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The Evolution of Climate Risk Insurance: Strategies for Increasing Resilience in a Changing Environment

Abstract
The purpose of the article is to systematize and analytically summarize the transformation of the insurance sector under the influence of climate risks and identify mechanisms for increasing its financial stability in the face of increasing catastrophic losses. The study focuses on assessing changes in the loss structure, capital adequacy, the level of insurance coverage and the role of institutional risk redistribution instruments. *Methodology*. The analytical base was formed by comparing the financial indicators of insurance companies for the period 2015–2024 using aggregated statistical data from supervisory authorities and international analytical reports. A scenario approach was used to model the basic and stress trajectories of climate risk development. The assessment of stability was carried out through the calculation of the combined ratio, capital adequacy ratio and loss coverage index. Additionally, a comparative analysis of institutional mechanisms was used, in particular reinsurance, catastrophic bonds and public-private funds. *Results*. The obtained calculations showed that during periods of large-scale disasters, the combined ratio systematically exceeds the break-even level, which reduces the operating profitability of insurers. At the same time, the integration of scenario forecasting and the expansion of reinsurance coverage allow reducing the volatility of income and increasing the capital adequacy ratio. It is shown that a multi-level risk distribution model, which combines private and public instruments, significantly reduces the insurance gap and stabilizes the premium policy. *Practical significance*. The proposed approach can be used by insurance companies to adjust the tariff strategy, optimize reserves and form long-term development scenarios. For regulators, the results create a basis for improving mechanisms for guaranteeing and stimulating adaptation measures. *Scientific novelty*. The work offers an integrated model for assessing the stability of the insurance sector, which combines financial ratios, scenario modeling and institutional analysis within a single analytical circuit.

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1 Introduction

Climate fluctuations are increasingly turning into financial shocks. The insurance sector is the first to feel this. In recent years, the number of events with large-scale losses has increased not by percentages, but by multiples. In some regions, the average amount of payments has increased by more than a third in five years. The relevance of the study is determined by this change in the scale of risk. Insurance traditionally performs a stabilizing function in the economy, but today it itself needs stabilization. Capital requirements are significantly increasing. Premiums are growing faster than household incomes. The share of uncovered losses in high-exposure areas reaches 50%. In such conditions, the issue of the sustainability of insurance companies ceases to be narrowly professional. It acquires macroeconomic significance. At the same time, the climate factor is not limited to physical events. Regulatory changes, new environmental reporting standards, and the revaluation of energy sector assets create additional financial pressure. Insurers' investment portfolios are losing predictability. Yields fluctuate and concentration risk increases.

The research problem is to identify mechanisms that will allow the insurance sector to adapt the structure of capital, reserves and tariff policy to the growing volatility of losses. It is necessary to find out how to combine risk-oriented management, long-term forecasting and institutional tools for risk redistribution into a single system. It is not only about financial indicators. It is about the ability of the market to maintain the protection function in conditions where the frequency of extreme events no longer obeys historical patterns. It is this contradiction that forms the research question.

2 Literature Review

Scientists Botzen and Robinson (2025) summarized approaches to assessing climate risk in the insurance system. The authors showed the transformation of underwriting and pricing mechanisms under the influence of the increasing intensity of extreme events. The issue of integrating long-term scenarios into capital planning practice remained open. Kumar and Rao (2023) analyzed modern risk mitigation tools. Researchers focused on portfolio diversification and reinsurance. The problem of the insurance gap is outlined, but there is no institutional algorithm for its reduction. Ingels and al. (2024) presented an overview of climate risk models. The authors identified directions for their development. The models need to take into account complex interactions between physical and economic factors.

Simpson and al. (2025) extended this logic. They argued for the need for multi-level systems for evaluating adaptation measures. The financial implications for the insurance sector are not detailed. This creates room for further research. Jarzabkowski, Meissner and Mason (2025) considered insurance as a tool for urban climate policy. The authors justified the feasibility of partnerships between private companies and municipalities. The long-term solvency of insurers in such models has not received sufficient coverage. Roper, Casagrande and Bocchini (2025) emphasized the importance of resilience for the survival of the private market. Refusal to adapt increases the risk of companies leaving areas of high exposure.

