereign bonds than what banks did and, interestingly, sovereign bonds exposures were particularly large and increasing in countries most affected by sovereign debt risk (e.g., Italian insurers went from holding one third of their assets in Italian public debt to one half between 2008 and 2012), resulting in a significant home bias. The unweighted averages reported by a paper from Deutsche Bundesbank highlight that the percentage of home sovereign bond holdings over total assets is a major part of the total sovereign bond holdings over total assets, as reported in the following figure (Düll, Robert and Koenig, Felix and Ohls, Jana, On the Exposure of Insurance Companies to Sovereign Risk: Portfolio Investments and Market Forces).

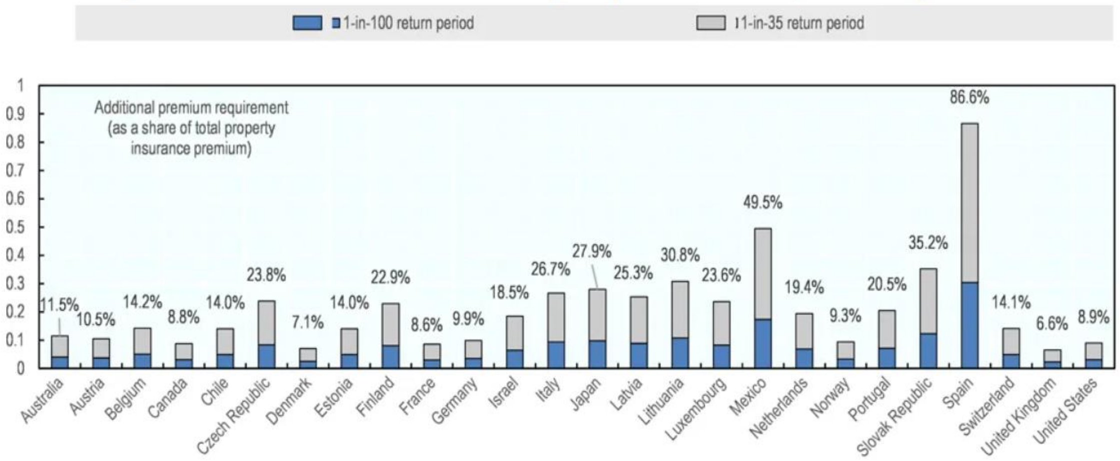


The Deutsche Bundesbank's report analyzed the risk/return effect of these exposures in sovereign bonds. The increasing riskiness of those bonds brought their returns to increase as well, following the usual risk/return relationship. However, this paper found out that the increasing default risk of sovereign bonds has been transmitted to the bondholders, in particular the default risk of insurers was hit as well. Particularly for Germany and Italy, the period from 2008 and 2012 has seen a very similar "performance" of the credit default swap spread for insurance companies and sovereign. The Italian peaks in the CDS sovereign spread of November 2011 and June 2012 were closely followed by similar peaks in the CDS spread of the insurance sector. Since a large part of the sovereign bonds held by insurers was held to constitute a liquidity buffer in case of need, the change in the price of these bonds was likely to affect the insurers' capital position. The increase in the returns of the sovereign bonds, as any other bond, consequently causes a drop in their price, thereby impacting the asset side of insurers' balance sheet and causing a potential capital loss in case of selling for eventual liquidity needs. An additional study, conducted by DeNederlandscheBank (DNB), analyzed the trading behavior of some Dutch insurance companies during the European sovereign debt crisis, to assess how they have dealt with this crisis and how they changed their asset allocation during this period. In particular, it considers the behavior of insurers in choosing to "flight home" and "flight to quality". Flight to quality happens when, as a reaction to market turmoil, insurers disinvest from assets considered risky and shift their asset allocation towards assets considered safer, which could be both foreign and domestic assets. Flight home is the shift in investments towards, as its name suggests, domestic asset, due to the previously mentioned home (or familiarity) bias. In this study, the authors grouped the countries of investment into four distinct categories, allowing to discriminate for home bias (the Netherlands), between countries most hit by the sovereign debt crisis (i.e., Southern Europe, including Greece, Italy, Spain and others) and the ones that were less severely affected (i.e., Northern Europe, including France, Germany and others) and non-Euro area countries; if the coefficient on the Netherlands and on Northern Europe is significantly higher than the coefficient on Southern Europe, that means there is evidence of flight to quality; if instead the coefficient on the Netherlands is significantly higher than both Southern and Northern Europe, there is evidence of flight home. They also distinguished five period of times to analyze the insurers' behavior in different periods of crisis, i.e., a pre-crisis period (i.e., before the subprime crisis), the subprime crisis, the Lehman Brothers crisis, the European sovereign debt crisis and the post-Draghi, which is the period after the renowned speech when the former ECB's President Mario Draghi and his "whatever it takes" put an end to the speculation on the sovereign debt. The empirical evidence in the estimation suggests that up until the subprime crisis there is no sign of neither flight home nor flight to quality; however, starting from the Lehman Brothers crisis through sovereign debt crisis and even in the post-Draghi period (even if less strongly), there is evidence of flight to quality, since the coefficient on the Southern Europe is significantly lower than the other two. Flight home instead is not relevant, in contrast with the ideas and the data evidence from the previously mentioned Deutsche Bundesbank study, since the coefficients on the Netherlands and on Northern Europe do not differ significantly.

2.3 Pandemic

The Covid-19 pandemic that spread around the world in 2020 has brought massive economic losses, starting from a decline in the global gross domestic product (GDP), which registered a -3.2% year on year with respect to 2019. The major losses have been incurred in the period when the whole was in quarantine, as many businesses were forced to close and recording huge business interruption losses. However, these losses were mainly absorbed by business owners, since the majority of companies, according to the OECD, did not have business interruption coverage that could respond to the losses incurred, estimated to be $1.7 trillion for a month of lockdown in all 27 OECD countries. Furthermore, most countries' insurers that provide policyholders a business interruption coverage line have signed it with a "clause" that the policy would be triggered only if the business interruption is due to a physical damage of the property, which was not the case in the pandemic. For example, the Italian Associazione Nazionale fra le Imprese Assicuratrici (ANIA), stated that not only the business interruption coverage is not a common practice, but added that, when acquired, this type of insurance need a physical property damage to be triggered; therefore, businesses that suffered losses due to lockdowns were likely to receive no payment from insurance companies. Other countries' insurers (e.g., United States, Switzerland) provided the coverage with a specific exclusion of losses due to virus or bacteria. Some insurance regulators have proposed to retroactively expand the insurers' obligations to provide coverage to Covid-related losses; however, due to the huge amount of business interruption losses, IAIS raised concerns about this proposal, stating that it could put in danger the financial stability of the industry, adding further economic impacts of Covid-19. In fact, policy premiums collected, if pandemic coverage was specifically excluded from the policy, were calculated not considering the costs of claims arising from such losses, therefore, insurers' solvency could be undermined since they would not be able to pay for other types of claims. Estimates by OECD show, as reported in the figure below, that insurers would need to collect a significant amount of premiums in addition to the actual collection in order to provide coverage for one month of business interruption losses.

Figure 2. **Pandemic-related business interruption: potential annual premium requirement**



Source: OECD Policy Responses to Coronavirus (COVID-19), Responding to the COVID-19 and pandemic protection gap in insurance, 2021. The 1-in-100 return period means a recurring pandemic disease once every 100 years (as it was between the Spanish Flu of 1918-1920 and the Covid-19 in 2020). The 1-in-35 return period is based on a predicted increased frequency of the occurrence of a pandemic disease, consistently with estimates provided by the Geneva Association

On the other hand, the pandemic has brought policymakers, insurance companies and policyholders to have some form of interest in business interruption coverage; for example, in the United States it has been proposed to the Congress a federal pandemic risk reinsurance program, the Pandemic Risk Insurance Act (PRIA) of 2020. With this proposal, there would be a loss sharing pattern between the insurance sector and the federal reinsurance; in particular, the insurance sector would bear a portion of the pandemic risk, while the federal reinsurance would provide coverage for 95% of losses above a participating insurers' deductible. Moreover, some US insurance associations have submitted a proposal for a Business Continuity Protection Program (BCPP), which would cover up to 80% of specific operating expenses for a maximum of three months of emergency, subject to the fact that these coverages would be used to pay employees and other operating expenses and that the policyholder would applicate every health and safety measure during the emergency. Regarding Italy, Generali has issued a perspective on pandemic risk pooling, advocating a public-private relationship to provide insurance coverage against pandemic-related business interruption losses for small and medium enterprises (SMEs), which are the main and driving factor of the Italian economy.

Depending on a country's environment and its jurisdiction, there would be an appropriate approach to take on, aimed at providing business interruption insurance coverage; IAIS, to this extent, stated that an approach that fits well with all different jurisdictions does not exist. In fact, some lines of insurance may be more developed in some countries with respect to others; in the case of the pandemic, life insurance in Emerging Markets and Developing Economies (EMDEs) could not be available as easily as it is for Developed Economies (DEs). To this extent, the intermediation role of insurance supervisors could help the coordination between governments and policymakers, the insurance industry and policyholders. Supervisors could in fact exploit their knowledge and expertise in the industry helping governments to design and implement some appropriate initiatives to address pandemic risk and reduce the losses arising from it; furthermore, they could collect data, provide guidelines and monitor insurance companies on the consequences and implications of their involvement in such coverage of pandemic risk. Moreover, insurance supervisors during the pandemic had to deal with cases that concerned business interruption coverage claims between policyholders and insurance companies. In these cases, supervisors needed to ensure both the fair treatment and protection of customers – one of the requirements of the Insurance Core Principle[4] (ICP) 1 – and the financial stability of insurers and the whole sector. Finally, insurance supervisors could give advice to the insurers in developing their business plans and/or strategies to pursue in order to reinforce the resilience against pandemic risk and business interruption coverage if implemented. Insurance supervisors, in future pandemic events, will have the role of ensuring that the risk-sharing frameworks are sustainable for insurance companies, both from a micro and a macro prudential point of view; in addition, they will have to ensure that new initiatives of risk-sharing will be appropriate for a larger segment of the population and policyholder needs, including low-income population and with a focus on EMDEs markets.

2.4 Russia-Ukraine war, high inflation and rising interest rates

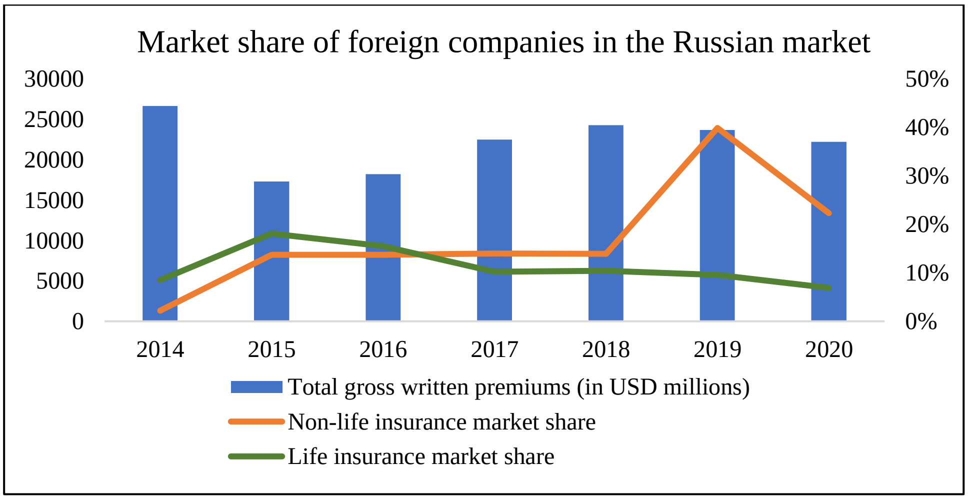
In early 2022, the escalation of the geopolitical tension in eastern Europe between Russia and Ukraine and the starting of the "special military operation" ordered by Russian president Putin has caused reactions from all over the world, some countries stood with Russia while the majority of the world condemned its action by standing with Ukraine and imposing heavy sanctions on Russia, in order to try to put an end to the war, hitting particularly the financial transactions with some persons and entities. Moreover, it has been set a prohibition to provide some goods and services to the Russian economy, including lines of insurance and reinsurance. As a response, Putin developed a list of "unfriendly states" to which Russia has initiated a "counter attack" by applying sanctions of its own and prohibiting to enter into any contract with businesses from countries in that list. This prohibition of providing insurance to Russian has caused some market distortions on sea transportation; in fact, the embargo on Russian oil and gas has heightened the "ghost transportation", since usual transportation has seen a reduction in frequency because of lack of insurance coverage. This mechanism could have severe

[4] IAIS states that "*Insurance Core Principles (ICPs) are comprised of Principle Statements, Standards and Guidance, as a globally accepted framework for insurance supervision*"

consequences on the environment as well, since this type of transportation has involved criminals to retrieve obsolete cargo ships that are way less safe in terms of probability of accidents and could cause a spilling of oil in the sea during transportation. The ongoing war has brought some major losses in specific lines of insurance, (e.g., aviation insurance, marine insurance – the economic sectors directly involved in the war) but also to other and more general lines, such as property and political risk insurance. Moreover, there has been an increase in cyber risk[5], since many cyber-attacks have hit Russia, Ukraine and other involved countries. The OECD states that the number of cyber incidents has increased since the beginning of the conflict, even in non-directly involved countries like the US. Insurance losses referred to property insurance (e.g., home insurance, SME assets) in Ukrainian territory have been limited, since the market penetration of insurance is relatively low, and consequently the magnitude of this market is not so high. In addition, as it was for the Covid-19 business interruption losses, standard property insurance policies were designed excluding direct and indirect war-related damages and losses. The sanctions imposed has had some serious consequences in trade credit and political risk insurance. The prohibition of payment transfers has increased the risk of payment defaults, thereby causing this type of insurers to avoid signing new policies with the two countries in war; political risk insurance aims at covering risk arising from "*currency inconvertibility* – due to currency transfer restrictions – *confiscation, expropriation, and nationalization, contract frustration and political violence*" (OECD (2022), "Impact of the Russian invasion of Ukraine on insurance markets", *OECD Business and Finance Policy Papers*). In general, the impact of the conflict on the insurance industry seems not disruptive; S&P Global expects no consequences on insurance companies' solvency, apart from some outliers; Fitch Ratings noted that the insurance industry proved to be resilient in other situations (e.g., natural catastrophes during 2021) in which the losses appeared to be of the same magnitude or

[5] This trend has however started during the pandemic in 2020. Since the whole world was in lockdown, the percentage of cyber criminals has increased during that period

even larger. In addition, non-Russian insurers activity in Russia is a small portion of their business; on the other hand, non-Russian owned insurers with a branch in Russia have a significant insurance market share in the country (see figure[6] below, data from OECD Global Insurance statistics), particularly for non-life insurance line. In fact, from 2019 the market share of non-Russian owned insurers with a branch in Russia in non-life insurance line has increased significantly from the average of the previous years, reaching a market share of 40% in 2019, before decreasing to 22% (still larger than the 14% average of the previous 4 years).



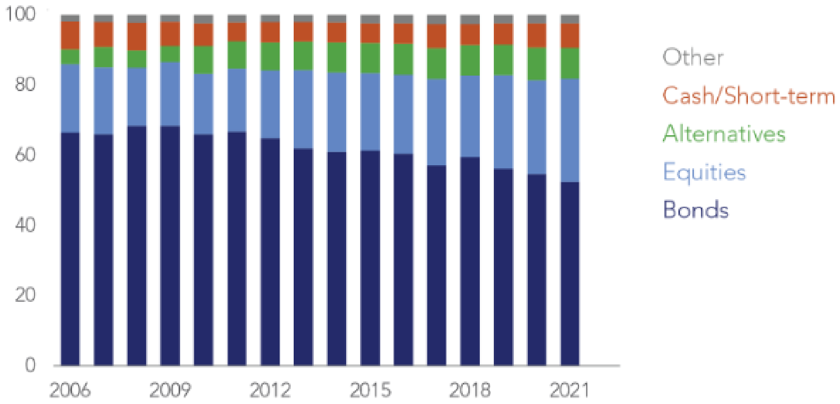
However, the importance and the magnitude of the Russian insurance and reinsurance market is not so relevant in the global business of the industry; in fact, reinsurance premiums in Russia account for an estimated 2% (estimate developed by Fitch Ratings) of the global written premium.

The ongoing war has brought severe consequences on the global supply chain, triggering a rapid and consistent increase in inflation, mainly driven by energy and food prices. In order to cool down this inflationary trend, central banks have started to tighten their monetary policy approach by increasing interest rates. Analyzing the action of the two

[6] Source: OECD Global Insurance statistics, https://stats.oecd.org/Index.aspx?DatasetCode=INSIND

main central banks, Fed and ECB, it can be noted that the Fed has been more hawkish and adopted a much stricter monetary policy, with seven consecutive increases, as of January 2023, in the target Federal Fund Rate (four of them of 75 basis points each consecutively) starting from March 2022. On the other hand, ECB has not been as strict as the Fed; in fact, as of January 2023, it has opted for a less aggressive approach by increasing interest rates four times starting from July 2022 with a 50 basis points increase, followed by two consecutive 75 basis points increase in September and October 2022 and an additional 50 basis points increase in mid-December 2022. This tightening of the monetary policy comes after a long period of flat interest rates (the last increase was in 2011 and the main refinancing operation (MRO) rate has been equal to zero since 2016). The straightforward consequence of a tightening in monetary policy is a bearish stock market due to an increase in the discount rate of companies' cash flows (i.e., the weighted average cost of capital, WACC), favoring an increase in the attractiveness of the bond market, due to higher expected bond yields. As far as the insurance industry is concerned, inflation hits by increasing the cost of claims by policyholders. Although hedging this risk by raising insurance premiums, the industry needs to make efficient investments to contrast this macroeconomic situation; in fact, if relying only on premium increases, policyholders may withdraw from signing insurance policies, thereby causing a fall in the insurers' premium revenues. Furthermore, high inflation and rising interest rates could provoke insurers' balance sheet worsening and compromise the capital requirements and the company ratings. In addition, in the last years of low interest rates, insurers adopted alternative investments strategies than the ordinary investments in equity and bond markets (which constitute the greatest share of property and casualty insurers' portfolios), in order to achieve higher yields. In fact, the share of investments made by this line of insurers has increased, although slightly, over the years, as shown in the figure below by the Office of Financial Research. However, these investments are not as liquid as equity and bonds and can therefore be a source of liquidity risk for insurers.

Figure 2: Property & Casualty Insurers' Investment Portfolios (percent)



In the last high inflation period of the 1980s, insurers, especially the ones active in property and casualty insurance lines, experienced a trend of increasing claim costs, poor underwriting and investment returns while the hawkish monetary policy caused a deterioration in the fixed-income asset class.