European Central Bank and EIOPA (2023) proposed policy instruments to reduce the insurance gap. Haedtler and Weinhouse (2025) analyzed regional regulatory initiatives in the USA. The difference in approaches between states is noted. Loisel, Stephan, and Vigneron (2025) outlined the methodological challenges of scenario generation for life and health insurance. Xu, Fang, and Wang (2025) empirically proved the connection between climate risk and the operational efficiency of insurers. The considered framework captures the multidimensionality of the problem. There is no holistic system for integrating scenario forecasting. This generates a request for such research.

Problem Statement. The purpose of the article is to form an analytical approach to assessing changes in the insurance sector under the influence of climate risks.

Objectives:

– assess the impact of climate risks on the financial performance of insurers and the structure of insurance portfolios;
– analyze the effectiveness of institutional and financial mechanisms for the redistribution of catastrophic losses in the private and public insurance system;
– to justify the integration of scenario forecasting and risk-based management into the strategic planning of insurance companies.

3 Material and Methods

The study combines quantitative analysis of insurance companies' financial performance with institutional analysis of climate risk redistribution mechanisms. The sample covers the period 2015–2024. The data include aggregate loss ratios, provisioning levels, capital adequacy ratios, and reinsurance volumes in countries with different insurance market structures.

The first stage involved a dynamic analysis of the combined ratio and the share of catastrophic losses in the overall payout structure. Financial sustainability was assessed through the Combined Ratio, Capital Adequacy Ratio and Coverage Ratio. Calculations are based on formalized dependencies. They determine the sensitivity of capital to changes in the frequency of extreme events. The second stage included scenario modeling. Three scenarios of climate risk development were formed: basic, stressful, extreme. The expected loss and the magnitude of extreme losses were estimated for each scenario using the Expected approach Shortfall. Results compared to actual technical reserves. The impact of institutional mechanisms on insurers' earnings volatility is analyzed separately. State guarantees, public-private pools and catastrophe bonds are considered. The comparative coefficient method is applied. A resilience index is calculated that integrates the level of coverage, the amount of reserves and the volatility of earnings.

4 Results and Discussion

Physical climate risks are no longer isolated extreme events. They form a new loss structure, change the frequency of payments and undermine traditional diversification principles. Transition risks act differently. They arise due to changes in regulatory policy, energy consumption structure and market behavior. Together, these two risk blocks change the very logic of the insurance business. The changes began with underwriting. Insurers revised the criteria for assessing exposure, introduced detailed geospatial models, and increased the requirements for information about insurance objects. Instead of average risk coefficients, companies switched to micro-segmentation. Now not only the region is taken into account. They take into account the height above sea level, the condition of the infrastructure, the type of development, the presence of flood or fire protection systems.

Transition risks have affected the investment portfolio. Insurance reserves have traditionally been placed in long-term bonds and corporate assets. Now assets with high carbon intensity carry the risk of depreciation. Insurers are reducing the share of energy companies in the portfolio, refocusing on infrastructure and "green" projects. This reduces long-term volatility, but creates short-term adjustments to returns. Here is the essence of the changes: insurance ceases to be a mechanism for post-facto compensation and becomes an element of risk management before the event occurs. Companies encourage clients to implement protective measures. Discounts for installing fire protection systems or modernizing buildings appear in contracts. Some insurers finance audits of the climate vulnerability of facilities (Table 1).

Physical risks are forcing insurers to reconsider spatial diversification. Where losses used to be local, extreme events now cover large areas. Risk correlation between regions is increasing. This increases reinsurance and equity requirements. Some companies are switching to using catastrophe bonds. Others are increasing their own retention, but at the same time reducing exposure to the most dangerous areas. Transition risks are affecting long-term liabilities. Regulatory restrictions on emissions are changing the solvency of customers. A carbon tax has a similar effect. Banning the use of certain technologies is amplifying this impact. The company is losing competitiveness due to decarbonization policies. The insurer faces credit risk in such a situation (United Nations Development Program, InsuResilience Global Partnership, 2025).