3 Climate change context

In the climate change context, there are many risks in place which have to be accounted for by companies, individuals and public authorities. After the Paris Agreement, climate change has become a relevant issue to tackle. The 196 countries that signed the Agreement have taken the responsibility to apply and carry out climate action known as Nationally Determined Contributions (NDCs). With NDCs, each country declares how it will act in order to reduce greenhouse gases emissions and reach the goals of the Paris Agreement and also how it is adapting to rising global temperatures. If this is not the case, continuative emissions of GHGs will cause the planet to heat up, bringing long-lasting changes in all components of climate system (e.g., icebergs melting and consequent increase of sea level, ocean acidification) and increasing the likelihood of extreme climatic events that will damage people and ecosystems. The commitments made by the countries bring with themselves some changing in climate policies and some risks. It is interesting to look at major countries' NDCs, especially at USA's one. The country has rejoined the Paris Agreement after it left the deal under Trump administration. It aims at reducing its net greenhouse gases emissions by 50-52% below 2005 levels in 2030 and states that it is necessary to drive towards net zero global emissions no later than 2050; USA's NDC contributes significantly to achieve the ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC), which is to stabilize greenhouse gases concentration in the atmosphere, thereby helping to prevent human interference with the climate system, ensuring that the ecosystem adapts naturally to climate change and allowing economic development to take place in a sustainable way. The European Union submitted a joint NDC from all Member States (since Brexit, so from 31st December 2020, United Kingdom is not part of this NDC anymore) which closely follows USA with respect to the target aimed to achieve. In fact, the European Council endorsed the objective of making the EU climate-neutral by 2050; furthermore, two sources of funds (i.e., the Multiannual Financial

Framework for 2021-2027 and Next Generation EU) will be the main European instruments to achieve the objectives of the European Union. However, those objectives may have been too optimistic to achieve in such a relatively short period of time. In fact, according to Peiran R. Liu and Adrian E. Raftery (2021), even if all countries meet their NDCs and continue to reduce emissions at the same rate after 2030, the probability of keeping global warming below 2°C by 2100 (as aimed by the Paris Agreement) is a not comforting 26%; if the USA alone does not meet its NDC, that probability declines to 18%. The unwelcome news is that from this research USA has a 2% probability of meeting what stated in its NDC. To have a 50% probability of achieving the more ambitious Paris Agreement's objective of keeping global warming below 1.5°C compared to pre-industrial levels, the rate of decline in emissions would have to be 8 times higher than the actual annual rate and for a 90% probability it would have to be 30 times higher, reaching close to global net zero emissions by 2023, way before the aims of NDCs and too little amount of time left to make it possible. Therefore, the conclusion of the research is that global warming is very likely to go beyond 1.5°C and a pretty high probability remains of surpassing 2°C, unless the greenhouse gases emissions are drastically reduced in the upcoming years.

3.1 Transition risk and physical risk

Depending on the type of changing of the climate policy, also known as climate policy shocks, two types of risk can be distinguished. They are transition risk and physical risk; the former is linked to the transition to a low-carbon economy which may have severe impacts on financial assets thereby increasing probability of defaults and having consequences for financial portfolios. This is particularly relevant in a case where NDCs and the transition to a low-carbon economy are carried out in a disorderly manner; in this scenario, carbon-intensive firms that depend on fossil fuel production or utilization will most likely incur in losses which will negatively affect firm's assets and portfolios exposed to those firms (e.g., stocks, bonds, bank loans). The latter, instead, is linked to the physical losses that climate change can cause; in particular, it can damage the production capacity of firms, produce losses for the insurance sector and increase the credit risk of banks. Physical risk can affect the economy in two ways: by causing acute impacts arising from extreme weather events (e.g., storms, heatwaves) and increasing underwriting risks for insurers and a possible lower insurance coverage in particular regions more exposed to adverse climate events, or by having chronic impacts coming from persisting events (e.g., sea level rise) which could cause business disruptions and would require a significant level of investment and adaptations from the society. Furthermore, climate change can cause other severe consequences, not only financial losses but also socio-economic ones. For instance, human health could be in danger, both for extreme high temperatures accompanied by high levels of humidity, which are associated with a higher mortality rate across countries (Deschênes, O., Greenstone, M., 2011) and for a more rapid spreading of vector-borne diseases such as malaria, since mosquitoes reproduce faster with high temperatures. Another strong implication is about food production: in fact, climate change can cause negative and chronic consequences on food production and so to the supply chain, making the prices of food to increase due to a lower supply. An example was the Russian heatwaves in 2010, which brought the ban of grain export and a 60% increase of the price in just two months.

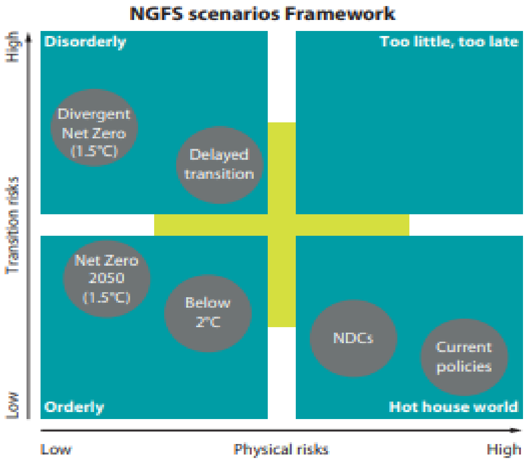
An interesting concept that relates both to transition and physical risk is about the so called 'climate tipping points' which are "*level of change in system properties beyond which a system reorganizes, often in a nonlinear manner, and does not return to the initial state even if the drivers of the change are abated. For the climate system, the term refers to a critical threshold when global or regional climate changes from one stable state to another stable state*"[7]. These tipping points were thought to be reached only at very high rates of global warming in the first reports produced by the Intergovernmental Panel on Climate Change (IPCC). However, the more recent ones see them likely to happen even with much lower rates of global warming, which poses a serious threat to

[7] As defined by the Intergovernmental Panel on Climate Change

the Earth's system. The OECD developed a table[8] for summarizing different climate tipping points and their probability of occurrence in different global warming scenarios. Given that there is a relatively low probability of meeting the Paris Agreement's goals of limiting global warming below 2°C compared to the pre-industrial levels, we can understand how many climate tipping points are likely to happen.

When looking at different policies that can be put in place to reduce greenhouse gases emissions to achieve the goals of the Paris Agreement, it is important to understand the relative amounts of transition and physical risk that each one of them bring with itself. To this regard, the Network for Greening the Financial System (NGFS) has developed a Framework for climate scenarios, based on the IPCC scenarios. The scenarios are represented in the Figure 1 below, taken by NGFS Climate Scenarios for central banks and supervisors, 2021.

Figure 1



Positioning of scenarios is approximate, based on an assessment of physical and transition risks out to 2100.

This figure shows different scenarios and their related amounts of transition and physical risks. We can see that the policies in place nowadays (i.e., *NDCs*, *Current policies*) will

[8] See OECD's 'Managing Climate Risks, Facing up to Losses and Damages', Chapter 3.2 available at OECD

bring a high amount of physical risk, meaning that these scenarios will have the effect of causing physical losses on various assets, like insurance sector or banks' assets. On the other hand, *Divergent Net Zero (1.5°C)* and *Delayed transition* have high transition risk. From these scenarios, high-carbon activities will have difficult times in adapting to climate policies, mainly because the transition to a low carbon economy will have to happen rapidly to avoid irreversible consequences of climate change. Therefore, high-carbon activities will face big troubles changing their production chain in a relatively little amount of time, not being able to replace fossil fuels with renewable sources of energy. The most virtuous scenarios are *Net Zero 2050* and *Below 2°C*. Both of them have low physical risk and low transition risk. In fact, these scenarios put in place policies that anticipate irreversible climate consequences, reducing the impact of climate events on assets and, at the same time, allowing carbon intensive activities to shift their sources of energy from fossil fuels to green sources of energy.

With respect to physical risk, these scenarios have different consequences on climate related variables that could cause property damage and business interruptions. Regarding global warming, the four scenarios with low physical risk have some probability to achieve to goals of the Paris Agreement to keep the temperature increase below 2°C above pre-industrial levels, while *Current policies* and *NDCs* would see an increase of above 3°C in global warming. Global warming would increase the likelihood of heavy precipitations in some regions of the world like Asia and Central Europe while it would bring severe droughts in regions that have a drier climate (e.g., Southern Europe). In addition, labor productivity would be impacted negatively; even if there is a range of uncertainty in modelling the numerical impact, the consequence is surely not good for the economy. The worst-case modelling predicts a global lowering of a 10-15% in physical labor productivity in 2100 with respect to a baseline of 0,6°C of warming (representing the period from 1986 to 2005) above pre-industrial levels. The combination of global warming affecting the environment causing physical damages and losses and lower labor productivity would have an impact on GDP growth. Given 2005 as the baseline year, the Northern Hemisphere is the region less heavily impacted, with a decrease in GDP of nearly 5%, while Equatorial regions would be heavily hit with a loss of above 15% in GDP. Globally, *Net Zero 2050* would cause a relatively small decrease of a range between 1 and 4%, while *Current policies* scenario would have a much larger loss between 4 and 13%, with an estimated average of -7% with respect to 2005 baseline year.

All the six scenarios have a different pathway and a different outcome for variables such as CO_2 emissions and a “price” for carbon. More stringent policies such as *Divergent Net Zero (1.5°C)*, *Delayed Transition* and *Net Zero 2050*, which are the ones that bring higher transition risk, have a steep increase in the carbon price by the end of 2050, reflecting a more intense policy strength, while the CO_2 emissions would be drastically reduced. These two factors would see a much steeper increase or decrease (depending if we look respectively at carbon price or CO_2 emissions) as long as the transition to a low-carbon economy is delayed in time; the further is the change in climate policy, the more they will have to shift in order to meet the ambition on climate change mitigation. From the analysis of the NGFS, comparing *Current policies* and *Net Zero 2050*, there has to be a deep changing in the sources of primary energy, starting already from the current decade. The two major sources of energy that need to be considered are coal and renewable energy. The former remains the most common source in the *Current policies* scenario up until 2050, representing 25% of the total energy, evenly distributed with other sources, while in *Net Zero 2050* it is drastically reduced to a minor source in 2030 and in 2050 it is no more considered available; the latter instead, approaching 2050, slightly increases its “share” in *Current policies* while in *Net Zero 2050* becomes the large majority of the sources used, accounting for almost 70% of the total. Moreover, global land use should change, since intensive agriculture and livestock breeding are responsible for high greenhouse gases emissions, particularly carbon dioxide and methane. For *Net Zero 2050*, CO_2 emissions from land use should be erased and the land use should shift from food crops and pasture to forest and energy crops (which help carbon capturing).

Furthermore, from an analysis of the International Association of Insurance Supervisors (IAIS), insurance companies would be impacted as well in all the four main scenarios (i.e., *Disorderly*, *Too little, too late*, *Orderly*, and *Hot house world*). It has estimated that under an orderly transition scenario, which is the best-case scenario developed by NGFS and comprises *Net Zero 2050* and *Below 2°C*, there would be a drop in insurers' available capital of 7 to 8% of their required capital. This amount increases to over 14% in a disorderly scenario (i.e., *Divergent Net Zero (1.5°C)* and *Delayed transition*) and to a huge 50% under the *Too little, too late* scenario.

Transition risk is a main concern for industries basing their supply or production on fossil fuels, which are responsible for high greenhouse gases emissions. Looking at Paris Agreement's goals and the actions needed to achieve them, a straightforward conclusion is that these types of industries will need to change their production radically. Furthermore, their cash flows would be impacted unavoidably, and their assets would depreciate. The timeline of both the change in climate policies and the consequent industries necessary speed of adaptation will play a crucial role in determining the survival of these industries. On one hand, if the transition to a low-carbon economy occurs in a fast way, fossil fuels-based industries will be highly affected in terms of cash flows and assets, while on the other hand fast-growing low-carbon sunrise industries may originate, which pose the risk of a '*green bubble*' (Semieniuk G. et al, 2020). Transition risk translates then into transition costs; apart from the above mentioned changing in cash flows and firms' assets values, all sectors will face an adjustment in price and quantity of products and the expectations for the future will change as well. Some regulatory policies have aimed to allocate a price to carbon emissions, either by taxing high-carbon products or by providing subsidies to low-carbon products; that is the case of the italian '*ecobonus*' to encourage the transition to green housing, e.g., the use of solar panels and the use of materials that dissipate little heat.

3.2 Ethical issue in climate change context

Almost every government, regulators, companies and so on agree on the fact that we need to reduce carbon emissions to avoid entering in a point of no return where climate change consequences become irreversible. But how should these reductions be achieved? With the Paris Agreement many countries of the world have convened to take on policies to reduce their own carbon emissions comparing to past levels by 2030 and/or 2050 (i.e., short term target and medium-long term target) through the submission of their Nationally Determined Contributions. All of them proposed a percentage reduction in their emissions of greenhouse gases, but is that efficient? Wealthier countries are the ones that are more responsible for carbon emissions in terms of per capita levels and, in many cases, in absolute levels. Not surprisingly, the three most populous countries (i.e., China, India, USA) in 2016, according to Worldometer, were the ones with the highest emissions in terms of absolute values[9]. Other rich countries like Australia, Saudi Arabia, UAE (and all other major oil producers) have even higher per capita emissions than the three mentioned before. In the context of the Paris Agreement and the NDCs a percentage reduction seems not equal between different countries. Taking two extremes to make a comparison, Qatar had 37.29 tons per capita of CO_2 emissions in 2016 while the Democratic Republic of the Congo had only 0.08 tons per capita in the same year. An equal percentage reduction (e.g., 30%) seems highly inefficient, since Qatar reduction would be much larger in absolute terms but, at the same time, the result would be a huge level of per capita emissions compared to the reduction achieved by DR Congo. This objective of percentage reduction, although being a good starting point in combating climate change, seems to be "unethical" since richer countries of the world would be allowed to pollute more than poorer areas of the planet.

Apart from the regulatory perspective of climate regulation of the insurance industry, the overall increasing recognition of climate change issue has brought some other effects when

[9] India, however, has much lower per capita emissions, nearly 1/10 with respect to USA and 1/4 with respect to China

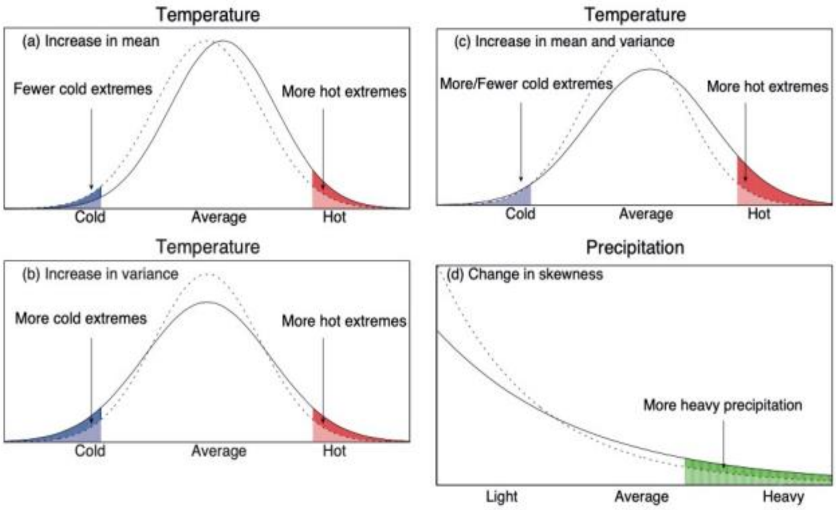
it comes to public opinion. It is recent news that insurance companies and brokers in Queensland, Australia, have become a target for groups campaigning against high carbon activities. Two companies, Marsh McLennan, the world's biggest broker, and Lockton, a top 10 global broker, walked away from the negotiations with Adani Enterprises' Carmichael mine in north-eastern Australia. This mine this year will produce 10 million tons of thermal coal to produce heat and electricity and will increase the amount of emissions in the upcoming years. That stop in the negotiations from the parties is not due to un-insurability of risks – in fact Adani still has the adequate insurance coverage to operate – but it is linked to a spreading recognition of climate change issue. In addition, 44 of the world's biggest insurers, including five that has already insured this mine coal, have said they will not enter in negotiations with the mine in the future. Furthermore, some banks have interrupted financing operations to Adani. The Australian government, facing increasing climate change risks (remember for example the massive bushfires in early 2020) as every other country, mandated a strengthening in greenhouse gases reduction, adjusting the objective to a 43% reduction in carbon emissions from 2005 levels by 2030, much higher than the previously setting of 28%; on the other hand, it has failed to grant the request from the Green party to put an end on developing new fossil fuels projects.

3.3 Measures of risk

When speaking about insurance and losses in general, one main topic is about determining an appropriate mathematical measure of the risk of incurring in these losses. To this regard, the Profit & Loss function, and in particular its distribution function, can help. Ordering the possible losses from the lowest to the highest (a negative loss is the same as a positive profit), can make us understand how these losses are distributed in probability. Straightforwardly, a high probability of a high loss would be problematic, both for consumers and for insurance companies. Before going into the details of quantitative measures of risk, it is interesting to note how the shift in frequency and severity of climate events and the global warming impact on the distribution frequency of, for example, temperatures (measured in extreme cold and hot days) and precipitation (ordered from light to heavy precipitations). There are four main possibilities of a shift in the distribution function (assumed to be a Normal distribution function) of these variables, represented in Figure 2 below from IPCC, Fifth Assessment Report, Working Group 1, which are:

- (a) increase in mean. This effect, taken on its own, does not imply a change in the shape of the distribution function but simply its translation to the right. This change implies that extreme hot days, i.e., the right tail of the distribution, increase in frequency and that the frequency of extreme cold days, i.e., the left tail of the distribution, decreases;
- (b) increase in variance. This shift in the variance causes a change in the shape of the distribution, which becomes flatter in the middle, meaning that the frequency of days with average temperature decreases, while the tails become thicker, causing an increase in the number of both extreme cold and extreme hot days;
- (c) increase in both mean and variance. This combined effect causes a translation of the distribution to the right and a change in its shape; the total effect is a certain increase in the frequency of extreme hot days while the effect on cold days is ambiguous, depending on the prevailing of the change in mean or variance; in the first case cold extremes will be less frequent as in scenario (a), while in the second case they will increase in frequency as in scenario (b);
- (d) change in skewness. In this case the distribution function would not be a Normal distribution function anymore, with a consequent change in both the average and, more importantly, in the thickness of the tails. In particular, in the context of global rising temperatures, it is reasonable to assume that the frequency of extreme hot days and/or heavy precipitation increases, (i.e., the right tail becomes thicker).

Figure 2[10]



Alongside with this risk of the increase in the fatness of the tails of the distribution, there are other two types of climate change related risks, analyzed by Kousky and Cooke (2009). These are global micro-correlations and tail dependence.

The first refers to very small but positive correlations, between variables considered in a model estimation, which could potentially be neglected. Every variable could have small or large, positive or negative correlation with the other variables in the model. Single correlations could also be not statistically different from zero but could have positive average. If the average variance is different from zero, consequently, it has to be that the average covariances are not zero, thereby causing some form of correlation between the variables considered. This is the case of the model estimated by the authors for US flood and crop insurance data.

The second, taking only two variables for this example, stands in the fact that one variable realizing an extreme value causes a higher probability for the other variable to realize an extreme value as well. However, there could more variables in the model, one affecting the behavior of the others and having tail dependence with them. That was the

[10] Note that the initial state is the dashed line, the final state is the solid line

case of extreme temperatures in the summer of 2003. These extreme temperatures caused extended bushfires across Europe, which brought large losses to citizens and insurance companies, severe droughts that jeopardized crops harvesting and nuclear power plants in France to shut because of lack of water, thereby causing a cascading effect on electricity prices.

Neglecting fat tails, micro-correlations and tail dependence can have an impact on the insurance industry, since the rising economic costs deriving from climate related natural disasters are increasing over time and consequently insured losses do the same. On the other hand, these three concerns can be a starting point for considerations by the insurance industry, regulators and supervisors in developing new strategies aimed at giving a response to climate change issue.

When evaluating, for example, a portfolio of assets or an insurance policy, there should be a proper risk assessment by the holder of the portfolio or the insurance company that issues the contract for insurance. In order to do that, the returns in the case of the portfolio or the losses arising from the insurance contract should be properly estimated, alongside with their respective probabilities of occurrence. Then, the probability distribution of returns and/or losses can be computed, thereby allowing to make some reasonings and calculating some mathematical risk measures on it. There are two main measures of risk that we can derive from the probability distribution function of the losses. They are Value at Risk (VaR) and Expected Shortfall (ES).

3.4 Value at Risk

The Value at Risk (VaR) is a common measure for determining the overall riskiness of a portfolio. Denoting with $F(L)$ the cumulative distribution function of losses, where $F(L) = P(L<l)$, the Value at Risk of the portfolio, given a confidence level α (usually a high α, e.g., $\alpha = 90/95\%$), is the smallest value in the cumulative distribution function of losses for which the total loss L is larger than l with a probability $p = 1- \alpha$. In other words, from a more statistical point of view, the Value at Risk is the α-quantile of the

cumulative distribution function of losses ($VaR = F^{-1}[\alpha]$). In a portfolio, this measure is significant because it is the maximum loss to be incurred in if an extreme event does not occur; in the climate change context it is even more important because of the increase in frequency of extreme events. From an insurer point of view, if an amount of capital equal to Var_{α} is allocated to prevent losses, any non-extreme loss is funded and therefore with a probability of $p = 1 - \alpha$ the default is avoided. However, VaR does not give further information about the tail events and the losses related to them. It is not possible to determine, using only this measure, the impacts of extreme events on the overall loss of the portfolio. It is important to clarify that VaR is a given amount, e.g., of money lost, not a probability. A VaR, with a 99% confidence level, equal to 1 (e.g., million euro) could be interpreted as "the loss on this portfolio will be smaller than 1 with a probability of 99%. That is misleading in the context of climate change, since tail extreme events are happening with more frequency, thereby changing the shape of the distribution of losses which will very likely become a non-Normal distribution.

The issue with Value at Risk lies in the fact that it is not a coherent risk measure. To be a coherent risk measure (Föllmer, H., Schied, A., Convex and coherent risk measures, 2008) there are four properties to meet which are:

1. monotonicity: taking two different portfolios, A and B, where A has a worse return/bigger loss than B, the risk measure of A should be higher than the one of B;
2. translative invariance: if an amount of cash L is added to a portfolio with a risk measure equal to r, the risk measure of the portfolio will be reduced by the cash amount. The risk measure will then be $r – L$;
3. homogeneity: if a portfolio has a risk measure equal to r and its size is increased by a factor C, the risk measure will increase by the same factor. The risk measure will then be equal to $r*C$;
4. sub-additivity: taking two different portfolios, A and B, with risk measures r and s respectively, the risk measure of the merged portfolio should not be greater than the sum of the two risk measures.

As said before, VaR is not a coherent risk measure since it satisfies only three of these four properties. In fact, it violates the last one, the sub-additivity. Given two portfolios with two different loss distributions (*FL1* and *FL2*), the Value at Risk of the merged portfolio is not straightforwardly lower than the sum of the two distinct VaRs of the two portfolios, therefore it is not sub additive and hence problematic as a risk measure. A very simple but at the same time very clear example is the one provided by Chen, J. M. (2014), to understand how VaR does not meet the sub-additivity requirement to be a coherent risk measure. Consider two different statistically independent bad projects/portfolios, each with a $10 million loss with a probability of 2% and a $1 million loss with probability of 98%. The VaR with a 97.5% confidence level is $1 million for each project, since the worst loss is a tail event not captured at this confidence level. Combining the two into the same project/portfolio, they will give three different scenarios: (i) a $2 million loss in the best-case scenario of both having the lowest loss with a probability of 96.04% *(98% x 98%)*, (ii) a $11 million loss in case of one low and one high loss, with a probability of 3.92% (*2 x 2% x 98%*), and (iii) the worst-case scenario of a $20 million loss, when both have the highest loss, with a probability of 0.04% (*2% x 2%*). Now looking at the VaR of the combined portfolio with the same 97.5% confidence level, it lies at $11 million loss, which is way larger than the sum of the VaRs of the two single portfolios ($2 million). This simple example demonstrates how VaR is not a sub additive risk measure.

3.5 Expected Shortfall

Since VaR is not a coherent risk measure, it may be useful to consider another measure which satisfies the property of sub-additivity. In this case the Expected Shortfall, also known as the Tail Value at Risk (TVaR) or the Conditional Tail Expectation, could be a good replacement for VaR. The expected shortfall is defined as the average Value at Risk across levels of confidence higher than α, i.e., the worst quantile of the distribution at the given confidence level. In other words, it is the weighted average (i.e., the expected value) of the loss values larger or equal than VaR_α, where the weights are the probabilities of occurrence of the different values of the losses. The Expected Shortfall, unlike VaR, tells something about the tail of the distribution by best capturing tail events. In fact, it gives information about the losses that a portfolio would face in case an extreme event occurs, bringing in high losses. Basically, it gives the expectation of the loss given already that a tail event has happened; in fact, one of the computations for Expected Shortfall is $ES_\alpha(L) = E(L|L > VaR_\alpha)$. Expected shortfall is a more precise risk measure than Value at Risk when considering distributions that have a high spike in the tail, since it gives a more accurate indication of the expected value of the loss if an extreme but low probable event occurs, since it may not be captured by the confidence level chosen.

Recall back the example in the previous paragraph. Conditioning that Expected Shortfall is calculated in the worst-case scenario, i.e., worst 2.5% of the distribution for the given confidence level used in the example, the 2% probability of the high loss becomes a *2%/2.5%* = 80% probability of a $10 million loss, while the remaining 20% is the low $1 million loss. For each project, therefore, the Expected Shortfall will be the weighted average of the losses in the tail of the distribution. In particular, each project will have an Expected Shortfall of *80% x $10 million + 20% x $1 million* = $8.2 million, for a total sum of $16,4 million. Recalling the probabilities of the combined portfolio (0.4% of $20 million loss, 3.92% of $11 million loss and 96.04% of $2 million loss), the same reasoning done for the two single portfolios applies. The Expected Shortfall for the combined portfolio will be (*0.04%/2.5%*) x $20 million + (*2.46%/2.5%*)[11] x $11 million = $11.144 million. Comparing the combined portfolio with the sum of the two single portfolios (i.e., $11.144 million vs $16.4 million), the straightforward conclusion is that Expected Shortfall satisfies the sub-additivity requirement to be a coherent risk measure.

[11] 2,46% is the remaining share of probability to be accounted for, since we are in the 2,5% tail of the distribution and 0,04% is the probability of the worst loss (*2,5% - 0,04% = 2,46%*)

Overall, Value at Risk, by disregarding losses beyond the confidence level, may mislead investors and insurance policy issuers; adopting Expected Shortfall as the risk measure of reference could help in capturing tail risks. However, in the case of a fat-tailed distribution, using expected shortfall may induce bigger estimation errors than by using Value at Risk (Yamai, Y., Yoshiba, T., Value-at-risk versus expected shortfall: A practical perspective, 2004), eventually resulting in a more costly scenario. Therefore, each risk measure is not dominant over the other and, instead, when evaluating the portfolio of assets or the insurance policy to be signed there should be a combination of the two, providing a more effective risk monitoring.

4 Insurance industry

The insurance industry plays a key role in the economy because it provides coverage against stochastic events that otherwise would harm individuals and businesses that are not able to bear the risks arising from those events. The insurance industry is able to bear risks because it aggregates those risks making a fair prediction about the overall risk borne by each insurer. In exchange for an amount of money, called insurance premium, business and individuals can buy protection against the losses coming from the above-mentioned stochastic events. With the arising frequency of severe weather events in the climate change context, insurance has an even more important role; according to Hecht, Sean B. (2008), as long as the increasing risks are insurable and individuals and/or businesses are prone to buy insurance, insurers will have new business opportunities. Insurability is the main feature of risks for insurers, meaning that the highest loss should not be causing the insurer's insolvency. Furthermore, the average loss should be determinable with a proper precision, in order for the insurer to ask a premium that allows it to make a predictable profit when signing the insurance policies and, finally, risks borne by insurers should be independent rather than correlated and well distributed. Correlation among risks poses a high potential loss for the insurer in the case of a severe event that would cause a high number of claims. For instance, correlated risks could be due to the geographical concentration of policies signed: if an insurer signs many policies in a restricted area and, for example, a hurricane hits, there will be a large number of claims that, all together, could harm the solvency of the insurer.

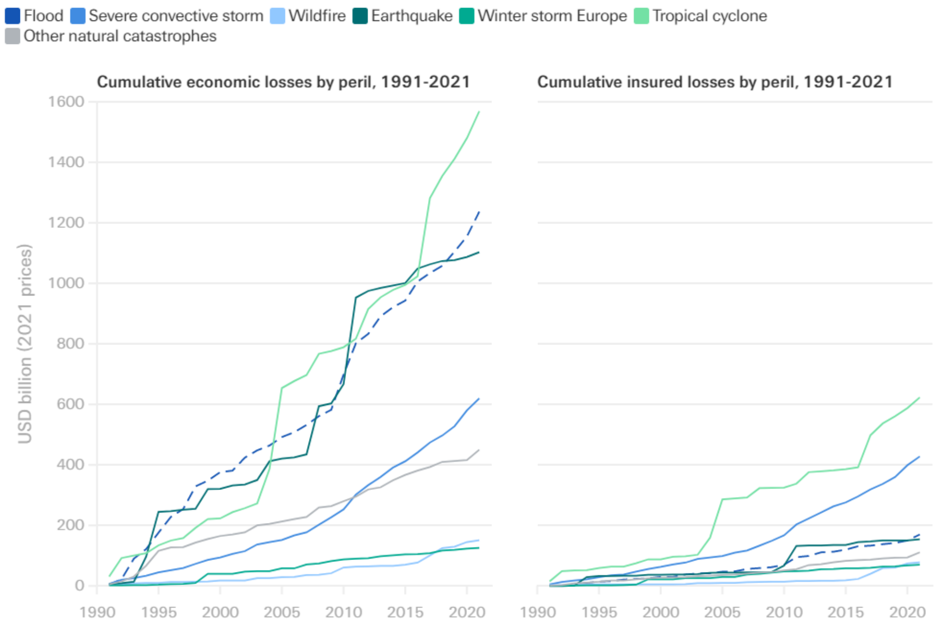
The main concern for insurers' solvency lies in catastrophe related events, where catastrophes are "*infrequent events that cause severe loss, injury or property damage to a large population of exposures*"[12]. Weather-related catastrophes have a huge impact on insurers' business, since they bring high losses with an increasing frequency. There are many cases in the recent past of losses related to climatic events, the highest one being

[12] As defined by the American Academy of Actuaries

the 2005 hurricane Katrina in USA, with a damage of more than $160 billion. Also 2017, again in the USA, was a disastrous year, when three different storms hit, causing a total economic loss of more than $220 billion, accounting for 35% of the total losses of the top 10 disasters around the world from 1970 to 2019, according to the World Meteorological Organization. As climatic events and catastrophe events are expected to rise in frequency, so will the insurers' costs to provide coverage to the insureds and, consequently, insurance premiums will have to increase to maintain financial soundness of insurance companies, thereby causing a potential disruption of the market. When insurance premiums will be too high, there will be no point of contact between supply and demand for insurance products, leading to un-insurability of risks and to a potential collapse of the insurance market.

Climate change is likely to affect all types of insurance products, like property/casualty and health/life insurance. Property insurance is the one that is directly being affected by climate events, not only for the effects of extreme weather events like hurricanes, but also relating to side effects of climate change such as sea level rise or droughts hitting the agricultural sector. Particularly in 2022 droughts are deeply damaging agricultural crops. For instance, in France July 2022 has been the driest month since March 1961, with the level of precipitation down 84% from the average seen for July from 1991. Since France is the fourth-largest exporter of wheat, there will be further implications on food prices from the ones seen after the invasion of Ukraine by Russia in early 2022. Health and life insurance will be affected as well. As said previously, global warming can cause faster spreading of some viruses because of a more favorable environment for mosquitoes, which are responsible for the spreading of some diseases. Moreover, the greenhouse gases emissions contribute to worsening the quality of air we breathe, thereby increasing the likelihood of respiratory illnesses. Since these negative consequences on health become more common, health/life insurance premiums will likely increase.

According to Swiss Re Group, one of the world’s leading providers of insurance, reinsurance and other forms of insurance-based risk transfer, the global estimated insured losses arising from natural catastrophes were $35 billion in the first half of 2022, above the average of the past ten years ($29 billion). The most significant losses came from the series of winter storms that hit Europe in February, flooding in Australia and South Africa in February and March, and high number of thunderstorms that hit in the US. The main issue is that, as reported in the figure below (from Swiss Re Institute)[13], the total economic losses coming from different climatic events are covered by insurance only in a tiny portion. In fact, all the major catastrophe events present a protection gap, meaning that a fraction, in this case very large, of economic losses are uninsured – the highest protection gap is in flood events[14], where cumulative insured losses from 1991 to 2021 represent only ~14% of the total economic losses registered ($170 billion insured losses over $1237 billion of economic losses registered).



[13] Source: Swiss Re Institute, available at https://www.swissre.com/institute/research/sigma-research/sigma-2022-01/five-charts.html

[14] Represented by the dashed blue line in the figure

The increasing threats coming from climate change pose a challenge for the insurance sector in the near future because they are likely to create uncertainty about future losses, causing a potential contraction of the market due to un-insurability of risks.

4.1 How to determine an insurance premium

In a common insurance policy signing, the contribution to be paid to the insurer (i.e., the insurance premium) is known in advance, namely at the time of the signing of the policy, while the amount paid by the insurer as a benefit to compensate the insured for the losses incurred is not, although guaranteed, even if the policy commonly states some criteria for it. Simplifying an insurer's portfolio of risks, denote the total amount of money collected from the insureds with $S^{[P]}$ and with $X^{[P]}$ the total amount paid as a benefit to the insureds for the losses incurred, which is a random amount, since at the time of policy signing the monetary amount of losses to be funded is not known. The overall result $Z^{[P]}$ will be simply the difference between the collected premiums and the total benefits paid. Therefore, the risk borne by the insurer results in a speculative risk, since the result could be either a profit or a loss, depending on the amount of the random variable $X^{[P]}$. The benefit paid by the insurer in case of a claim could take the form of a reimbursement of expenses paid by the insured, an indemnity covering losses coming from some accidents/events or a forfeiture amount typically stated in the insurance policy. The first two types of benefit are commonly used in non-life insurance policies, while the forfeiture amount is typical of life insurance. When an insurer has to calculate the insurance premium to ask to policyholders, he has to set a premium that meets the random benefits paid. Assuming a single premium, which is a premium that is paid in just one amount at policy issue, that premium need to represent the value of the benefits; it has to give a summary of the benefit with respect to time of the payments (i.e., determining the random present value of the benefits) and with respect to randomness (i.e., addressing typical values of the probability distribution like expected value and standard deviation). Regarding the time value of benefits, insurer should determine an appropriate interest rate to discount the payments; however, for common short-term policies which are typically in place for a single year, this aspect can be disregarded since time does not have a major impact on the value of benefits. When calculating the premium to ask to policyholders, there are many factors that insurers take into consideration. There may be expenses that insurers could have to pay in the case of a claim which are not related to the payment of benefit and insurers are likely to charge, at least in part, to each insurance policy (expense loading). In addition, a further increase in the premium guarantees a profit margin to insurers. Leaving aside these aspects, we are left with the calculation of the so-called net premium (or pure premium). Denoting a case in which the possible loss has a fixed amount s, the benefit paid is given by that same amount in case of claim. Therefore, the random benefit X paid to the insured will be equal to s if the event causing the loss occurs with probability p and zero otherwise. The expected value of the benefit will be simply the product between s and p. Assuming that the premium P is calculated to cover the random amount of the benefit, it will also be equal to the product between s and p. The total result Z for the insurer would be equal to the difference between the premium collected and the benefit paid; taking the expected value of Z, $E[Z]$, it will be the difference between the premium collected which is certain P and the expected value of the benefit, which results in a null expected result. With these computations, the insurance premium P calculated in this way is called equivalence premium. Moving to a pool of n risks, a typical insurer portfolio, the equilibrium is met if the realized number of claims coincides with the expected number of claims. However, there is the probability that the actual number of claims exceeds its expected value, particularly in the context of climate change with rising frequency of weather events causing losses and therefore higher number of claims due to property damage or other insured losses. In that case, the equivalence premium does not work anymore because insurers would suffer a loss, since the amount of benefits paid to insurers is greater than the premiums collected from them. In order to keep the probability of a loss at portfolio level at an acceptable threshold, insurers need to charge an extra share of premium to the insured through the so-called safety loading m that is basically a surplus amount of money to be asked to policyholders at the issuance of the policy. The new premium will then be no more the equivalence premium as before, but it will be an amount $Q = P + m$. Going back to the generic policy and looking again at its net expected result for the insurer $E[Z]$, it will now be equal to the difference between Q and the expected value of the benefit. Since the expected value of the benefit, as before, is equal to P, the net result from the generic contract for the insurer will be the safety loading m charged to the insured. At the pool level, the total safety loading received by the insurer ($n \times m$) represents the total profit gained. The safety loading has therefore two different purposes: on one hand it guarantees a higher level of safety by reducing the probability of a loss, on the other it provides an expected profit to the insurer. The amount of the safety loading can be computed in two ways: the first one is explicit and is done by simply computing m as a percentage value of the equivalence premium P; the other one is implicit as it is based on a fictious rise in the probability p of occurrence of the event causing the loss. The higher the probability, the higher will be the premium asked to the insured.