Insurance companies have also revised the structure of their products. Parametric policies are emerging. They are tied to a temperature index, wind speed, or precipitation level. Payment is made automatically when a trigger is reached. This reduces administrative costs and compensation time. However, such a model shifts part of the risk of non-compliance to the insured. In addition, a new logic of interaction with the state is being formed. In regions with a high frequency of disasters, the private sector is unable to provide full coverage. Public-private funds, risk pools, and premium co-financing mechanisms are being created. The state assumes part of the catastrophic risk layer. This stabilizes the market, but requires a transparent distribution of responsibility. What does this actually mean for the insurer's financial model? The balance between risk, return, and capital is changing. Companies are implementing scenario testing, modeling extreme events, and assessing long-term trajectories of the transition to a low-carbon economy. Fang and Wang (2025). Capital adequacy is now assessed not only through historical losses, but also through the probability of structural changes (Table 2).

Analytical data demonstrate a two-vector pressure. Physical risks directly increase payments. Transitional risks affect through investment and regulatory channels. Adaptation strategies reduce the negative effect, but do not return the system to its initial state. The basic feature of the new model is its dynamism. The insurer constantly updates parameters. Reserves are reviewed more often than before. Scenarios are developed for a horizon of 20–30 years. Risk management is integrated into strategic planning. Financial sustainability now depends not only on the volume of premiums. It is determined by the company's

TABLE 1 Changes in insurance model parameters under the influence of climate risks

Change block	Parameter	Before the transformation	After exposure to physical risks	After the impact of transitional risks	Implications for financial sustainability
Underwriting	Geographical detail	Regional level	Micro-segmentation by quarter	Assessment of the region's regulatory profile	Improving tariff accuracy
Tariff formation	Bonus method	Average odds	Risk-based bets	Differentiation by carbon exposure	Premium growth in risk areas
Contractual conditions	Franchise	Standard	Enhanced for catastrophic events	Flexible terms for decarbonized assets	Redistribution of responsibility
Asset portfolio	Investments	Traditional energy assets	Partial exposure reduction	Exit from high-carbon assets	Reducing the risk of impairment
Reinsurance	Coverage model	Standard catastrophe bonds	Expanding coverage of extreme events	Stress testing of transition scenarios	Strengthening the capital base
Modeling	Forecasting type	Historical data	Scenario-based physical modeling	Integration of political scenarios	Forward-looking assessment
Customer policy	Client risk assessment	Minimum requirements	Mandatory preventive measures	ESG selection criteria	Reducing future losses
Reserves management	Capital calculation	Static evaluation	Dynamic catastrophic models	Taking into account carbon risks	Increasing reserve adequacy

Source: Developed by the author based on Haedtler, J., & Weinhouse, A. (2025); Makedon and al. (2024)

TABLE 2 The impact of climate risks on the financial performance of an insurance company

Indicator	Baseline	Impact of physical risks	Impact of transition risks	Adaptation strategy	Expected result
Combined coefficient	95%	Growth up to 110%	Minor impact	View rates	Up to 100% refund
Return on assets	4%	Reduction due to payments	Fluctuations due to portfolio rebalancing	Diversification	Stabilization by 3.5%
Capital level	Normative	Increased reserves	Investment risk adjustment	Stress testing	Strengthening solvency
Reinsurance share	30%	Growth up to 45%	Remains stable	Expanding catastrophic coverage	Volatility reduction
Premium income	Stable	Growth in risk areas	Differentiation by ESG profile	Risk-based segmentation	Maintaining portfolio volume
Investment return	5%	Minor impact	Reduction when exiting carbon assets	Investing in green bonds	Gradual recovery
Insurance availability	Wide	Reduction in dangerous regions	Review of conditions for carbon industries	Public-private mechanisms	Moderate coating restoration

Source: Developed by the author based on Tondi, M., & Rintamäki, T. (2025); Makedon and al. (2025)

ability to anticipate structural changes. Those insurers that remain within historical models face the risk of sudden losses. Companies that implement a forward-looking approach better allocate capital and reduce the volatility of results. The unprofitability of catastrophic risks has ceased to be a cyclical phenomenon. In recent years, the average volume of global economic losses from natural disasters exceeds $ 250 billion. USD per year, with insurance coverage varying between 40–45%. Thus, the insurance gap is over USD 130 billion annually. This means that almost half of the losses remain outside the scope of market compensation mechanisms (Yang and al, 2024).

When the frequency of events increases, the combined ratio of insurers exceeds 100%. The formula for the combined ratio (CR) is:

$$CR = \frac{Claims + Expenses}{Premiums} \times 100\ \%. \qquad (1)$$

where:

Claims – insurance payments and changes in loss reserves for the reporting period.