4.2 Information asymmetry in insurance

The economic theory on information and uncertainty certainly applies to the insurance market, since asymmetric information can have an impact on the final allocation of insurance and on the characteristics of the policies signed. Asymmetric information occurs when one party in the transaction possesses some piece of information that the other does not, and that could happen in both ways (i.e., the insurance companies or the insured could have an informational advantage with respect to the other) and could lead to a market failure. In particular, asymmetric information is commonly distinguished in adverse selection and moral hazard problems.

In the adverse selection case, the issue stands in the fact that bad quality people are likely to buy more insurance than the good quality one, because insurance policies are pretty standardized and cannot be properly modelled for every single client. Therefore, bad and good risks choose among the same set of possible contracts and, at a given price (premium), bad risk individuals will have a higher marginal utility and thus will likely buy more insurance than good risk ones. This is crucially important for life and health insurance. The insured knows everything about himself (e.g., diet, physical activity, etc.), while the insurer could not have access to this type of information, therefore the insurer cannot identify a priori the good and the bad risks ("hidden information"). In order to reduce the risks of adverse selection, insurers could try to screen (i.e., to discriminate) between the type of clients, between good quality and bad quality risks by offering a menu of contracts that allow insured to self-select. To achieve the self-selection, in the case of a choice between two contracts, these have to differ with respect to both the premium asked and the level of loss coverage, otherwise (i) if they have the same premium but different level of coverage, both types of client would choose the highest coverage and (ii) if they have same level of coverage but different premiums, both types would choose the contract with the lowest premium. In such a scenario, the two types of clients would self-select, meaning that good quality risks would choose the contract with lower premium and lower level of coverage and bad quality risks would opt for higher premium and higher coverage. In this way, every type chooses the contract that was thought for it.

For the differential information known in advance, adverse selection occurs before entering the transactions. The possible outcome of a situation of adverse selection is that bad quality risks will buy insurance coverage while good quality risks will not, leaving insurance companies with a portfolio of only bad risks. That was the case of individual health insurance in the State of New York. The Affordable Care Act (ACA, also known as "Obamacare") set the individual mandate penalty (that is basically a mandatory health insurance coverage unless an exemption is provided under penalty by the Internal Revenue Service) which was then removed in 2017. Since healthy people were no more obliged to sign an insurance policy, insurance companies were left with clients having a higher risk regarding their health (e.g., older and/or sicker people). This removal of obligation has caused, according to Rao et al., an increase in the insurance premiums by more than 20%.

In moral hazard, the market failure stands on the fact that the insured's actions are not observable by the insurer or, even if they are observable, they are not verifiable ("hidden action"). In this case the asymmetric information arises after the contract has been signed. The insured party could feel like he can avoid to put on an effort to reduce the probability of risk and loss, since the risk is already covered. The actions of the insured affect both parties' utility and payoff, thereby possibly causing the insurer to avoid signing the policy or the outcome of the relationship to be inefficient. An example of moral hazard is the US federal flood insurance. The government has offered subsidized flood insurance to homeowners and people started building front beach houses. If these houses are hit by waves coming from a storm, the insurance pays for the rebuilding. Before this type of subsidized insurance was set, beach houses were less numerous and typically low cost, because homeowners were afraid of damages and insurance was expensive. On the other hand, inland homeowners were not buying insurance coverage since their properties did not suffer or were less exposed to flooding risks. In order to reduce the risks arising from moral hazard, there are some ways in which insurers could try and achieve their aim. First of all, as it was the case for adverse selection, they could set differentiated premiums to allow their clients to self-select. Lower premiums will be charged to clients that can prove they have low risk and/or take on some actions to prevent the risk of a loss. Another way to make clients choose their proper insurance policy is to require a safety investment in order to sign a particular policy (that will have higher coverage and higher premium). In this case, insureds evaluate the discounted benefits provided by the higher coverage policy and compare them with the present costs of this safety investment. Straightforwardly, those clients who have a positive differential will put in place this safety investment and will buy the higher coverage policy, those who have a negative differential will not. In addition, insurers can collect information about the behavior of their clients by examining the insured's previous loss experience during the policy period and therefore they can adjust the pricing of the policy for the incoming future. In order to achieve an efficient insurance contract, the overall risk should be shared between the insurer and the insured; in this way the insured has "partial coverage" and has an incentive to prevent the risk. Insurers bear the risk of a claim and the consequent repayment of the loss incurred while insured are typically required to pay.

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4.3 The role of insurance industry in climate mitigation and adaptation

The insurance industry has a major role in the context of climate mitigation and adaptation. Adaptation role is relatively straightforward since individuals and businesses might prefer to transfer risks while paying a premium (risk-averse behavior) and insurers accept to bear those risks since they can reduce their total vulnerability by a risk pooling effect. Therefore, the insurance industry helps policyholders to adapt to climate disasters by providing funds to repay for the damages incurred. In addition, insurers can encourage policyholders to adopt climate-positive behaviors and to take actions to improve climate change outcomes and so to try mitigating climate change. Insurers should have an interest in reducing threats from climate change because of potential less variability and less uncertainty in their losses; however, there has not been much action in doing so (Hecht, Sean B., 2008).

On one hand they could simply charge lower insurance premiums to policyholders that behave in a climate-friendly way and higher premiums to the ones that do not behave in that manner; in this way there should be a potential reduction in greenhouse gases emissions and a reduction in insured's exposure to climate catastrophe events. Moreover, this premium reduction could also be linked to adaptation measures. An insurer could incentivize a policyholder to take on risk reduction measures by giving him premium discounts. An example could be about prevention action in limiting the possible damages on the building coming from a flood. These incentives in lower premiums charged or premium discounts for policyholders that take on climate-friendly behaviors are coherent with a risk-premium approach adopted by insurance companies. Policyholders that act in a climate-friendly manner aim to reduce the emissions of greenhouse gases, which is the main driver of transition risk. Lower transition risk means less concern about the future emission policies from a single policyholder point of view. Less risky policies should therefore be charged lower premiums. Even though there are these incentives for the insurance industry, insurers appear not to be pricing policies following that criterion. That is because climate-friendly behavior cannot work if it is done by only a single or a few market players, "*a rational individual reasons that if she behaves in a manner consistent with the collective good, her* *behavior will be meaningless unless other members of the group also participate*" (Ann Carlson, Recycling norms, 2000). Furthermore, there could also be the case of free riding, meaning that one market player can gain the benefits coming from the behavior of other market players even if he does not engage in that same behavior to achieve the collective good. For these reasons, insurers on their own, without a collective intent of actions, may not have much motivation to act for mitigation of climate change.

On the other hand, incentives on demand side could not work because of individuals and businesses biases that can cause a non-maximization of the expected utility function, such as loss aversion, in which a loss appears to be of higher value than a gain of an equal amount, or availability heuristic, in which events that can be more easily recalled appear to have high probability of occurrence. Moreover, people may think about insurance as an investment instead of a hedge against losses; since insurance does not yield a financial return, people may decide not to purchase insurance coverage against catastrophic risk.

Leaving aside supply and demand incentives for climate-friendly behavior in insurance, there are some examples of insurance products that aim to "reward" climate-friendly practices implemented by policyholders, such as green rebuilding insurance, which encourages rebuilding following environmental standards after a loss.

In the case of liability insurance (which provides protection to the insured against claims coming from injuries/damages to other people or property), if the risk becomes uninsurable to businesses that are not into climate-friendly behavior or the premiums asked by the insurers to this type of companies is too high, there will be a direct incentive to become climate-friendly. Another example of insurance product aimed both at mitigating climate change and reducing the overall risk of insurers is the so-called Pay-as-you-drive, which is used in the auto insurance sector. This is a particular type of product since it combines a potential reduction in insured losses (and so a reduction in number of claims and their relative amounts) with a reduction in greenhouse gases emissions. As its name suggests, Pay-as-you-drive charges an insurance premium that is proportional to the distance driven by the insured – the longer is the distance, the higher is the premium. This product gives insured a high incentive to reduce the miles driven to pay a lower premium and with that, at the same time, it contributes at reducing the amount of car greenhouse gases (carbon dioxide) emissions.

In addition, insurers could incentivize climate change adaptation by addressing business interruption risk (Scholer, M., Schuermans, P., 2022). Physical damages are not the only possible losses coming from natural disasters; the interruption of business activities could harm the business furtherly. As an example, hurricane Katrina has caused an estimated loss of 6 to 9 billion dollars linked to business interruptions. There could also be non-damage business interruptions, related to activities that cannot continue to operate even if not directly impacted by climate events. Business interruptions is rarely considered as part of the property insurance and therefore they are not properly assessed. Insurance on business interruptions is crucial to determine the adaptation to climate change and to build a resilient society in which the survival of businesses is dependent on the appropriate choice of the insurance policy. Insurers, to be able to provide coverage against business interruptions, will have to implement a risk assessment to determine an estimate of the potential losses deriving from natural events and to calculate a proper risk-based premium.

4.4 Insurance industry's exposure to climate change

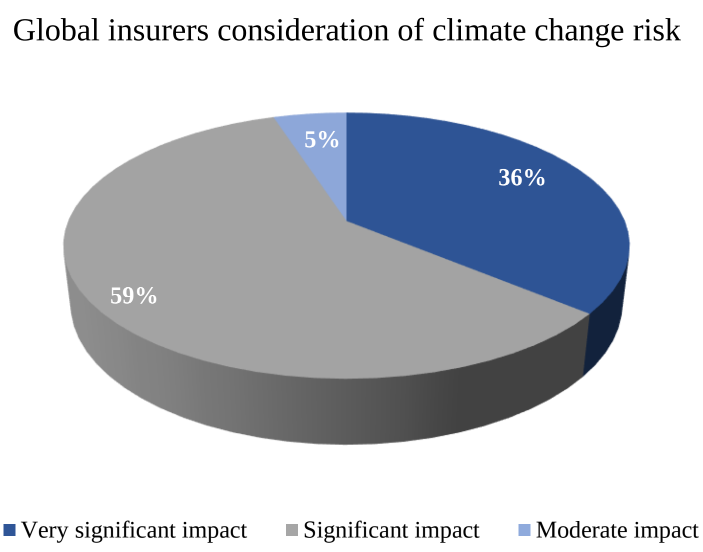
As far as climate change physical risk is concerned, the European Insurance and Occupational Pensions Authority (EIOPA) considers three key elements in order to assess the impacts of this type of risk on companies. Firstly, the level of exposure is of main significance, since it is determined by the presence of people, infrastructures or other assets that could be affected by climate related extreme events. The growth in the level of exposure to such type of events is the major driver of the increasing disaster losses. As an example, the concentration of people and economic activities in coastal regions could have dramatic effects with the ongoing icebergs melting and consequent sea level rising. Secondly, the hazard, describing the probability of occurrence of extreme weather events like floods or droughts and their intensity. It is computed using historical data about these types of events but, in the long term, their probability and intensity could increase in case of accelerated climate change. Finally, the vulnerability, described as the propensity of physical risk-exposed population or assets to suffer economic and non-economic losses as these events hit. Vulnerability is directly connected with the level of exposure, since people or buildings not exposed to physical risk are straightforwardly not vulnerable to them. On the other side, there can be an increasing vulnerability to physical risk, for example from a geographical perspective. Areas that are continuingly hit by natural disaster events and increasingly affected by climate change become more vulnerable; this fact could bring the insurance industry to avoid providing insurance coverage to people and businesses in that area (i.e., the risks become uninsurable). In the context of climate change, with respect to the effects that it has on portfolios, insurers could hedge the risks by engaging in green investments, referring to investments in companies or projects that operate in the renewable energy sector, clean technology as well as investments in environmental, social and corporate governance (ESG). Although being one of the industries more exposed to the threats arising from climate change, insurance seems not to take into proper consideration the implications of climate change when it comes to investment decisions. In fact, according to an analysis completed by S&P Global Market Intelligence for the California Department of Insurance, which examined 1200 insurance companies operating in California (and other parts of the United States), these companies increased their total investments in fossil fuel companies, even if they are the most exposed to transition risk in an eventual rapid shift to a low carbon economy. Using data by S&P Global, this report found out that from 2018 to 2019 insurance companies increased their investment in these high-carbon activities from $477 billion at the end of 2018 to $536 billion at the end of 2019. Among these investments, there has been an increase of about $20 billion of money invested in fossil fuel extraction activities, reaching a total amount of $96.8 billion. In addition, a survey by OECD, the OECD Large Insurers Survey, reported that the surveyed insurers' asset allocation to green investments is very limited with respect to the total amount of money invested and many of them stated that they do not have a specific policy or target on green investments.

Focusing on the European Economic Area (EEA), an analysis[15] conducted by the European Central Bank (ECB) and the European Systemic Risk Board (ESRB) mapped insurers' equity and bond holdings to individual firms and their technology of production to have a view on insurers' exposures to climate-relevant sectors particularly exposed to transition risk in the event of a re-alignment of the economy to a low-carbon base in order to reduce global warming and to meet the goals of the Paris Agreement. From this analysis, the main result is that insurance companies, even if they have well-diversified portfolios, have substantial holdings in the power sector, oil and gas sector and in vehicle production, three of the most carbon intensive sectors as of today. Despite a degree of heterogeneity between different countries, power sector is the one that attracts the major share of investments in most countries. In the event of a transition scenario from a fossil fuel-based economy to a low-carbon economy to renewable sources of energy, power generation would be heavily affected in terms of transition risk and value of the assets in this sector, thereby causing major consequences on portfolios highly exposed to it.

A recent report conducted by Blackrock (2021)[16] assessed the focus of insurers on sustainability and ESG factors, seeing an increase of 10% in the number of insurers publishing ESG-related commitments. More than half of the respondents confirmed that in the previous 12 months they had invested in specific ESG strategies, the most virtuous ones being the Europeans with 61%, while the less virtuous were in Asia Pacific with 47% of respondents investing in ESG. On the other hand, 52% of Asia Pacific insurers stated that they turned down an investment opportunity in the previous 12 months because of ESG concerns, while European were only 36% and Latin American 27%. An interesting fact is about post Covid focus on sustainable investments. Globally, 57% of the respondents admitted that they have become more aware of the need for climate risk mitigation and in Asia Pacific nearly 7 insurers out of 10 responded positively to this question. The average percentage of the assets under management invested in sustainable solutions, however, is low

[15] Source: Climate-related risk and financial stability, ECB/ESRB, July 2021
[16] Source: BlackRock Global Insurance Survey, June-July 2021

at 11% and expected to increase to 14% over the two-year period 2022-2023. Moreover, a very large majority of respondents (95% globally, with peaks of 97% and 100% in Europe and Latin America respectively) stated that climate risk will have a significant or very significant impact on portfolio construction and strategic asset allocation over 2022-2023.



The figure represents the percentage of respondents attributing "very significant impact", "significant impact" and "moderate impact" to climate change risk as investment risk. Source of data: BlackRock Global Insurance Survey, June-July 2021

The importance of sustainable investments is becoming more and more widespread, thereby ensuring a better risk-adjusted performance in the long period and compliance to regulation put in place by authorities and meeting public commitments to sustainability. However, regulation on sustainable investments appears to be a major issue for companies; in fact, 62% of the respondents to the report of Blackrock said that compliance with regulatory requirements was one of the biggest concerns in the previous 12 months in implementing an ESG strategy, with nearly 7 out of 10 being in this position both in Europe and in North America.

Apart from the investment decisions adopted by the management, insurance companies on their own, like any other firm, have a carbon footprint by emitting greenhouse gases, even if a relatively small amount if compared to other high emission industries. In the classification provided by the Greenhouse Gases Protocol Corporate Standard, emissions are divided into direct and indirect emissions, the first coming directly from sources owned or controlled by the company (Scope 1), the other being a consequence of the activities of the company but produced by other sources not owned or controlled by the company itself (Scope 2 and 3). Scope 2 are emissions arising from the generation of purchased energy consumed by the company, while Scope 3 emissions are the result of activities from assets not owned or controlled by the organization, but that the organization indirectly impacts in its value chain. With respect to insurance emissions, clearly, they have a low carbon footprint if considering Scope 1 and Scope 2 emissions, but could have huge Scope 3 emissions, in particular in business travels. According to BCG, insurance companies, particularly in the post Covid era, are prone to adopt new ways of business while ensuring a reduction in emissions, such as promoting smart working, the shift to hybrid vehicles and a reduction in the frequency of business travels.

4.5 Regulatory framework

As there has been an increasing recognition of the climate change issue in risk management activities, also from a regulatory point of view some institutions have started to tackle the problem as well. As said previously, the most important recognition of climate change issue is the Paris Agreement signed in 2015 at Conference of Parties 21, because it is the starting point for coordinated global climate action and signaled a step towards climate change addressing by governments. From then on, the Conference of Parties has met 6 more times, the last one being COP 27 in Sharm el-Sheik in November 2022. Since 2022 has been a non-ordinary year, with the well-known dispute between Russia and Ukraine and macro-economic turbulence observed, let's focus firstly on the main outcome of the second-to-last meeting held in Glasgow in November 2021, the Glasgow Climate Pact, which emphasizes the urgency of both adaptation and mitigation measures to prevent losses from climate change. From the adaptation point of view, it has reinforced the focus on the relationship between rising temperatures and weather extremes causing adverse impacts on people and nature, also taking into consideration the findings of Working Group I of the IPCC on Climate Change Sixth Assessment Report. In addition, it has noted that, as things stand, the actions in place in climate finance for adaptation are not sufficient to respond to climate change worsening, especially in developing countries participating at Conference of Parties, and has invited banks and other financial institutions to enhance finance mobilization to deliver the amount of resources needed to achieve climate plans and to explore innovative approaches and instruments for adaptation. From the mitigation point of view, instead, it has reaffirmed the long-term global goals set with the Paris Agreement, furtherly recognizing that reducing global warming would reduce risks and impacts of climate change significantly. Furthermore, it has called to action the Parties involved, stating that, in order to meet the goals of the Paris Agreement, countries are required to reduce global carbon dioxide emissions by 45% by 2030 relative to the 2010 levels and to net zero emissions around the 2050, as well as deep reductions in other greenhouse gases. Finally, it has encouraged Parties to mobilize financial resources, technology transfers and capacity building, in particular to help developing countries with respect to both mitigation and adaptation, and it has urged multilateral development banks and other financial institutions to scale up investments in climate action, through a continued increase in the amount and effectiveness of climate finance.

In Glasgow three important announcement have been made:

1. The Glasgow Financial Alliance for Net Zero (GFANZ), a private sector alliance composed by more than 450 banks, insurers and asset managers across 45 countries representing 40% of the world's financial assets, calculated that the capital to be committed to net zero emissions by 2050 is worth about $130 trillion;
2. The International Financial Reporting Standards (IFRS) Foundation stated that it would launch a new International Sustainability Standards Board (ISSB) to establish global reporting standards on climate and sustainability, based on existing initiatives (e.g., the Taskforce for Climate-related Financial Disclosures, TCFD);

3. The UK announced that asset managers, regulated asset owners and listed companies will have to publish their own plans for net zero transition by the end of 2023.

The previously mentioned TCFD is an initiative of the Financial Stability Board (FSB) that develops voluntary climate-related financial risk disclosures for private companies. In particular, it gives recommendations on how to provide climate-related financial disclosures for insurance companies, lenders and investors in general for better understanding material risks, since it stated that, in their current asset valuation, they do not have adequate information about organizations and their plans for preparing for a transition to a low-carbon economy.

The Conference of Parties in Glasgow highlighted the critical role of the insurance industry in the transition to net zero emissions and adaptation to climate change. In particular, insurance is the main actor that can help in adaptation and resilience to extreme weather events by bridging the protection gap. The protection gap is the difference between the economic losses from weather events and the amount of insurance available. This protection gap is now estimated to be around 60% for natural disaster loss, and 95% in less developed countries, which, at the same time, are the most exposed to climate change impacts. It is therefore crucial to bridge this gap and build a resilient society. To this extent, in 2016 the insurance industry, together with leaders of World Bank and United Nations, formed the Insurance Development Forum (IDF). During the Conference of Parties 26, the IDF announced three programs to tackle the issue of building resilience to climate change. The first is an agreement between the IDF and the Vulnerable 20 (V20) Group of Ministers of Finance of the Climate Vulnerable Forum, a dedicated cooperation initiative of economies systemically vulnerable to climate change, to build risk analytics capability as part of a new Global Risk Modelling Alliance (GRMA); the second is the establishment of the Global Resilience Index Initiative (GRII) that, with partial funding from the insurance sector, will provide a model for the assessment of resilience across all sectors and geographies; the last is the support for Start Ready, a new financial service that provides funding for predictable crises worldwide. Moreover, the whole industry has supported the implementation and development of TCFD recommendations about climate-related financial disclosures and reporting; in addition, the NGFS announced that more than 100 central banks have signed the NGFS Glasgow Declaration, thereby committing to adopt some forms of supervisory practices.

COP 27 of Sharm el-Sheik has had to deal with the geopolitical tension arisen during 2022 and the turbulence in the energy market, particularly in oil and gas prices. Participating countries restated their commitments to achieve a limitation of global warming well below 2°C and to keep the initial aim of 1.5°C alive. The focus on supporting developing countries to adapt to the impacts of climate change has been furtherly strengthened, with the definition of the institutional arrangements to operationalize the Santiago Network for Loss and Damage (this organization was firstly defined under Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts during COP 19 in Warsaw held in November 2013), which has the function of "*catalysing demand-driven technical assistance* […] *for the implementation of relevant approaches to averting, minimizing and addressing loss and damage in developing countries that are particularly vulnerable to the adverse effects of climate change*"[17]. Furthermore, parties in Sharm el-Sheik agreed on the way to reach the Global Goal on Adaptation that will conclude at the upcoming next COP 28 in December 2023 in the United Arab Emirates, particularly by providing new funding to the Adaptation Fund to help more vulnerable countries to face the impacts from climate change. The outcomes of Sharm el-Sheik however do not seem to be that confident about reaching the Paris Agreement goals of keeping the temperature increase at 1.5°C, in fact the actions in place nowadays are not sufficient to reach that objective. This is particularly evident in articles 30 and 35 of the Sharm el-Sheikh Implementation Plan, which say respectively that the Conference of Parties "*highlights that about USD 4 trillion per year needs to be invested in renewable energy up until 2030 to be able to reach net zero emissions by 2050, and that, furthermore, a global transformation to a low-carbon economy is expected to require*

[17] As defined in UNFCC – Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts - Santiago network, Annex I, § II.2.(b). Available at https://unfccc.int/documents/624374

investment of at least USD 4–6 trillion per year" and "*notes that global climate finance flows are small relative to the overall needs of developing countries, with such flows in 2019–2020 estimated to be USD 803 billion, which is 31–32 per cent of the annual investment needed to keep the global temperature rise well below 2 °C or at 1.5 °C* […]"[18]. These two statements about funds needed to combat climate change highlight the COP's concern about not achieving the goals set in 2015 at COP 21. In addition, from a mitigation point of view, COP 27 highlighted that the global greenhouse gases emissions need to be substantially reduced by 43 per cent by 2030 relative to 2019 levels in order to limit global warming to 1.5°C (article 11 of the Sharm el-Sheikh Implementation Plan).

Eventual regulatory actions that could be put in place by public policy could take the form of mandatory reporting as well as new additional capital requirements for banks and insurers; in doing so, new regulatory policies should aim to enable and incentivize the transition to a low-carbon economy, posing requirements for appropriate climate change mitigation and adaptation actions. Furthermore, since 2016, the Sustainable Insurance Forum (SIF) has put together insurance supervisors in order to create a common understanding and addressing climate change and sustainability issue across the insurance industry. IAIS promotes a high-level goal for insurance supervision, which has to work to achieve, at the same time, insurance market development and sustainable economic development. In addition, supervisors have to take on both micro and macro-prudential supervision on the insurance sector, for example by stress testing insurance companies and the whole industry to address the impact of climate change, and to develop systems to collect and analyze data to understand the evolution and the emerging of risks such as climate-related risks. Moreover, IAIS's Global Monitoring Exercise (GME) develops every year the Global Insurance Market Report (GIMAR), which shows that more than 35% of insurers' holdings (e.g., equities, corporate bonds, mortgages, real estate) could be exposed to climate change events and risks.

[18] See UNFCCC – Sharm el-Sheikh Implementation Plan. Available at https://unfccc.int/documents/624444

4.5.1 USA

After leaving the Paris Agreement under Trump administration, the USA rejoined it under the new Biden mandate, aiming to promote a significant increase in global ambition, exploiting its global – economic and non – leadership to tackle climate change, both by reducing short-term global emissions and by trying to achieve net zero global emissions by 2050, in order to prevent the dangerous climate trajectories forecasted. Biden has created a new figure in his administration, the Special Presidential Envoy for Climate, now held by the former US Secretary of State John Kerry, which has a seat on the National Security Council and will have authority over energy and climate policy to enhance climate ambition and integration of climate considerations across international forums. Moreover, on August 16th, 2022, Biden signed the Inflation Reduction Act (IRA), which is the most ambitious and potentially most impactful climate policy in US history. This act sets USA's emissions of greenhouse gases to be halved by 2030, below 2005 levels and it sent a signal that the historically most emitting country is beginning to face its responsibilities. The Climate Action Tracker has estimated that the signing of the IRA will meet its focus of reducing the American greenhouse gases emissions; however, not sufficiently to reach the proposed decline in emissions of 50-52% below 2005 levels in 2030. If no other policies are implemented, in 2030 US emissions will decline by a range of 26-42% compared to 2005 levels. The climate-related goals of Biden's administration could however be compromised this year, due to the geopolitical and macroeconomic environment of 2022. The Russian invasion of Ukraine brought many governments to impose sanctions against Moscow; among others, USA banned imports of Russian oil and gas. In order to substitute the lacking oil and gas, Biden had to release and is still releasing oil barrels from the national reserves and has encouraged oil and gas producers to drill and increase the production, with unavoidable emissions of greenhouse gases going against climate-related objectives. Moreover, the high levels of inflation, partially due to the geopolitical tensions, can have an impact on investments in climate change mitigation and adaptation projects.

In the US the Congress is the one responsible for authorizing laws to address climate change issues and for directing funds to relevant programs to tackle this challenge; in addition, it is responsible for oversighting the administration in correctly implementing laws. For example, the Clean Air Act is addressed to the United States Environmental Protection Agency (EPA), giving it responsibilities for protecting and improving the nation's air quality and the stratospheric ozone layer. Straightforwardly, protecting the air quality means dealing with pollution and preventing it which is directly connected to the reduction in greenhouse gases emissions, including carbon dioxide and methane. Regarding insurance industry regulation and climate change, the National Association of Insurance Commissioners (NAIC), completed this year the first full year of work by its Climate and Resiliency Task Force, where many additional states signed up to require domiciled insurers to answer to a climate disclosure survey similar to the one developed by the Financial Stability Board's (FSB) TCFD. At state level, the only one that has a quite developed climate change regulatory framework is the state of New York. For insurers domiciled there, the New York Department of Financial Services (NYDFS), which in this case is the insurers' primary solvency regulator, requires insurers to incorporate climate change into governance structures and risk management processes; moreover, the NYDFS will monitor insurer compliance by reviewing the answers given to the above mentioned NAIC's climate disclosure survey and require information to insurers which will not submit the survey. According to the National Law Review, however, it is unlikely that other states will follow the virtuous example of New York to subject domestic insurers to mandatory climate change disclosures and monitoring them, particularly in the Republican-governed states, going along with the view of the former president Trump. Only a few circumstances could make these states change their mind. Firstly, natural catastrophe events or climate related conditions in general could make governors more incline to address the climate mitigation challenge. Furthermore, sustainable economic activities that could become a major business in the upcoming years, also thanks to the implementation of the IRA, and tax advantages included in the IRA for people buying electric vehicles or businesses installing renewable power equipment. Finally, geopolitical crises that could bring up spikes in prices of fossil fuels could make governors to shift to renewable sources of energy.

4.5.2 Europe

European Member States' institutions have committed to turn the European Union into the first climate neutral continent by 2050. To do that, they are aiming to reduce greenhouse gases emissions by at least 55% by 2030 – a significant step up from the previous target of cutting emissions by 40% – compared to 1990 levels by signing the European Green Deal, which has then been transferred into law with the EU Regulation 2021/1119 of the European Parliament and of the Council, the so-called European Climate Law. This law sets out some goals to be met by Member States. Apart from the previous mentioned reduction in greenhouse gases emissions, with both a short-term view and a medium-long term one, (i.e., 2030 and 2050), the objectives for the European Union should be to create a sound system of monitoring of the progress made in this area while being able, at the same time, to intervene and strengthen the actions required to meet the reduction in emissions, to provide a relative financial stability for investors and economic actors and to ensure that the transition to a low-carbon economy and climate neutrality with respect to greenhouse gases emissions is irreversible. In addition, this law has included a process for setting climate target for 2040. In particular, the European Commission should make a legislative proposal to promote an amendment to the Regulation to include this new target basing it on a detailed impact assessment, taking into consideration some key elements[19]. For instance, the best and most recent available scientific evidence (including IPCC's report), the need to ensure a just and socially fair transition for all, both between and within Member States and the existing information on the projected Union greenhouse gas budget for the 2030-2050 period.

The insurance sector in the European Union is supervised by one of the three European Supervisory Authorities (ESAs), in particular by EIOPA. In 2021, EIOPA published an

[19] For the complete list of considerations, see article 4, comma 5 of EU Regulation 2021/1119

opinion stating its expectations about the supervision of national supervisors of insurers investment undertakings and their climate-change scenario analysis as part of their Own Risk and Solvency Assessment (ORSA). EIOPA encourages a forward-looking management of the risks arising from climate change, because it is accounted as an essential factor to establish a guarantee the long-term solvency and viability of the industry. The issued opinion provides practical guidance on how to manage climate-change scenarios, as EIOPA expects insurers to develop a sophisticated scenario analysis, taking into account some variables, like size, nature and complexity, of their climate change risk exposures arising from their investments.

In addition, alongside with the opinion by EIOPA, the European Commission issued a proposal requiring insurance companies to assess their material exposures to climate change risks and to assess the impact on the business at least every three years using at least two long-term climate change scenarios (in particular evaluating how the business would evolve in a below 2°C scenario or exceeding 2°C).

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5 Reinsurance industry

The insurance industry is in place to transfer the risk initially borne by individuals and businesses to insurance companies that accept the risk in exchange for a certain amount of money. However, insurance companies may need and/or want to get some insurance too. When, for example, risks are highly correlated (e.g., geographical concentration of the properties in an earthquake scenario), insurance companies may decide to transfer again part of the risk to prevent the portfolio of policies to face an overall risk and consequent losses that could cause the default of the company. This is a process named reinsurance, basically being an insurance company that signs an insurance policy with another insurance company transferring part of the risk coming from policies signed with its clients. As other common insurance policies, reinsurance is based on a transfer of risk from one party, the cedant, to the other, the reinsurer, in exchange for an amount of money, the reinsurance premium in this case. The difference is that this premium is calculated in a slightly different way than the one seen in chapter 4 (as we will see later on in this chapter). Reinsurance is in particular aimed at reducing the impacts arising from random fluctuations and extreme catastrophic events. It is important to understand the path of those fluctuations; in fact, if they are purely random, the reinsurer is more likely to accept to cover these risks. On the other hand, if they turn out to be systematic deviations, the reinsurer could probably deny providing coverage, since systematic deviation is a symptom of possible portfolio ruin. Moreover, reinsurance can help cedants, in particular by exploiting technical advice provided by the reinsurers in terms of expertise in the sector, and by having a sort of financial benefit, since the cedant and the reinsurer share policy and portfolio expenses.

Regarding this type of insurance coverage, the IAIS collects data on the global reinsurance market and publishes the annual Global Insurance Market Report (GIMAR). This report analyses the overall size of both insurance and reinsurance markets, comprising primary insurance, primary reinsurance, and secondary reinsurance (i.e.,

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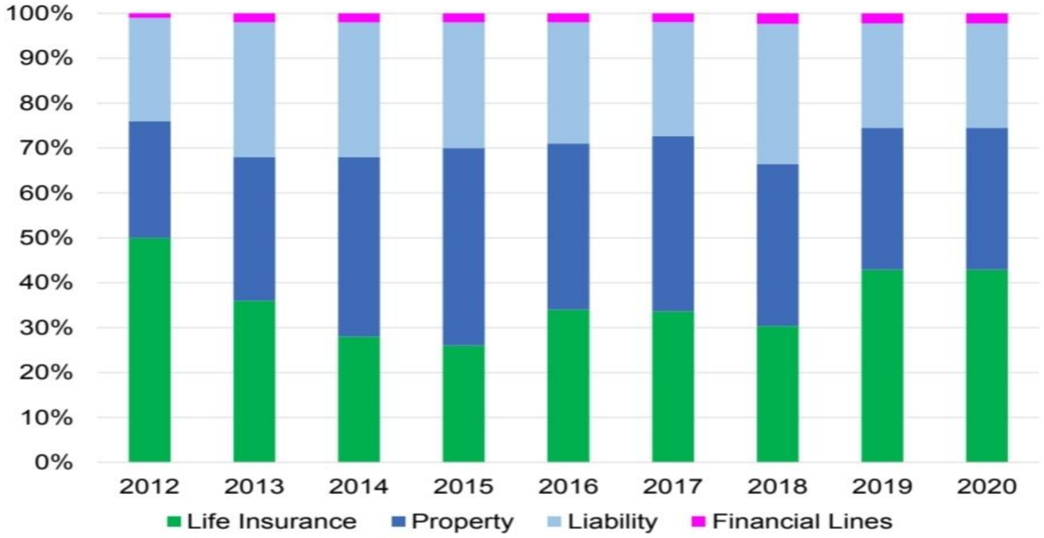
when reinsurers take on reinsurance themselves). The GIMAR's estimates in 2021 computed a 7% share to the reinsurance market as of all global gross insurance premiums. Moreover, it further divides the global reinsurance market in terms of lines of business, for the period 2012-2020, (i.e., life reinsurance, property reinsurance, liability reinsurance and financial lines of reinsurance) as a share of the total gross reinsurance premiums, as seen in the following figure from the Global Insurance Market Report 2021.



The figure shows that financial lines of reinsurance has basically been stagnant as a minor share of the market, property reinsurance and liability reinsurance have slightly diminished in percentage in the period considered, while life insurance has increased its market share in insurance from 2014 to 2020. However, non-life reinsurance still constitutes more than half of the reinsurance market. Furthermore, when looking at the reinsurers' asset allocation and comparing different geographic areas, it does not provide evidence of significant differences among different geographies. In fact, the main asset classes held by reinsurers are equities, corporate and sovereign debt and the first two account for almost half of the total reinsurers' assets across all regions considered (i.e., Asia and Oceania, Europe and Africa, Americas). Interestingly, there is a difference between Americas and Europe and Africa in the debt holdings; in fact, in the Americas reinsurers hold a significantly lower part of their assets in sovereign debt, compensating with a higher portion in corporate debt, than what European and African reinsurers do.

5.1 Reinsurance agreement

The cedant and the reinsurer can sign a reinsurance agreement by which they commit themselves to, respectively, cede part of the risks and to cover them. This arrangement can take three different forms:

- facultative for both parties. In this case it is up to the cedant to decide whether to transfer the risk or not and to the reinsurer whether to accept to cover it or not. The reinsurer must underwrite the individual risk, just as the cedant does in its normal business. This type of arrangement is usually adopted with single risks and high exposures;
- obligatory for both parties. The cedant transfers mandatorily a portion of the risks underwritten and the reinsurer must cover it;
- facultative for the cedant, obligatory for the reinsurer. As in the first case, it is up to the cedant to decide whether to transfer the risk or not but, if he decides to do so, the reinsurer must accept it and provide coverage.

The last two types of agreements, since they constitute a bilateral relationship between the two parties where at least one of them is required to take some actions, need to have a background contract that regulates the relationship, which takes the form of a reinsurance treaty. The reinsurance treaty covers the major aspects of the arrangement between the two parties, i.e., the time span of the reinsurance coverage, the form of reinsurance, eventual limitations to the coverage and the calculation of the reinsurance premium. The limitations in a reinsurance treaty could be either "vertical" or "horizontal". Vertical limitations refer to the reinsurer's payment with respect either to each single claim suffered by the cedant or to each single policy; horizontal limitations instead refer to the total reinsurer's payment along the time span of the insurance coverage provided. In the majority of these reinsurance treaties, once the contract and its terms have been established and cleared, all policies held by the cedant that fall within those terms are covered by the reinsurer, unless the agreement is solved. Both facultative arrangements and agreements that need to be regulated by a contract can take proportional and non-proportional structures, depending on the way in which losses are shared between the cedant and the reinsurer.