Expenses – operating expenses of insurance activities, including commissions, administrative and loss adjustment costs.

Premiums – earned insurance premiums for the relevant period.

If CR > 100%, the company is operating at a loss on its core business. In years of large-scale disasters, CR in a number of jurisdictions reaches 115–130%. Under such conditions, insurance coverage is supported not only by market instruments. A multi-level institutional architecture is formed. The first level is private capital. The second level is formed by reinsurance mechanisms and catastrophe bonds. The third level is provided by state funds, guarantees or premium subsidies (Wilkins, 2025). Let us consider the structure of the mechanisms in terms of their financial role (Table 3).

A valuable stabilization tool has become the public-private pool. Its logic is simple. The state assumes part of the catastrophic risk layer that exceeds the capabilities of the private sector. For example, if the expected loss EL is calculated as:

TABLE 3 Institutional mechanisms for covering catastrophic losses

Mechanism	Source of funding	Coverage Share (%)	Risk type	Advantages	Limitation
Private insurance	Insured premiums	40	Mass risks	Market discipline	Tariff increases
Reinsurance	International capital	20	Catastrophic peaks	Risk sharing	Dependence on global markets
Catastrophe bonds	Institutional investors	10	Extreme events	Long-term capital	High production cost
State Disaster Fund	Budget funds	15	System events	Market stabilization	Fiscal pressure
Public-private pool	Joint contributions	8	Territorial risks	Reducing the gap	Difficulty of administration
Premium subsidies	Budget	3	Socially vulnerable groups	Increasing accessibility	Moral hazard risk
Parametric programs	Donor funds	2	Fast payouts	Efficiency	Discrepancy to actual losses
Municipal reserves	Local budgets	1	Local events	Autonomy	Limited resource
International aid	Grants	1	Emergency events	Post-crisis support	Unpredictability

Source: developed by the author based on Jarzabkowski et al. (2025); de Medici Bruneau (2025)

$$EL = \sum_{i=1}^{n}(p_i \times L_i), \quad (2)$$

where:

p_i – probability of an event,

L_i is the amount of losses when the catastrophic layer is defined as losses exceeding a certain threshold L^*.

The state guarantees coverage of the part ($L_i - L^*$) when Li > L*. This reduces the insurer's need for capital and restrains the growth of premiums. The financial sustainability of the system depends on the coverage ratio:

$$Coverage\ Ratio = \frac{Insured\ Losses}{Total\ Losses}. \quad (3)$$

If *Coverage Ratio < 0.5*, the market is considered vulnerable. In countries with developed public-private schemes, this indicator reaches 0.7–0.8.

Catastrophe bonds play a significant role. Cat market size bonds exceeds 45 billion USD. Investors receive increased returns in the absence of an event. In the event of a disaster, funds are directed to compensate for losses. This allows for the redistribution of risk on a global level. However, the cost of such financing is increasing. Coupon rate for cat bonds exceeds 6–8% per annum. This means that the insurer must take into account additional costs in the tariffs. Another mechanism is parametric insurance. Payment is made when the trigger is reached (Goodwin Procter LLP, 2025), for example, wind speeds above 150 km/h. The insurance payout formula will be as follows:

$$Payout = k \times (Index - Trigger), \quad (4)$$

where:

Index – the actual value of a weather or other recorded indicator (wind speed, precipitation level, temperature, etc.);

Trigger – the threshold value of the index, exceeding which gives rise to the right to payment;

k – payment coefficient, which determines the amount of compensation per unit of index excess.

The advantage is the speed of compensation. The disadvantage is the risk of basis mismatch. Actual losses may exceed the payout. Let us consider the impact of financial mechanisms on key indicators of the insurance market (Table 4).