5.1.1 Proportional reinsurance

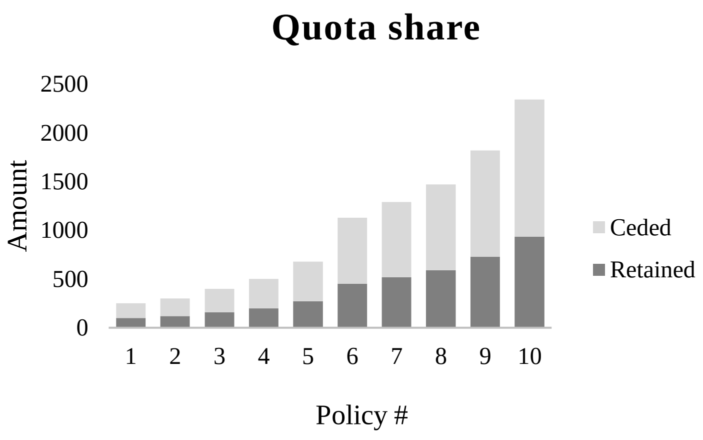
Proportional reinsurance is a form of agreement between the cedant and the reinsurer where the two parties share both the premium collected by the cedant from the policyholder and the related potential losses arising from that policy. There are two main types of reinsurance that fall into the proportional agreements, which are *quota share* (also called *Pro-rata*) and *surplus* reinsurance.

Quota share reinsurance applies a fixed and invariable percentage, meaningly the quota share ceded to the reinsurance company, to the entire portfolio of risks and the premiums and losses are split accordingly to this percentage. All the sums insured by the cedant are reduced in the same proportion. Defining as a $(0<a<1)$ the percentage of retained risk by the cedant, the overall loss and amount of money to pay in case of a claim for the cedant will be X^{ret} and it will be equal to $aX^{(j)}$ in case of claim and zero otherwise ($X^{(j)}$ is the total loss covered by insurance for the policyholder), while the reinsurance company's total outflows will be X^{ced} and will be equal to $(1-a)X^{(j)}$ in case of claim by the policyholder and zero otherwise. Coherently, as the total loss $X^{(j)}$ is shared between the parties, the amount of premiums collected and the overall net profit for the cedant will be shared as well. The safety loading[20] is therefore split accordingly to the fixed percentage; m^{ret} will be equal to am, as it was for the loss, while m^{ced} will be $(1-a)m$.

[20] Recalling chapter 4.1, the safety loading charged to each insurance policy represents the net profit gained by the insurer in the signing of the policy

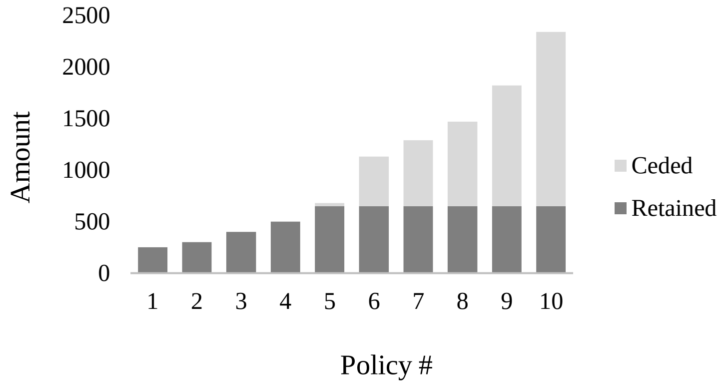
Surplus reinsurance relies on the so-called retention line, X^{ret}, which in this case is a fixed amount of the overall cedant's liability. Amounts of liabilities that are less than the retention line are fully covered by the cedant, while risks on which the cedant's liability exceed the retention line are ceded to the reinsurer, on the basis of the ratio between the amount in excess over the retention line and the overall cedant's liability. Therefore, to put in mathematical expressions, the amount retained by the cedant will be equal to the minimum amount between $X^{(j)}$ and X^{ret}, while X^{ced} will be equal to the maximum amount between 0 (i.e., the case in which the overall cedant's liability does not exceed the retention line) and $X^{(j)}$ - X^{ret}. Hence, the percentage a of retention of risks in this proportional reinsurance arrangement will be equal to the minimum between 1 (i.e., the case in which the overall cedant's liability does not exceed the retention line and so the total liability is retained) and the ratio between X^{ret} and $X^{(j)}$.

The two types of proportional reinsurance are summarized in the following figures[21].



[21] The amount of the payments is purely random

Surplus

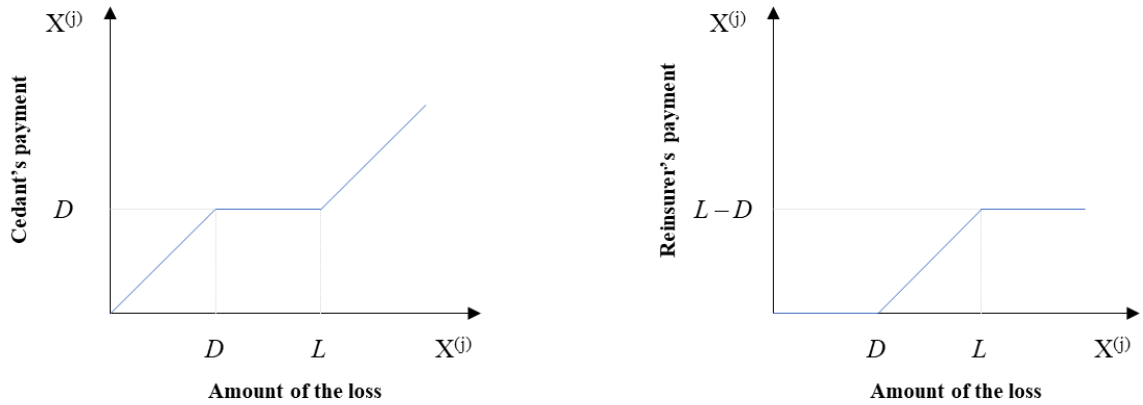


5.1.2 Non-proportional reinsurance

Non proportional reinsurance, unlike proportional which is based on the original liability and a proportional share of the losses, is based on a limited amount of coverage provided by the reinsurer. The main form of non-proportional reinsurance arrangement is the *Excess of Loss* reinsurance. This type of reinsurance involves setting a fixed limit, in terms of amount of the loss (similarly to what happens in *surplus*), denominated “deductible”, up to which the cedant bears all the losses arising from claims and a fixed limit of coverage, denominated “layer”, up to which the reinsurer provides coverage against the cedant’s portfolio ruin. For claim amounts in excess of the layer the cedant bears the losses. Assuming the deductible is an amount equal to D and the layer is a higher amount L (it could also be a multiple of D), if the total loss $X^{(j)}$ is

- lower than D, the cedant bears all the loss
- in between D and L, the cedant pays an amount equal to D and the reinsurer covers the rest of the loss, namely $X^{(j)} - D$;
- higher than L, the cedant pays up to D and the amount over L, $(X^{(j)} - L)$, while the reinsurer pays $L - D$.

The structure of the *Excess of Loss* reinsurance is summarized in the following figure.



To avoid the risk of incurring in extreme losses, that is one of the risks in the climate change context with arising frequency of climate disaster events, or to the fact that a number of insureds can suffer from a single exogenous accident such as an explosion or fire, the *Excess of Loss* reinsurance could be furtherly layered by signing multiple reinsurance agreements of these type, where other reinsurers intervene in the third case of the simple *Excess of Loss* above mentioned, i.e., for losses higher than L they provide coverage against the cedant's portfolio ruin.

5.2 Asymmetric information in reinsurance

As it was for the common practices of primary insurance policies signing, also the reinsurance market presents the common forms of asymmetric information, i.e., moral hazard and adverse selection. Focusing first on moral hazard, coherently with traditional insurance practices, it is costly for the reinsurer to monitor the activity of the primary insurer and his action to mitigate losses. In the case of catastrophic events, such as floods and earthquakes, the costs for the reinsurer could be significantly high. However, reinsurance business is usually carried out as a long-term relationship between primary insurer and the reinsurance company, so that the access to each other information is relatively easy, and the cost of monitoring is kept at reasonably low levels. When this is not the case, the cost of monitoring to reduce moral hazard could be high enough to cause the reinsurer to decide not to monitor the primary insurer's activity but to rely only on price control activity. An analysis conducted by Doherty and Smetters (2005) assessed the presence of moral hazard in the reinsurance market. The monitoring cost to the reinsurer determines his actions in order to prevent moral hazard: if this cost is high enough that the reinsurer has not the incentive to take on monitoring measures on the primary insurer's actions (and also if the monitoring cost is sufficiently low but the information acquired are not informative of primary insurer's actions), he will base his action only on price incentives to control moral hazard; on the other hand, when the monitoring cost is sufficiently low and the monitoring provides adequate insights of the primary insurer's actions, the reinsurer will base his control over moral hazard by relying on monitoring activities rather than adopting price incentives. The authors found empirical evidence of their theory: in fact, among hundreds of property and liability insurance companies, the line of homeowners insurance presents moral hazard and the actions to control it depend on the type of the companies involved. In particular, discriminating between affiliates and nonaffiliates (i.e., companies are or are not part of the same financial group), monitoring has been proved to be the main action to prevent moral hazard, since the monitoring cost in this group is reasonably lower than nonaffiliates, even if price incentives are present in a minor extension. Between nonaffiliates, where the monitoring cost is higher, there is no evidence of monitoring controls, while price incentives are the main driver of moral hazard prevention. The same evidence is reported for the liability line if insurance: affiliates mainly rely on monitoring activity while nonaffiliates engage in price control incentives.

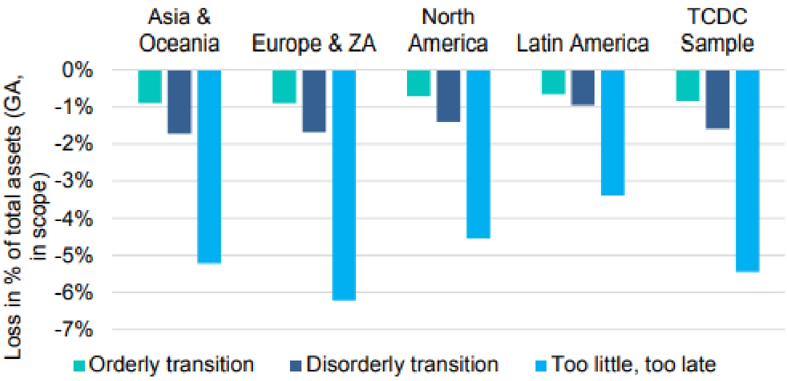
As the case for primary insurance, when it comes to reinsurance there is adverse selection in some extent, since the cedant has better information than the reinsurer about the risk being ceded. As the severity and the frequency of the risk being ceded increase, the information asymmetry should increase as well, since the cedant would not like to give too many insights about the higher riskiness of the reinsurance. Again, adverse selection brings some costs for the reinsurer and these costs increase as the information asymmetry increases. This issue is addressed and mitigated by establishing long-term relationship between the cedant and the reinsurer, and by developing broader information flows between the two parties. Jean-Baptiste and Santomero (2000) and Garven et al. (2014) showed that long-term relationship allows the two parties to achieve a more efficient agreement on insurance and that the cedant not only demands more reinsurance as the relationship becomes longer, but also that he becomes more profitable and less incline to bankruptcy risk. As long as the relationship goes on in time, the informational asymmetry – and its negative impacts on the relationship – decreases over the period.

5.3 Reinsurance and climate change

As previously mentioned, reinsurance works to lower the risks of extreme losses for primary insurance providers by providing coverage in case of catastrophic events. In the context of climate change, we have seen that extreme events are becoming more frequent. As well as primary insurance, reinsurers have to deal with climate change, by accounting for its impact when it comes to pricing their products, since climate change can cause high volatility of losses. An adequate pricing methodology is therefore crucial to overcome unexpected changes in the earnings and outflows of reinsurers, and to maintain their financial stability. Alongside direct climate change catastrophes, reinsurers need to take into consideration secondary perils too and to evaluate their exposures to climate change physical and transition risks. According to a survey conducted by S&P Global Ratings, which analyses the action of 17 rated insurers, all of the respondents well know the importance of climate change consideration in their decision-making process and have put in place some actions to account for climate change in their risk management tools. Although there are some differences in the climate change consideration between respondents, due to different market conditions, regulations and so on, the common line is to view climate change as a main factor in strategic business decisions, considering climate change in property insurance decision-making either of medium or high importance. Moreover, according to Joss Matthewman,

a senior director for Climate Change Product Management & Strategy at RMS (Risk Management Solutions), all the clients of RMS are committed to strategies involving the creation of climate resilient businesses, with an increasing understanding of climate change risks and their role in climate mitigation and adaptation. Most reinsurers and other companies in the business demonstrate a view that is a little bit in contrast with the regulatory perspective seen in the previous chapter. In fact, looking at the Paris Agreement goals, they are set with a long-term view when talking about abating carbon emissions and reducing the increase in temperature. NDCs are also implemented with a long-term view, most of them have objectives of reduction of greenhouse gases emissions by 2050 and also by 2100. This cannot be always in accordance with the view of companies, which of course do not avoid looking at shorter term (i.e., 5-10 years).
Recalling back the climate scenarios developed by NGFS and their impacts in terms of physical risk and transition risk, IAIS, in its GIMAR special edition on climate change of 2021, developed the percentage losses in insurance and reinsurance companies' assets with respect to an orderly transition towards a low-carbon economy, a disorderly one, and the worst-case scenario of *Too little, too late* and dividing by geographical areas. The results are reported in the following figure by IAIS, Global Insurance Market Report (GIMAR) Special edition, The impact of climate change on the financial stability of the insurance sector, 2021[22].

[22] ZA stands for South Africa, TCDC stands for Targeted climate data collection.



As one would expect, *Too little, too late* is the worst scenario and hits with the highest magnitude the assets of European and South African insurers, which would decline by more than 6%; on the other hand, an orderly transition to a low carbon economy is the best-case scenario that would have the lowest impact on insurers' assets, which would decline in all different geographic areas by less than 1%.

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6 Empirical analysis

In the context of climate change, as seen in the previous chapters, people and businesses could be prone to acquire a higher amount of insurance coverage to protect themselves against increasing risk of their home being destroyed by climatic events or to cover against damages on business properties and the continuation of the business itself. The focus of the analysis is the US insurance market, in particular five different lines of insurance, which are *private passenger auto*, *commercial auto*, *homeowners*, *farmowners* and *commercial* insurance, each of them recorded at US State level. The data collected are from three main sources: the Insurance Information Institute (III) for the different amounts of gross written premiums collected in each US State, the National Center for Environmental Information (NCEI), in particular its National Oceanic and Atmospheric Administration (NOAA) for climate data in those states, and the Federal Reserve Economic Data (FRED) for other macroeconomic data that will be explained later.

The data about the amount of insurance coverage bought by policyholders, reported by the III, were divided, as said, at US State level and available from 2008 to 2021, each year had an annual sum of coverage acquired, i.e., every State counts 14 observations of amounts of premiums written by its inhabitants and businesses.

Alongside, climate data by NOAA is available at many levels (i.e., Nation, Region, State, Division, County and City). In order to have a coherent dataset, State level is the aim of the analysis. The data downloaded were on a monthly basis, so that from 2008 to 2021 each State had 168 observations; to make data comparable with gross premiums written, the temperature was calculated as the average of the 12 months in a year, so that each State had again 14 different average temperatures for each year considered. However, NOAA does not have data about Hawaii and Alaska, which instead are counted by the III; therefore, in the dataset these two States were not considered. The dataset comprises totally 48 States, each of them with 14 yearly observations, for a total of 672 observations. The complete list of the States that entered the dataset is reported in Table 1 in the Appendix.

Other main variables of interest are the levels of precipitations in the States considered and the Palmer Drought Severity Index (PDSI), an index that is representative of the level of moisture of the soil. Negative values refer to dry conditions (values < - 4 represent extremely dry ones) while positive values represent humid conditions (values > 4 represent extremely humid ones). Again, the values taken from NOAA are monthly values. However, with these variables a measure of deviation from the mean was constructed. In particular, I calculated the mean for every month (i.e., the mean between January values from 2008 to 2021, between February values and so on) in order to have an average of the values observed during that particular month over the 14-year period considered. Then, both for precipitation and for the PDSI, I computed the squared deviation from the mean.

$$sd_{i,j} = (v_{i,j} - n_j)^2$$

The value $sd_{i,j}$ is the squared deviation for the year i and month j, $v_{i,j}$ is the value registered in each different State in the year i and month j, while n_j is the computed average across all years for the same month as said before. Finally, to have annual values comparable to other data used, I computed the sum of all the sd_js for each year i. Therefore, in the end each State has 14 different values both for the precipitation levels and for the PDSI.

The regressions performed to study the impacts of climate change see the amount of insurance coverage as the dependent variable, while the three different climate variables are explanatory variables. In order to control for the significance of the coefficients, I used two different control variables in the model. The first one is represented by the GDP of each State, again detected on an annual basis from 2008 to 2021, to match the observations of premiums written and climate data. Since all values about premiums and GDP were on a nominal basis, to take into account the macroeconomic developments of this 14-year period and to have a more precise insight of the increase of both written premiums and GDP, real numbers were developed by adjusting all values for the annual inflation rate[23] registered in the US. The first year, 2008, was used as the starting point, therefore nominal and real 2008 values are equal;

[23] The annual inflation rate was observed in FRED database, as it was for GDP

the adjustment for inflation starts from 2009. The last corrective measure adopted for the GDP control variable and for the dependent variable was to transform real dollar values (i.e., data for written premiums and GDP) in their natural logarithm for three main reasons:

- the logarithm allows to reduce the scale and the interval of both the dependent and the independent variables and to avoid outliers to have a significant impact on the regression;
- the values were available in two different scales, i.e., in thousand dollars (for insurance premiums) and million dollars (for GDP). To avoid transforming GDP in thousand dollars and having huge numbers and probably high coefficients, the logarithm was useful to have comparable scales;
- on the other side, transforming insurance premiums in million dollars, thereby approximating the values, could have meant losing significance in the data collected.

The other control variable I used is a demographic trend of population growth. Data about resident population (in thousands of individuals) in every single State was taken again from FRED; in particular the data about population was transformed into natural logarithms to reduce the scale and the interval of the variable.

The rationale of using these two control variables is intuitively. When the GDP increases, it means that some components of it increases, consumption being one of them. Insurance purchasing can be seen as a part of the consumption component. Therefore, the increase in the insurance coverage purchased could be explained by the increase in GDP. The increase in population was used instead for a simple relation of the higher the resident population in a State, the higher is the number of potential policyholders that could purchase insurance coverage, thereby explaining the annual increase in written premiums collected in each State.

For each of the five lines of insurance coverage I computed the following final regression:

$$lnPremiums_{i,t,j} = c + \beta_1 * Avgtemperature_{t,j} + \beta_2 * PImeandev_{t,j} + \beta_3 * Precdev_{t,j} + \gamma_1 * lnGDP_{t,j} + \gamma_2 * lnPop_{t,j} + \varepsilon$$

where the dependent variable is different for each of the previously mentioned five categories of insurance premiums (inflation adjusted) collected in each business lines *i*, *c* is the constant term, *Avgtemperature* is the average temperature for year *t* in State *j* (*j* = 1,2,...,48), *PImeandev* and *Precdev* are the previously explained sums of the squared deviations from the mean (respectively for the PDSI and for the levels of precipitation) for each year *t* and each State *j*, *lnGDP* and *lnPop* are the two control variables explained above, for each year *t* and each State *j*. The main coefficients of interest are therefore β_1, β_2 and β_3. Since the model estimated considers a log-linear relationship between written premiums and the three explanatory variables related to climate change, the three β coefficient of the variables means that when the explanatory variable increases by one single unit, the dependent variable increases by β x 100%. In other words, for example, when the average temperature recorded increases by 1 °C, written premiums increase by β x 100%.

In the whole panel data, the approach adopted was to detect fixed effects among the data collected, so the regressions on all five business lines of premiums collected were performed using fixed effects in Stata. I used both State and year fixed effects because climate change is likely to affect all different States in a similar way in each year *t*.

This approach comes from a test that was performed for all five categories of insurance, the Hausman test, which allows to pick the correct model between fixed-effects and random-effects. The null hypothesis of this test assumes that the random-effects model is appropriate, while the alternative ones assumes that fixed-effects is the correct one to use. In all five lines of insurance, the p-value of this test is equal to zero, therefore the null hypothesis is rejected and the alternative one is accepted.

The main issue of this empirical analysis stands in the fact that climate change is a trend that is of course ongoing and quickly changing the environment, but the effects may need a long period of time to be evident. Therefore, a 14-year period seems to be a relatively short period of time to show evident impacts caused by climate change on the insurance industry. As an example, the average temperature is likely to change in a long period of time, as well as dry and wet seasons, which contribute to the values of the PDSI, do not become more intense year on year, but rather it takes a longer period of time to see the effects of climate change.

A practical example stands in the Paris Agreement itself. In fact, COP 21 agreed on limiting global warming to 2° C above pre-industrial levels. Even if there is no unanimous reference to when the pre-industrial period took place[24], the range for defining it varies from the second half of the 18th to the second half of the 19th century. The period of time considered for the increase of 2° C is quite large if compared to the time span considered in the analysis. Therefore, to evaluate a greater impact of climate variables on the insurance industry, this analysis should be repeated in the future, when more data will be available, both for written premiums collected in each State and for climate data from NOAA.

6.1 Empirical evidences

As it can be seen in the tables in the Appendix, when the regression takes into account State fixed effects (see tables 2, 3, 4, 5 and 6), some business lines of insurance are "hit" by the increase in temperature while some others do not. Furthermore, the other two variables of climate change are affecting insurance premiums but the impact is negligible. In particular, *homeowners* insurance line (Table 4 in Appendix) sees a significant coefficient of interest β at 95% confidence interval, while the other four do not have a significant impact of the variable *Avgtemperature* on the dependent variable. However, if the confidence interval is widened at 90% confidence, *farmowners* insurance line (Table 5 in Appendix) is impacted as well by the *Avgtemperature* variable. The results are reasonable if we think about what they mean, why they could be significant and why they could not in the other three lines (i.e., *private passenger auto*, *commercial auto*, and *commercial*, respectively Table 2, Table 3 and Table 6 in Appendix). From a citizen point of view, it is reasonable to assume that one is more concerned about damages on his/her home rather than his car when he/she has to choose between the two what to firstly insure for. From hurricanes and/or flood events both goods (homes and cars) are likely to suffer damages/be destroyed, but the dollar value of the loss is much higher for homes than for cars; therefore, a citizen should be more incline to acquire

[24] IPCC's Fifth Assessment Report considered the second half of the 19th century as the reference period to assess global warming, even if not formally defining it as "pre-industrial period"

insurance for his/her home first.

Furthermore, from a farmer point of view, the increasing frequency of occurrence of climatic events, ranging from hurricanes and extreme rains to heatwaves and consequent droughts, can harm the source of income of these people. Both types of events have the potential to cause severe damages and to disrupt the agriculture and the harvest of farm owners, that could be left with nothing to sell and consequently with no income on their products.

The other lines of insurance, even if they should be concerned about climate change too, show no significance on the coefficients of interest of the analysis. Even though climate change has the potential to harm the goods of these lines, as said before the average values involved are reasonably lower than the average values of two lines that show significance; therefore, this is not a result that goes in contrast with the hypotheses of the analysis.

The estimates are not significant in *private passenger auto*, *commercial auto*, and *commercial* since the p-value of test statistic on the three coefficients β is always bigger than α, set at 5% (or 0.05 to be compared with the values reported in the table). Another way to look at it is by judging the 95% confidence interval of the coefficients of the three variables related to climate change, *Avgtemperature*, *PImeandev* and *Precdev*; in these three cases all the three intervals for all three lines of insurance always span from negative to positive values, meaning that the null hypothesis of the coefficients being equal to zero cannot be rejected.

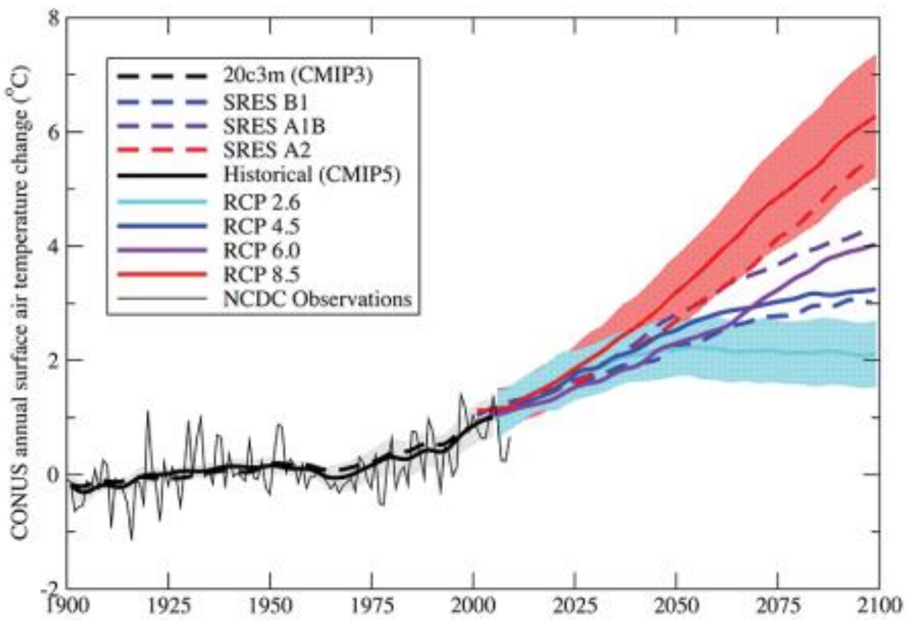
In contrast, *homeowners* regression shows that the p-value of the test statistic related to *Avgtemperature* is below 0.05 and the 95% confidence interval contains strictly positive values, thereby bringing to reject the null hypothesis of the coefficient being equal to zero, meaning that:

- the explanatory variable has some impacts on the dependent variable;
- the relationship between the two variables is strictly positive.

As far as *farmowners* line of insurance is concerned, the impact of *Avgtemperature* is, as said, not statistically significant at 95% confidence level, but it is indeed at 90% confidence level, since the p-value of the test statistic is 0.066, higher than 0.05 but lower than 0.1. Therefore, the change in the average temperature recorded affects the levels of insurance coverage purchased by farmers across USA with an acceptable confidence interval.

Looking at the magnitude of those significant coefficients, an increase in the recorded temperature of 1°C is responsible for the increase in the amount of *homeowners* premiums written of ~ 0.0125 x 100% = ~ 1.25%, while *farmowners* insurance has a 90% confidence interval significant increase of ~ 0.0143 x 100% = ~ 1.43% in the amount of premiums written with an increase of 1°C in the average temperature.

From the figure below, taken from Wuebbles et al., 2014, it can be projected how much the premiums will increase in the future, basing on different scenarios for the contiguous United States. The scenarios projected are developed by using two different Coupled Model Intercomparison Projects (CMPI3 and CMPI5) that use respectively Special Report on Emissions Scenarios (SRES) and Representative Concentration Pathways (RCP).



Projected CMIP3 and CMIP5 annual temperature changes (°C) over CONUS for the multimodel average (lines) and range (shown for RCP8.5 and RCP2.6 only, for illustrative purposes) relative to the 1901–60 average. Shaded regions for the higher RCP8.5 and lower RCP2.6 scenarios represent one standard deviation across the models. The total multimodel range is larger. The standard deviation range in intermediate scenarios (RCP4.5 and RCP6.0) is similar but omitted here for clarity

It can be seen that, considering RCP 2.6 as the lower bound scenario and RCP 8.5 as the upper bound scenario, from the period considered in the analysis to 2100, the best-case scenario (the light blue line) entails an increase of ~ 1° C, that means *homeowners* and *farmowners* real premiums would increase by 1.25% and 1.43% respectively. Looking at the worst-case scenario, RCP 8.5, from the period of analysis to 2100, the temperature is expected to increase by ~ 5° C, meaning that *homeowners* and *farmowners* real premiums would increase by 6.25% and 7.15% respectively.

These results for the variable related to temperature increase, when using State fixed effects, are coherent with the view presented in the whole work, with climate change being a threat for the insurance industry in the upcoming future, both from people and from insurance companies' point of view. An additional insight of the upcoming threats of climate change comes from the Union of Concerned Scientists; in fact, it has predicted that almost every State in the US will suffer an increase in the number of homes at risk due to sea level rise by 2045, and a further major increase by 2100. Coastal States are straightforwardly more concerned and more exposed to this particular type of risk. This of course goes along with an increase in the number of people that will be threatened by this climatic event and an increase of the total home value at risk of sea level rise.

However, when looking at year fixed effects results (tables 2.1, 3.1, 4.1, 5.1 and 6.1 in Appendix), none of the coefficients related to climate variables turns out to be significant, neither at 95% nor at 90% confidence interval. That represents another issue related to this analysis, since none of the variables capture climate change effects in the amount of insurance coverage. This issue could be related to misrepresentation of the variables considered. For example, some lines of insurance could not be worried about the average temperature recorded in a given year, but rather be concerned about extreme high or extreme low temperatures. *Farmowners*, for instance, could be more incline to purchase insurance coverage when anomaly high temperatures in summer induce prolonged droughts that threat the income of the agricultural sector.

It could also be that none of the variables used in the analysis are evaluated from policyholders when they decide whether to purchase insurance coverage or not. They could be incline to acquire more insurance coverage only if a severe climatic event hit them directly or nearly directly. For instance, if in the period 2008-2016 they were not particularly involved into climatic events and then suddenly in 2017 they were hit by one of the three hurricanes that turned out to be three of the ten costliest hurricanes in the USA, these events could function as a trigger to purchase insurance coverage.

On the other hand, it could also be that not only policyholders react to climatic events, but insurance companies become more concerned too. In this other case, the increase in the amount of premiums written during the period examined would be supply-driven, meaning that the single policy is on average more expensive over the years. NAIC reports every year a picture of the *homeowners* insurance industry in the US, by developing some tables of total insurance contracts in place every year for this type of insurance. To study the supply effect of the increase in total premiums written, I compared total insurance contracts signed by homeowners in 2015 and 2020 for every State considered in the previous analysis (i.e., the same States of Table 1 in Appendix). It turned out that in every State the number of homeowners policies increased in this five-year period. Overall, for the 48 States considered, in 2015 there were ~ 82.9 million policies in place for all types of *homeowners* insurance, while in 2020 this number rose to ~ 91.1 million, an increase of ~ 9.95%. Total premiums collected in 2015 and 2020 for *homeowners* insurance were ~ $88.44 billion and ~ $109.44 billion respectively. Using 2015 as the baseline year and adjusting 2020 premiums for inflation in that five-year period, the total amount of premiums collected is ~ $100.06 billion. Hence, the percentage increase stands at ~ 13.1%, higher than the percentage increase in the number of policies, therefore it is reasonable to assume that the increase in total premiums written is related to an average higher premium charged to the single policyholder rather than to an increase in the demand side of insurance coverage. When breaking down the number of policies and total premiums written for each of the 48 States considered, and doing the same comparison done for the whole USA, it turns out that the effect is the same for 36 out of the 48 States. The 12 States in which the increase in the written premiums did not meet the increase in the number of policies outstanding are Alabama, Connecticut, Indiana, Kansas, Kentucky, Missouri, New Jersey, New York, North Dakota, Oklahoma, South Carolina and West Virginia. In the other 36 States the inflation adjusted percentage increase in *homeowners* premiums collected is higher than the percentage increase in the number of policies outstanding. Therefore, in 75% of the States the increase in the insurance coverage purchased is more supply-driven than demand-driven.

7 Conclusion

This paper has analyzed the implications of climate change on our society and in particular on the insurance industry. Severe climatic events bring with themselves physical risk due to the damages on properties and businesses. The transition to a low-carbon economy is therefore crucial in order to keep global warming at an appropriate level. The annual Conference of Parties is focused on actions to achieve the goal of limiting global warming and consequently reducing the impacts from climate change. The transition from the current economy to a new one with zero or near zero greenhouse gases emissions has an implicit transition risk that is high for businesses that base their activities on fossil fuels and non-renewable sources of energy, while it is low for the ones that have already in place actions to mitigate the reduction in emissions and base their activities on renewable sources of energy. Insurance companies on their own could choose to insure themselves, through reinsurance, for example in the case in which the risks are too concentrated in terms of geography or other criteria that could cause a high number of claims and amount of insured losses if a climatic event hits. Both insurers and reinsurers are main actors in combating climate change, since they are themselves exposed to clients that face both physical and transition risk and have a role in climate adaptation (i.e., actions of adaptation to the impacts on buildings and properties caused by climate change) and mitigation (i.e., action to be performed to reduce greenhouse gases emissions and achieve the goals of the Paris Agreement).

Global warming and climate change, as said, have impacts on the insurance industry, since more frequent climatic events have severe consequences on the economy as a whole. The increase in the average temperature is one of the main drivers of climate change and hence one of the main factors to be concerned of, as well as precipitation levels. Therefore, the focus of the data analysis was the impact of climate change (with three variables, i.e., average temperature and a measure of deviation from the mean for precipitation levels and for the PSDI, capturing different effects of climate change) in the US insurance market. Five different lines of insurance were examined and the evidence shows that only the temperature

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variable has a positive impact on the amount of insurance coverage purchased by two of the five lines, i.e., *homeowners* and *farmowners* insurance. On the other hand, analyzing the supply side of the industry, it seems that insurance companies are more reactive in the risk assessment, since the amount of insurance coverage purchased in *homeowners* insurance is more supply-driven than demand-driven, i.e., it is not related to more people buying insurance coverage but rather it is due to a higher average price for a single policy. This means that the increased riskiness related to climate change affects the amount of income that *homeowners* spend to cover against damages in general.

Homeowners and *farmowners*, between the five categories analyzed (the other three are *private passenger auto*, *commercial auto* e *commercial insurance*), are the most likely to be impacted by climate change, hence the results of the analysis are coherent with the view presented in the paper.

Many studies have been conducted in the field of climate change and insurance sector and further ones will be conducted as well, may this paper be a source of inspiration for follow-up studies about this topic.

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8 Appendix

Table 1

List of States		
Alabama	Maine	Ohio
Arizona	Maryland	Oklahoma
Arkansas	Massachusetts	Oregon
California	Michigan	Pennsylvania
Colorado	Minnesota	Rhode Island
Connecticut	Mississippi	South Carolina
Delaware	Missouri	South Dakota
Florida	Montana	Tennessee
Georgia	Nebraska	Texas
Idaho	Nevada	Utah
Illinois	New Hampshire	Vermont
Indiana	New Jersey	Virginia
Iowa	New Mexico	Washington
Kansas	New York	West Virginia
Kentucky	North Carolina	Wisconsin
Lousiana	North Dakota	Wyoming

Private passenger auto

Table 2 (State fixed effects)

```
. xtreg lnppaliabilityia avgtemperature pimeandev precdev lngdp lnpop, fe

Fixed-effects (within) regression               Number of obs     =        672
Group variable: state1                          Number of groups  =         48

R-squared:                                      Obs per group:
     Within  = 0.1977                                         min =         14
     Between = 0.9545                                         avg =       14.0
     Overall = 0.9331                                         max =         14

                                                F(5,619)          =      30.51
corr(u_i, Xb) = -0.9417                         Prob > F          =     0.0000

------------------------------------------------------------------------------
lnppaliabili~a | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
---------------+----------------------------------------------------------------
avgtemperature |  -.0121576   .0096051    -1.27   0.206    -.0310202     .006705
     pimeandev |  -.0000865    .000116    -0.75   0.456    -.0003144    .0001413
       precdev |   .0000564   .0000696     0.81   0.418    -.0000802     .000193
         lngdp |   .2653805    .088872     2.99   0.003     .0908534    .4399076
         lnpop |   1.479168   .3794434     3.90   0.000     .7340155     2.22432
         _cons |  -1.351551   2.315088    -0.58   0.560     -5.89793    3.194828
---------------+----------------------------------------------------------------
       sigma_u |  .69969586
       sigma_e |  .16912247
           rho |  .94480182   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0: F(47, 619) = 20.22                    Prob > F = 0.0000
```

Table 2.1 (year fixed effects)

```
. xtreg lnppaliabilityia avgtemperature pimeandev precdev lngdp lnpop i.year, fe

Fixed-effects (within) regression               Number of obs     =        672
Group variable: state1                          Number of groups  =         48

R-squared:                                      Obs per group:
     Within  = 0.2656                                         min =         14
     Between = 0.9567                                         avg =       14.0
     Overall = 0.9364                                         max =         14

                                                F(18,606)         =      12.17
corr(u_i, Xb) = -0.9684                         Prob > F          =     0.0000

------------------------------------------------------------------------------
lnppaliabili~a | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
---------------+----------------------------------------------------------------
avgtemperature |  -.0037526   .0140477    -0.27   0.789    -.0313406    .0238354
     pimeandev |  -1.87e-06   .0001234    -0.02   0.988    -.0002442    .0002405
       precdev |  -.0000298   .0000713    -0.42   0.676    -.0001699    .0001103
         lngdp |   .5096783   .1659806     3.07   0.002     .1837113    .8356454
         lnpop |   1.455433   .3862641     3.77   0.000     .6968537    2.214011
```