Analytical calculations show that the complex model gives the greatest effect. The combined ratio is reduced to a level below 100%. Income volatility is reduced by more than half. However, the fiscal burden increases. If the state fund covers 15% of losses, budget expenditures can amount to 0.3–0.5% of GDP per year. This requires strict budget discipline. Institutional mechanisms must take into account moral hazard. If the premium is subsidized, the insurer may not implement preventive measures. Therefore, co-financing conditions or mandatory protection standards are used in agreements. The weighted indicator of sustainability will be the capital adequacy ratio:

$$CAR = \frac{Available\ Capital}{Required\ Capital}. \quad (5)$$

If CAR < 1, the company loses its solvency. In years of major disasters, CAR can drop to 0.9. The involvement of reinsurance and state guarantees increases it to 1.1–1.2. Institutional mechanisms act as a buffer. They distribute risk between the private sector, the state, and the global financial market. Without this distribution, insurance loses economic sense in regions with a high frequency of disasters. On the other hand, excessive dependence on the state distorts the market. If the share of budget coverage exceeds 30%, private capital reduces its participation. The optimal model assumes a balance. The state share should not exceed 20% of the total coverage.

Let's consider the insurance gap indicator: Gap = 1– Coverage Ratio. In countries with a comprehensive model, the Gap decreases from 0.55 to 0.22. This means that more than 78% of losses are covered by organized financial instruments. The financial architecture also affects the cost of capital. If the market is stable, the cost of reinsurance decreases by 1–1.5%. The stability of the system depends on the transparency of risk allocation. Stress testing should be carried out regularly. The scenario with a probability of 1% should take into account extreme losses. If Expected Shortfall exceeds available capital, the mechanism is revised. Institutional and financial

TABLE 4 Financial effect of institutional mechanisms

Indicator	Baseline	After reinsurance	After the state pool	After cat bonds	Comprehensive model
Combined coefficient (%)	120	110	105	103	98
Reserve level (%)	100	115	120	118	125
Premium load (%)	100	108	102	110	105
Loss coverage (%)	45	55	65	70	78
Volatility (%)	20	15	12	10	8
Share of uncovered losses (%)	55	45	35	30	22
Insurance availability (%)	60	65	72	70	80
Fiscal burden (%)	0	0	5	0	4

Source: developed by the author

mechanisms do not eliminate risk. They make it manageable. Each level of the system assumes a certain share of responsibility. The market ensures efficiency. The state guarantees stability. Global capital expands capacity. The conditions for the growth of catastrophic losses require just such a multi-level architecture. Without it, the insurance sector loses its solvency, and society faces financial shocks. The effectiveness of the mechanisms is confirmed by indicators. A decrease in income volatility to 8%, a reduction in the insurance gap to 22%, and stabilization of CAR at a level above 1.1 indicate the achievement of financial equilibrium. The growth of catastrophic losses changes the planning horizon of insurance companies (Parsons and al, 2025).

If earlier calculations were based mainly on historical series, today this is not enough. The average annual loss from natural disasters in many regions has increased by 30–40% over the past decade. The frequency of events with losses exceeding 1 billion USD has doubled. Such trends undermine models built on the assumption of stationary risk. The management response is to switch to scenario forecasting. Companies form a set of alternative risk development trajectories over a horizon of 10–30 years. Each scenario describes a combination of physical parameters, macroeconomic changes and regulatory decisions (Botzen & Robinson, 2025). After that, the impact on capital, liquidity and profitability is assessed. However, this is not enough for strategic management. Companies use the Expected Shortfall:

$$ES\alpha = E(L \mid L > VaR\alpha), \tag{6}$$

where:

VaR α is the marginal loss with a given confidence level.

If *ES* exceeds available capital, the strategy is revised. Scenario forecasting is integrated into risk-based management through ORSA procedures and stress testing. Companies model extreme events with a probability of 1% or 0.5%. After that, they determine the capital deficit and develop measures to cover it. This is the practical logic. Risk is considered not as a single indicator, but as a range of possible outcomes. The strategy is formed for the worst-case scenarios. This reduces the likelihood of loss of solvency (Table 5).

The table shows the reduction in volatility and liquidity shortages under the scenario approach. Premiums increase although profitability decreases slightly. The individual premium formula becomes:

$$Premium_i = Base\ Rate \times Risk\ Factor_i \times \times Adjustment\ Coefficient. \tag{7}$$

where:

$Premium_i$ – individual insurance premium for a specific insured;

Base Rate – basic tariff rate for the relevant type of insurance;

$Risk\ Factor_i$ – the individual risk factor of the insured, taking into account his exposure, industry, geography and level of vulnerability;

Adjustment Coefficient – a correction factor that takes into account the results of scenario analysis, preventive measures or additional terms of the contract.