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year						
2009	.0147314	.0340706	0.43	0.666	-.0521793	.0816422
2010	-.0061264	.0345481	-0.18	0.859	-.0739748	.0617221
2011	-.0491788	.0357991	-1.37	0.170	-.1194842	.0211266
2012	-.066877	.0427081	-1.57	0.118	-.1507509	.0169969
2013	-.0732404	.037273	-1.96	0.050	-.1464405	-.0000404
2014	-.0839533	.0403308	-2.08	0.038	-.1631585	-.0047481
2015	-.0650874	.0438927	-1.48	0.139	-.1512876	.0211128
2016	-.0360982	.047552	-0.76	0.448	-.1294848	.0572884
2017	-.0120181	.0493448	-0.24	0.808	-.1089257	.0848895
2018	-.0138622	.0523858	-0.26	0.791	-.116742	.0890176
2019	-.0387392	.0561367	-0.69	0.490	-.1489853	.0715069
2020	-.173859	.0563336	-3.09	0.002	-.2844917	-.0632262
2021	-.2007742	.0676749	-2.97	0.003	-.33368	-.0678684
_cons	-4.188257	2.554921	-1.64	0.102	-9.205832	.8293178
sigma_u	.92872592					
sigma_e	.16353885					
rho	.96992505	(fraction of variance due to u_i)				

F test that all u_i=0: F(47, 606) = 21.61 Prob > F = 0.0000

Commercial auto

Table 3 (State fixed effects)

```
. xtreg lncaliabilityia avgtemperature pimeandev precdev lngdpia lnpop, fe

Fixed-effects (within) regression               Number of obs     =        672
Group variable: State1                          Number of groups  =         48

R-squared:                                      Obs per group:
     Within  = 0.4355                                         min =         14
     Between = 0.9653                                         avg =       14.0
     Overall = 0.9330                                         max =         14

                                                F(5,619)          =      95.51
corr(u_i, Xb) = -0.9934                         Prob > F          =     0.0000

------------------------------------------------------------------------------
lncaliabilit~a | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
---------------+----------------------------------------------------------------
avgtemperature |  -.0108747   .0093687    -1.16   0.246    -.0292731    .0075237
     pimeandev |   -.000032   .0001139    -0.28   0.779    -.0002557    .0001918
       precdev |   -.000089   .0000678    -1.31   0.190    -.0002222    .0000442
       lngdpia |   1.237739   .1458954     8.48   0.000     .9512289    1.524249
         lnpop |   1.495062   .3567902     4.19   0.000     .7943961    2.195728
         _cons |   -14.8565   1.808493    -8.21   0.000    -18.40803   -11.30498
---------------+----------------------------------------------------------------
       sigma_u |  1.7896007
       sigma_e |  .16604091
           rho |  .99146516   (fraction of variance due to u_i)
--------------------------------------------------------------------------------
F test that all u_i=0: F(47, 619) = 16.07                    Prob > F = 0.0000
```

Table 3.1 (year fixed effects)

```
. xtreg lncaliabilityia avgtemperature pimeandev precdev lngdp lnpop i.year, fe

Fixed-effects (within) regression               Number of obs     =        672
Group variable: state1                          Number of groups  =         48

R-squared:                                      Obs per group:
     Within  = 0.5809                                         min =         14
     Between = 0.9691                                         avg =       14.0
     Overall = 0.9465                                         max =         14

                                                F(18,606)         =      46.67
corr(u_i, Xb) = -0.9703                         Prob > F          =     0.0000

------------------------------------------------------------------------------
lncaliabilit~a | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
---------------+----------------------------------------------------------------
avgtemperature |   .0068254   .0124203     0.55   0.583    -.0175666    .0312174
     pimeandev |  -.0000528   .0001091    -0.48   0.629     -.000267    .0001615
       precdev |  -.0000228   .0000631    -0.36   0.718    -.0001466    .0001011
         lngdp |   .4962945    .146752     3.38   0.001     .2080902    .7844989
         lnpop |   1.195739   .3415161     3.50   0.000     .5250402    1.866438
```

year						
2009	-.0776072	.0301236	-2.58	0.010	-.1367665	-.0184479
2010	-.1444665	.0305457	-4.73	0.000	-.2044548	-.0844782
2011	-.1988754	.0316519	-6.28	0.000	-.2610361	-.1367148
2012	-.2093561	.0377605	-5.54	0.000	-.2835134	-.1351989
2013	-.1716747	.032955	-5.21	0.000	-.2363947	-.1069548
2014	-.1544864	.0356586	-4.33	0.000	-.2245158	-.0844569
2015	-.127421	.0388078	-3.28	0.001	-.2036351	-.051207
2016	-.1263536	.0420431	-3.01	0.003	-.2089216	-.0437857
2017	-.1387669	.0436283	-3.18	0.002	-.2244479	-.0530858
2018	-.0447215	.046317	-0.97	0.335	-.1356828	.0462398
2019	.0194819	.0496334	0.39	0.695	-.0779924	.1169562
2020	-.0258124	.0498074	-0.52	0.604	-.1236286	.0720037
2021	.0582935	.0598349	0.97	0.330	-.0592155	.1758024
_cons	-3.496637	2.258938	-1.55	0.122	-7.932934	.939661
sigma_u	.7712151					
sigma_e	.14459316					
rho	.96604212	(fraction of variance due to u_i)				

F test that all u_i=0: F(47, 606) = 16.86 Prob > F = 0.0000

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Homeowners

Table 4 (State fixed effects)

```
. xtreg lnhomeownersmultipleperilia avgtemperature pimeandev precdev lngdpia lnpop, fe

Fixed-effects (within) regression               Number of obs     =        672
Group variable: State1                          Number of groups  =         48

R-squared:                                      Obs per group:
     Within  = 0.7232                                         min =         14
     Between = 0.9597                                         avg =       14.0
     Overall = 0.9511                                         max =         14

                                                F(5,619)          =     323.53
corr(u_i, Xb) = -0.9925                         Prob > F          =     0.0000

------------------------------------------------------------------------------
lnhomeowners~a | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
---------------+----------------------------------------------------------------
avgtemperature |   .0125567   .0039881     3.15   0.002     .0047249    .0203885
     pimeandev |  -.0000874   .0000485    -1.80   0.072    -.0001827    7.85e-06
       precdev |  -.0000762   .0000289    -2.64   0.009    -.0001329   -.0000195
       lngdpia |   .4408481   .0621047     7.10   0.000     .3188867    .5628096
         lnpop |   2.275536   .1518783    14.98   0.000     1.977277    2.573795
         _cons |  -10.63648   .7698384   -13.82   0.000    -12.14829   -9.124669
---------------+----------------------------------------------------------------
       sigma_u |    1.76986
       sigma_e |  .07068023
           rho |   .9984077   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0: F(47, 619) = 110.58                   Prob > F = 0.0000
```

Table 4.1 (year fixed effects)

```
. xtreg lnhomeownersmultipleperilia avgtemperature pimeandev precdev lngdp lnpop i.year, fe

Fixed-effects (within) regression               Number of obs     =        672
Group variable: state1                          Number of groups  =         48

R-squared:                                      Obs per group:
     Within  = 0.8822                                         min =         14
     Between = 0.9553                                         avg =       14.0
     Overall = 0.9538                                         max =         14

                                                F(18,606)         =     252.18
corr(u_i, Xb) = -0.6227                         Prob > F          =     0.0000

------------------------------------------------------------------------------
lnhomeowners~a | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
---------------+----------------------------------------------------------------
avgtemperature |   -.005354   .0040029    -1.34   0.182    -.0132153    .0025073
     pimeandev |  -.0000292   .0000352    -0.83   0.406    -.0000983    .0000398
       precdev |   2.75e-06   .0000203     0.14   0.893    -.0000372    .0000427
         lngdp |  -.0168246   .0472966    -0.36   0.722    -.1097099    .0760606
         lnpop |   1.192669    .110067    10.84   0.000     .9765096    1.408828
```

year						
2009	.045813	.0097085	4.72	0.000	.0267466	.0648795
2010	.072609	.0098446	7.38	0.000	.0532754	.0919426
2011	.0761194	.0102011	7.46	0.000	.0560857	.0961532
2012	.1110602	.0121698	9.13	0.000	.0871601	.1349603
2013	.1417318	.0106211	13.34	0.000	.1208733	.1625904
2014	.1655141	.0114924	14.40	0.000	.1429444	.1880838
2015	.2056374	.0125073	16.44	0.000	.1810744	.2302003
2016	.2170895	.0135501	16.02	0.000	.1904787	.2437003
2017	.2196012	.0140609	15.62	0.000	.1919871	.2472153
2018	.2336485	.0149275	15.65	0.000	.2043327	.2629644
2019	.2602649	.0159963	16.27	0.000	.22885	.2916798
2020	.2902878	.0160524	18.08	0.000	.2587627	.3218129
2021	.3060928	.0192842	15.87	0.000	.2682209	.3439647
_cons	3.989359	.7280319	5.48	0.000	2.559588	5.419131
sigma_u	.27555903					
sigma_e	.04660085					
rho	.97219569	(fraction of variance due to u_i)				

F test that all u_i=0: F(47, 606) = 229.19 Prob > F = 0.0000

Farmowners

Table 5 (State fixed effects)

```
. xtreg lnfarmownersmultipleperilia avgtemperature pimeandev precdev lngdpia lnpop, fe

Fixed-effects (within) regression               Number of obs     =        672
Group variable: State1                          Number of groups  =         48

R-squared:                                      Obs per group:
     Within  = 0.4021                                         min =         14
     Between = 0.1316                                         avg =       14.0
     Overall = 0.1322                                         max =         14

                                                F(5,619)          =      83.27
corr(u_i, Xb) = -0.7514                         Prob > F          =     0.0000
```

lnfarmowners~a	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
avgtemperature	.0142613	.0077415	1.84	0.066	-.0009415	.029464
pimeandev	-.0001444	.0000942	-1.53	0.126	-.0003293	.0000405
precdev	-.0001763	.000056	-3.15	0.002	-.0002864	-.0000663
lngdpia	.802515	.1205549	6.66	0.000	.5657689	1.039261
lnpop	1.303215	.2948194	4.42	0.000	.7242473	1.882182
_cons	-10.29386	1.494376	-6.89	0.000	-13.22852	-7.359197
sigma_u	2.1356003					
sigma_e	.1372013					
rho	.99588957	(fraction of variance due to u_i)				

```
F test that all u_i=0: F(47, 619) = 1232.44                  Prob > F = 0.0000
```

Table 5.1 (year fixed effects)

```
. xtreg lnfarmownersmultipleperilia avgtemperature pimeandev precdev lngdp lnpop i.year, fe

Fixed-effects (within) regression               Number of obs     =        672
Group variable: state1                          Number of groups  =         48

R-squared:                                      Obs per group:
     Within  = 0.5758                                         min =         14
     Between = 0.0542                                         avg =       14.0
     Overall = 0.0416                                         max =         14

                                                F(18,606)         =      45.70
corr(u_i, Xb) = 0.1005                          Prob > F          =     0.0000
```

lnfarmowners~a	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
avgtemperature	-.0156422	.010033	-1.56	0.120	-.0353458	.0040615
pimeandev	-.0000245	.0000881	-0.28	0.781	-.0001976	.0001486
precdev	-.000078	.0000509	-1.53	0.126	-.000178	.0000221
lngdp	.2065801	.1185451	1.74	0.082	-.026229	.4393892
lnpop	-.1434763	.2758738	-0.52	0.603	-.6852612	.3983086

year						
2009	.0486693	.0243336	2.00	0.046	.000881	.0964577
2010	.087295	.0246746	3.54	0.000	.038837	.1357531
2011	.1096395	.0255681	4.29	0.000	.0594267	.1598524
2012	.1585149	.0305026	5.20	0.000	.0986113	.2184186
2013	.1857985	.0266208	6.98	0.000	.1335183	.2380787
2014	.2189778	.0288047	7.60	0.000	.1624086	.275547
2015	.2794219	.0313486	8.91	0.000	.2178568	.340987
2016	.2936009	.0339621	8.64	0.000	.2269032	.3602986
2017	.2986688	.0352426	8.47	0.000	.2294563	.3678812
2018	.302628	.0374145	8.09	0.000	.2291502	.3761058
2019	.308259	.0400934	7.69	0.000	.22952	.3869979
2020	.3439591	.040234	8.55	0.000	.2649441	.4229742
2021	.3282735	.0483341	6.79	0.000	.2333508	.4231962
_cons	9.114548	1.824751	4.99	0.000	5.530943	12.69815
sigma_u	1.4908102					
sigma_e	.11680115					
rho	.99389913	(fraction of variance due to u_i)				

F test that all u_i=0: F(47, 606) = 1647.31 Prob > F = 0.0000

Commercial

Table 6 (State fixed effects)

```
. xtreg lncommercialmultipleperilia avgtemperature pimeandev precdev lngdpia lnpop, fe

Fixed-effects (within) regression               Number of obs     =        672
Group variable: State1                          Number of groups  =         48

R-squared:                                      Obs per group:
     Within  = 0.5397                                         min =         14
     Between = 0.9568                                         avg =       14.0
     Overall = 0.9541                                         max =         14

                                                F(5,619)          =     145.17
corr(u_i, Xb) = -0.4573                         Prob > F          =     0.0000

------------------------------------------------------------------------------
lncommercial~a | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
---------------+--------------------------------------------------------------
avgtemperature |  -.0022291   .0028426    -0.78   0.433    -.0078114    .0033532
     pimeandev |  -.0000705   .0000346    -2.04   0.042    -.0001384   -2.57e-06
       precdev |  -.0000474   .0000206    -2.30   0.022    -.0000878   -6.98e-06
       lngdpia |   .4819543   .0442666    10.89   0.000     .3950234    .5688852
         lnpop |   .4838242   .1082548     4.47   0.000     .2712329    .6964154
         _cons |   3.200705   .5487204     5.83   0.000     2.123126    4.278284
---------------+--------------------------------------------------------------
       sigma_u |  .21017032
       sigma_e |  .05037899
           rho |  .94566336   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0: F(47, 619) = 159.90                   Prob > F = 0.0000
```

Table 6.1 (year fixed effects)

```
. xtreg lncommercialmultipleperilia avgtemperature pimeandev precdev lngdp lnpop i.year, fe

Fixed-effects (within) regression               Number of obs     =        672
Group variable: state1                          Number of groups  =         48

R-squared:                                      Obs per group:
     Within  = 0.6737                                         min =         14
     Between = 0.9592                                         avg =       14.0
     Overall = 0.9563                                         max =         14

                                                F(18,606)         =      69.51
corr(u_i, Xb) = 0.8480                          Prob > F          =     0.0000

------------------------------------------------------------------------------
lncommercial~a | Coefficient  Std. err.      t    P>|t|     [95% conf. interval]
---------------+--------------------------------------------------------------
avgtemperature |  -.0017097   .0036826    -0.46   0.643    -.0089419    .0055225
     pimeandev |   -.000012   .0000324    -0.37   0.712    -.0000755    .0000516
       precdev |   7.46e-06   .0000187     0.40   0.690    -.0000293    .0000442
         lngdp |   .3416314   .0435119     7.85   0.000      .256179    .4270838
         lnpop |   .2355346   .1012593     2.33   0.020     .0366728    .4343964
```

year						
2009	-.0186797	.0089316	-2.09	0.037	-.0362204	-.001139
2010	-.0645453	.0090568	-7.13	0.000	-.0823318	-.0467588
2011	-.0814729	.0093848	-8.68	0.000	-.0999035	-.0630423
2012	-.0465656	.011196	-4.16	0.000	-.0685532	-.024578
2013	-.0264649	.0097711	-2.71	0.007	-.0456544	-.0072755
2014	-.0255243	.0105727	-2.41	0.016	-.046288	-.0047607
2015	-.0243139	.0115065	-2.11	0.035	-.0469114	-.0017165
2016	-.0361566	.0124658	-2.90	0.004	-.060638	-.0116753
2017	-.0550974	.0129358	-4.26	0.000	-.0805018	-.029693
2018	-.069292	.013733	-5.05	0.000	-.0962619	-.042322
2019	-.0526496	.0147163	-3.58	0.000	-.0815507	-.0237486
2020	-.0127859	.0147679	-0.87	0.387	-.0417884	.0162165
2021	-.0249456	.017741	-1.41	0.160	-.059787	.0098957
_cons	6.965109	.6697738	10.40	0.000	5.649749	8.280469
sigma_u	.3467673					
sigma_e	.04287179					
rho	.98494506	(fraction of variance due to u_i)				

F test that all u_i=0: F(47, 606) = 220.29 Prob > F = 0.0000

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9 Acronyms

ACA: Affordable Care Act

ANIA: Associazione Nazionale fra le Imprese Assicuratrici

BCPP: Business Continuity Protection Program

CMPI: Coupled Model Intercomparison Projects

COP: Conference of Parties

DEs: Developed Economies

DNB: DeNederlandscheBank

ECB: European Central Bank

EEA: European Economic Area

EIOPA: European Insurance and Occupational Pensions Authority

EMDEs: Emerging Markets and Developing Economies

EPA: Environmental Protection Agency

ES: Expected Shortfall

ESG: Environmental, Social and Corporate Governance

ESRB: European Systemic Risk Board

FRED: Federal Reserve Economic Data

FSB: Financial Stability Board

GAO: Government Accountability Office

GDP: gross domestic product

GFANZ: Glasgow Financial Alliance for Net Zero

GFC: Global Financial Crisis

GHG: greenhouse gases

GIMAR: Global Insurance Market Report

GME: Global Monitoring Exercise

GRII: Global Resilience Index Initiative

GRMA: Global Risk Modelling Alliance

IAIS: International Association of Insurance Supervisors

ICP: Insurance Core Principle

IDF: Insurance Development Forum

IFRS: International Financial Reporting Standards

III: Insurance Information Institute

IRA: Inflation Reduction Act

ISSB: International Sustainability Standards Board

IPCC: Intergovernmental Panel on Climate Change

MRO: main refinancing operation

NAIC: National Association of Insurance Commissioners

NCEI: National Center for Environmental Information

NDC: Nationally Determined Contributions

NGFS: Network for Greening the Financial System

NOAA: National Oceanic and Atmospheric Administration

NYDFS: New York Department of Financial Services

OECD: Organization for Economic Cooperation and Development

ORSA: Own Risk and Solvency Assessment

PDSI: Palmer Drought Severity Index

PRIA: Pandemic Risk Insurance Act

RCP: Representative Concentration Pathways

RMS: Risk Management Solutions

SIF: Sustainable Insurance Forum

SMEs: small and medium enterprises

SRE: Special Report on Emissions Scenarios

TCFD: Taskforce for Climate-related Financial Disclosure

TVaR: Tail Value at Risk

UNFCCC: United Nations Framework Convention on Climate Change

VaR: Value at Risk

WACC: weighted average cost of capital

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