Risk Factor includes climate exposure, quality of protective infrastructure, and sectoral vulnerability. Adjustment Coefficient takes into account the results of scenario analysis. Companies are moving to dynamic reserve management. Instead of a static approach, they use an adaptive coverage ratio:

$$Reserve\ Ratio = \frac{Technical\ Reserves}{Projected\ Losses}. \tag{8}$$

A level above 1.2 in a stress scenario is considered optimal. Let us consider the impact of risk-based management on the portfolio structure (Table 6).

The portfolio restructuring reduces the total expected loss by 12–15%. At the same time, the share of renewable energy and segments with low climate vulnerability increases. Scenario forecasting also changes investment policy. If companies previously focused on a return of 5–6%, now the priority is stability. The share of assets with high carbon intensity decreases from 18% to 9%. The expected return falls by 0.4%, but the portfolio risk ratio decreases by 30%. Reducing profit volatility from 22% to 12% reduces the

TABLE 5 The impact of scenario forecasting on the financial performance of an insurers

Indicator	Before implementing scenarios	After implementation	Change (%)	Management effect	Level of stability
Combined coefficient	112	101	–9.8	Tariff adjustment	High
Capital level	1.0 CAR	1.15 CAR	+15	Additional reserves	Stable
Profit volatility	22%	12%	–45	Portfolio diversification	Moderate
Catastrophic loss share	35%	28%	–20	Extended reinsurance	Reduced
Premium load	100	106	+6	Risk-based pricing	Controlled
Liquidity shortage	8%	3%	–62	Increasing cash reserves	Low
Share of uncovered losses	40%	25%	–37	Public-private agreements	Moderate
Return on assets	4.2%	3.8%	–9	Reducing risky investments	Stable

Source: developed by the author

TABLE 6 Portfolio restructuring under scenario management

Segment	Share to (%)	Share after (%)	Expected loss (million)	Risk factor	Strategic decision
Real estate in coastal areas	20	14	480	High	Exposure reduction
Agriculture	15	18	350	Average	Parametric products
Industry	25	22	400	Moderate	Increasing the deductible
Infrastructure	10	12	300	Average	Long-term agreements
Transport	12	11	210	Low	Saving a share
Renewable energy	5	10	150	Low	Portfolio expansion
Traditional energy	8	5	260	High	Exiting a segment
SMEs	3	5	120	Average	State guarantees
Public sector	2	3	90	Low	Affiliate programs

Source: developed by the author

likelihood of a capital shortage. Increasing the CAR to 1.15 provides a buffer against extreme events.

Companies are taking into account the cost of transformation. The costs of modeling, analytical systems and external consultations are 1–2% of operating expenses. Reducing unforeseen losses compensates for these costs. Risk-oriented management affects client policy. Policyholders receive discounts of up to 15% for implementing adaptation measures. This factor stimulates preventive behavior. Future payments are reduced. Scenario management changes the interaction with the regulator. Companies submit stress test reports. The adequacy of reserves needs to be proven. The regulator assesses not only the current state, but also readiness for future shocks. The system becomes proactive. Decisions are made before the event occurs. Capital is allocated taking into account potential changes in climate parameters and economic policy. The sustainability of the insurance sector is no longer determined by the volume of premiums. It depends on the ability to integrate long-term scenarios into daily management practices. Companies that have adapted models reduce the risk of sudden losses.

5 Conclusions

The analysis revealed a structural transformation of the financial architecture of the insurance sector under the influence of climate risks. Extreme events occur more often. Regulatory pressure is increasing. The ratio between premiums, reserves and capital is changing systematically. The combined ratio exceeds the break-even threshold in catastrophic periods. The reinsurance model needs adjustment. Transition risks reduce the profitability of the investment portfolio due to the revaluation of assets with high carbon intensity. It has been shown that the financial sustainability of an insurer does not depend on the volume of premiums. The decisive factor is the ability to integrate long-term risks into the capital structure and portfolio decisions. Coverage of catastrophic losses requires multi-level risk distribution. The private sector, the state and the global financial market shape this distribution. Private insurance establishes the basic pricing discipline. In peak years, its resources are insufficient. State guarantees stabilize the system. Public-private pools perform a similar function. Both mechanisms create fiscal liabilities. Capital market instruments expand coverage capacity but increase the cost of financing.

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